EUROPEAN COMMISSION
DIRECTORATE-GENERAL
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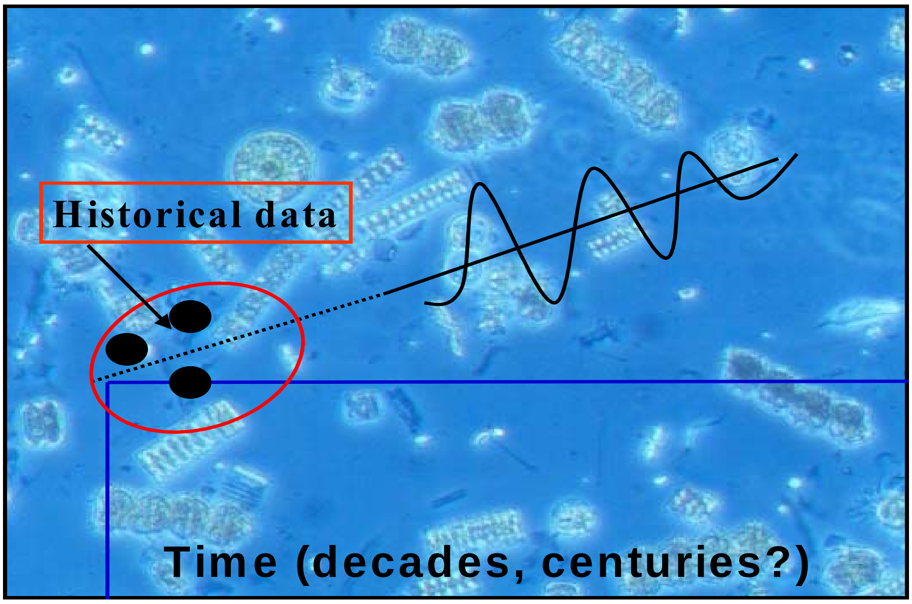
Inland and Marine Waters Unit
I-21020 Ispra (VA), Italy

INLAND & MARINE WATERS

Developing reference conditions for phytoplankton in the Baltic coastal waters



Part I: Applicability of historical and long-term datasets for reconstruction of past phytoplankton conditions

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CHARM

2005

EUR 21582/EN/1

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EUR 21582/EN/1

Printed in Italy

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List of Contents

Executive Summary

The EU Water Framework Directive has imposed new challenges for development of the surface water classification and assessment methods. The ecological quality assessment based on ecological quality ratios (EQRs) requires setting of type specific reference conditions for biological and chemical quality elements. One tasks of the CHARM project was to evaluate the applicability of different approaches and to provide guidance and tools for the establishment of reference conditions for phytoplankton in the Baltic Sea. In this report we evaluate the possibility to use historical data and long-term monitoring datasets to hind-cast past phytoplankton biomass and composition. We also discuss the potential applicability of paleoecological investigations, and dynamic modelling for reconstruction of historical reference conditions for phytoplankton indicators, such as biomass and composition of dominant taxonomic groups.

The history of biological and oceanographical research in the Baltic Sea is relatively long in comparison to many other sea areas. Therefore it provides a unique possibility to evaluate the applicability of historical records for setting the reference conditions. In early 1900, a number of investigators carried out studies on composition and abundance of phytoplankton in several areas of the Baltic. However, the early studies were mostly based on qualitative sampling and covered only limited spatial and temporal scales. The methodological differences in sampling and in analytical methods, makes it very difficult to compare historical data with present day monitoring results.

The potential approaches allowing proper comparison of current and historical data would require that the 'reconstructed' historical methods were calibrated against the current sampling and analytical methods throughout the seasonal cycle in several coastal type-areas. However, such approach is beyond the scope of the CHARM project. Instead we evaluated the historical records using 'expert opinion' (e.g. evaluation which species would have not been sampled by early researchers and scoring the dominance and abundance evaluations of the early researchers with most probable corresponding scoring of current data).

The comparison of the data from the Gulf of Gdansk, in the Polish coastal waters, collected in 1940's with current monitoring data suggested that in 1940s diatoms were

more dominant throughout the seasonal cycle than at present. Likewise there has apparently been an increase in the abundance of filamentous, nitrogen-fixing, cyanobacteria since the 1940s. Also in the Gulf of Riga, possible differences during summer blooms could be detected: there has been a potential increase of cyanobacterial biomass in the late 1990's in comparison of 1960-80s (but potentially dense blooms also in the 1940s). Likewise, the long term monitoring data since late 1970s, from the Eastern Gulf of Finland indicates some changes in the summertime phytoplankton composition, with an increase in dominance of cyanobacteria in the late 1990s. While in the Tallinn Bay, Estonia, the monitoring results since 1979, suggest decrease of spring and autumn phytoplankton biomass with concurrent decrease of average total nitrogen concentrations towards the late 90s and early 2000.

The quantitative monitoring of phytoplankton and nutrients started only after 1970s in most of Baltic coastal areas. Therefore the evaluation of changes in phytoplankton biomass based on comparative data sets is only possible for this relatively 'short' period of 30 years (in time scales of ecological changes, although a long period for any ecological monitoring!). The last 30 years of monitoring results generally indicate that the trophic status was higher in many coastal embayment in the 1960s and early 1970s, than at present. Improvements in the water quality have occurred in the vicinity of some large urban areas such as the Laajalahti Bay close to Helsinki, in Finland, and in the Tallinn Bay in Estonia. Due to the high nutrient levels indicating overall eutrophication of the Baltic coastal waters in the 1960s and 1970s, the early results of the long term monitoring data cannot be used to estimate reference conditions of phytoplankton.

The applicability of paleoecological reconstruction of reference conditions for the past composition of phytoplankton is limited. In many coastal areas (such as the German coastal waters) coastal sediments are too unstable to allow paleoecological studies after the Mya-stage. However, some promising results are available through another EU-project (*Molten*, 2001-2004), which is currently carrying out comprehensive paleoecological studies for development of transfer functions for reconstruction of past nutrient conditions based on sediment sampling and analysis of sediment and water column diatom composition in relation to nutrient concentrations. The methodology developed and calibrated in the *Molten* project is applicable to estimate past nutrient and phytoplankton biomass and to set time perspective for the estimation of the reference conditions. The approach is not applicable for reconstruction of the composition of the past phytoplankton communities (since only a sub-set of phytoplankton species leave some identifiable traces in the sediments). However, the reconstructed nutrient conditions can be used in predictive modelling (i.e. as an input to statistical or dynamic models) in order to estimate the reference conditions for phytoplankton biomass.

Further approaches for reconstruction of historical phytoplankton biomass include evaluation of the applicability of empirical relationships between secchi depth and chlorophyll a concentrations. There appears to be generally a good correlation between these two parameters. While secchi-depth measurements in the Baltic Sea have started already in the 1930s, it was considered possible to use this data to hind-cast historical phytoplankton biomass. However, an example from the German coastal waters indicated that there was no clear difference between historical and current secchi-depth results due to a large variability. Moreover, it was not possible to extrapolate historical biomass values using the relationship because there was only a small number of historical secchi-depth data available. However, this approach may be worth trying and applicable in other coastal areas, where long-term series of secchi-depth measurements with concurrent phytoplankton biomass (as chlorophyll a) are available.

Finally, applicability of dynamic ecosystem models for reconstruction of past phytoplankton biomass, was considered. There is some modelling work on-going in the Baltic, where the combined hydro dynamical-ecological model is forced using the calculated nutrient loadings from the major rivers to the Baltic Sea. The first model simulation results extrapolating the late 1800 century phytoplankton biomass and composition of some major groups are promising, and can be used to support other approaches to set the reference conditions combined with a critical expert evaluation.

This report is reviewing the potential approaches to set reference conditions for phytoplankton in the Baltic Sea. The next step will be to apply the most promising tools to establish type specific draft reference conditions for the phytoplankton indices, using the CHARM typology and type factors, and the phytoplankton data available in the CHARM phytoplankton database.

Introduction

The Water Framework Directive (WFD, 2000/60/EC) creates a new legislative framework to manage, use, protect, and restore surface and ground water resources within the river basins (or catchment areas) and in the transitional (lagoons and estuaries) and coastal waters in the European Union (EU). The WFD aims to achieve sustainable management of water resources, to reach good ecological quality and prevent further deterioration of surface- and ground waters, and to ensure sustainable functioning of aquatic ecosystems (and dependent wetlands and terrestrial systems). The environmental objectives (WFD, article 2), i.e. the good ecological quality of natural water bodies and good ecological potential of heavily modified and artificial water bodies should be reached in 2015.

The WFD stipulates that the ecological status of the surface water is defined as *"... an expression of the quality of the structure and functioning of aquatic ecosystems associated with surface waters, classified in accordance with Annex V*." (WFD, Article 2: 21). This implies that classification systems for the ecological status should evaluate how the structure of the biological communities and the overall ecosystem functioning are altered in response to anthropogenic pressures (e.g. nutrient loading, exposure to toxic and hazardous substances, physical habitat alterations, etc.). Such requirements are a novel approach in the European water policy, which has been mostly based on the regulation of emissions at the source through the establishment of emission limit values (ELV), rather than on the regulation of the allowed impacts on the recipient ecosystems. The WFD states following "… [ecological quality classification] *shall be represented by lower of the values for biological and physico-chemical monitoring results for the relevant quality elements*…" (Annex V, 1.4.2). Furthermore it is required that the ecological quality of water bodies should be classified into five quality classes (high, good, moderate, poor, and bad) using Ecological Quality Ratio (EQR), defined as the ratio between reference and observed values of the relevant biological quality elements.

In establishing reference conditions for surface waters, the WFD gives four approaches: (i) spatially distributed data, (ii) predictive modeling, (iii) historical data or paleoreconstructions and (iv) expert judgment. Sspatially based reference conditions are defined by collecting biological information from water bodies, which are (almost) in natural base-line conditions (sites with minor anthropogenic impacts). If reference conditions are to be defined using modelling, either predictive models or hind-casting using historical, paleolimnological, and other available data can be applied (Anonymous, 2003a). If there are no reference sites available or data are insufficient to carry out statistical analysis or validate models, expert opinion may be the only possibility to define reference conditions. Also the establishment of common networks of reference sites could help in setting type specific reference conditions in a comparable way between different countries.

A stepwise procedure for establishing reference conditions, based on availability of data, is suggested (**Fig. 1**). The most unimpacted sites for different types can be selected using both available monitoring data and/ or pressure criteria (Anonymous, 2003a,b). This approach would also allow establishment of a reference site network, where data for biological quality indicators in reference conditions can be obtained. In combination to that also predictive models can be validated and used to establish reference values for the parameters that represent the different biological quality elements, and apply these models to sites where biological data may be scarce or not available for all quality elements. In some cases collaboration across national borders is required since natural baseline sites for a given types may be found in other countries. If there are no sites with minor anthropogenic impacts, historical monitoring data or paleoecological methods should be used to reconstruct reference conditions before the onset of significant human impact. Expert judgement may be needed to evaluate when the human impact started to increase, and which period would represent conditions with a minor impact. Finally, if neither a site nor any data is available for a given type, expert judgement remains the only alternative.

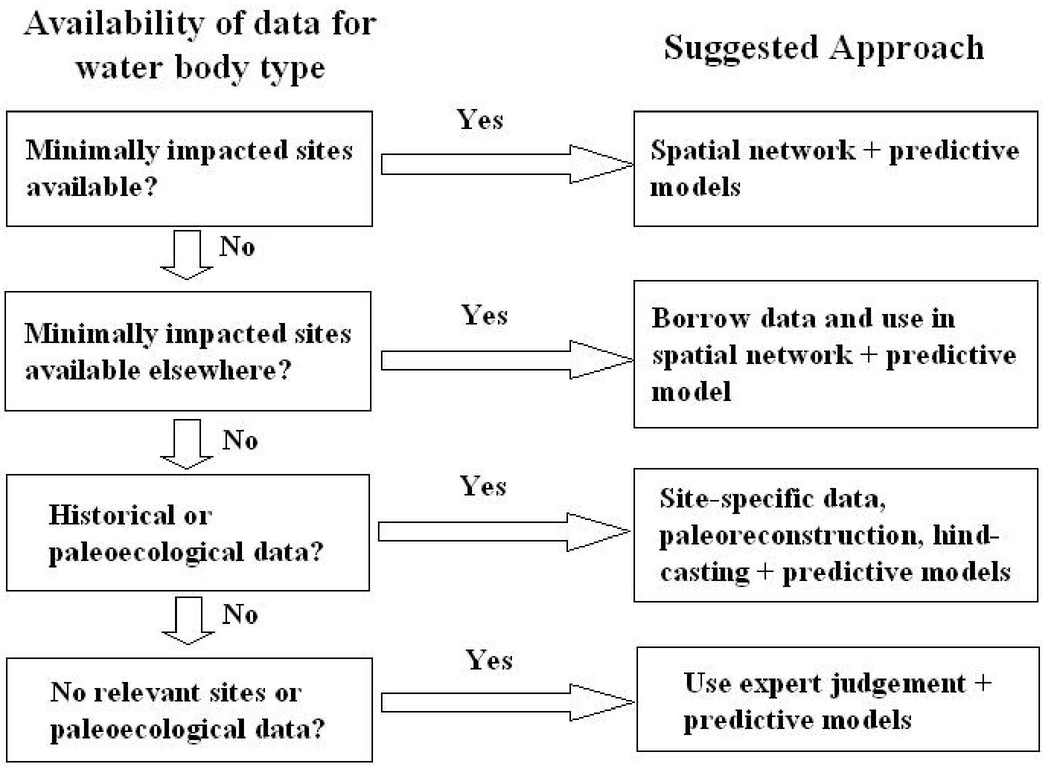

Figure 1*. A step-by-step approach for selection of the method for determination of reference conditions for surface water bodies based on availability of reference sites and paleoecological data.*

STEP 1: Based on the long-term changes of inorganic nutrient concentrations in the Baltic Sea, it is unlikely that there are reference sites which are in (almost) natural conditions with minor anthropogenic impacts for all coastal types. This rules out the application of the step 1 in estimation of the reference conditions for all Baltic coastal waters body types.

STEP2: Baltic Sea is a unique ecoregions with specific hydro-morphological characteristics, such as low salinity, no tides, and ice coverage in the north. The geologically young age of the Baltic results in a specific composition of benthic and pelagic communities. Consequently, the typology is unique for the Baltic Sea only. Therefore reference sites from other sea areas cannot be applied. Also reference sites for some Baltic coastal types may not be applicable for other types (e.g. it would not be justified to use potential reference conditions derived from minimally impacted sites from the Northern Baltic to estimate reference conditions for the Central of Southern Baltic due to differences in salinity, ice cover, etc.).

STEP3: There are considerable records of long term historical data from different regions of the Baltic Sea particularly for hydro-chemical parameters, but less so for the biological parameters. This approach may be promising in estimating reference conditions, particularly for hydro-chemical data. The current report is reviewing the possibility to use historical data for estimation of reference conditions for phytoplankton for some Baltic coastal types. The possible strength of using historical data is that natural variability within a type may be included into estimations. The weakness of the approaches of historical data/ paleoreconstructions is that they are more or less site-specific.

The reference conditions of phytoplankton should be estimated to reflect the following parameters:

- composition and abundance of phytoplankton taxa
- average phytoplankton biomass
- transparency conditions
- frequency and intensity of plankton blooms

This report is the first effort to evaluate the usability of the historical data and literature, and to compile the preliminary information on modeling works in order to establish reference conditions for phytoplankton for some Baltic coastal types. We have compiled historical publication and data on phytoplankton species composition, abundance and biomass from coastal areas from Germany, Poland, Latvia, Estonia, and Finland. The current report is critically reviewing the applicability of the historical data and other potential approaches (pale ecological reconstruction, long-term data sets on phytoplankton, secchi depth and nutrients, predictive modeling) for establishing the reference conditions. Next step will be to develop type-specific reference conditions for the specific coastal types, using the most promising approaches for areas where data are available, as numerical values of expert opinions/ descriptions of the potential values.

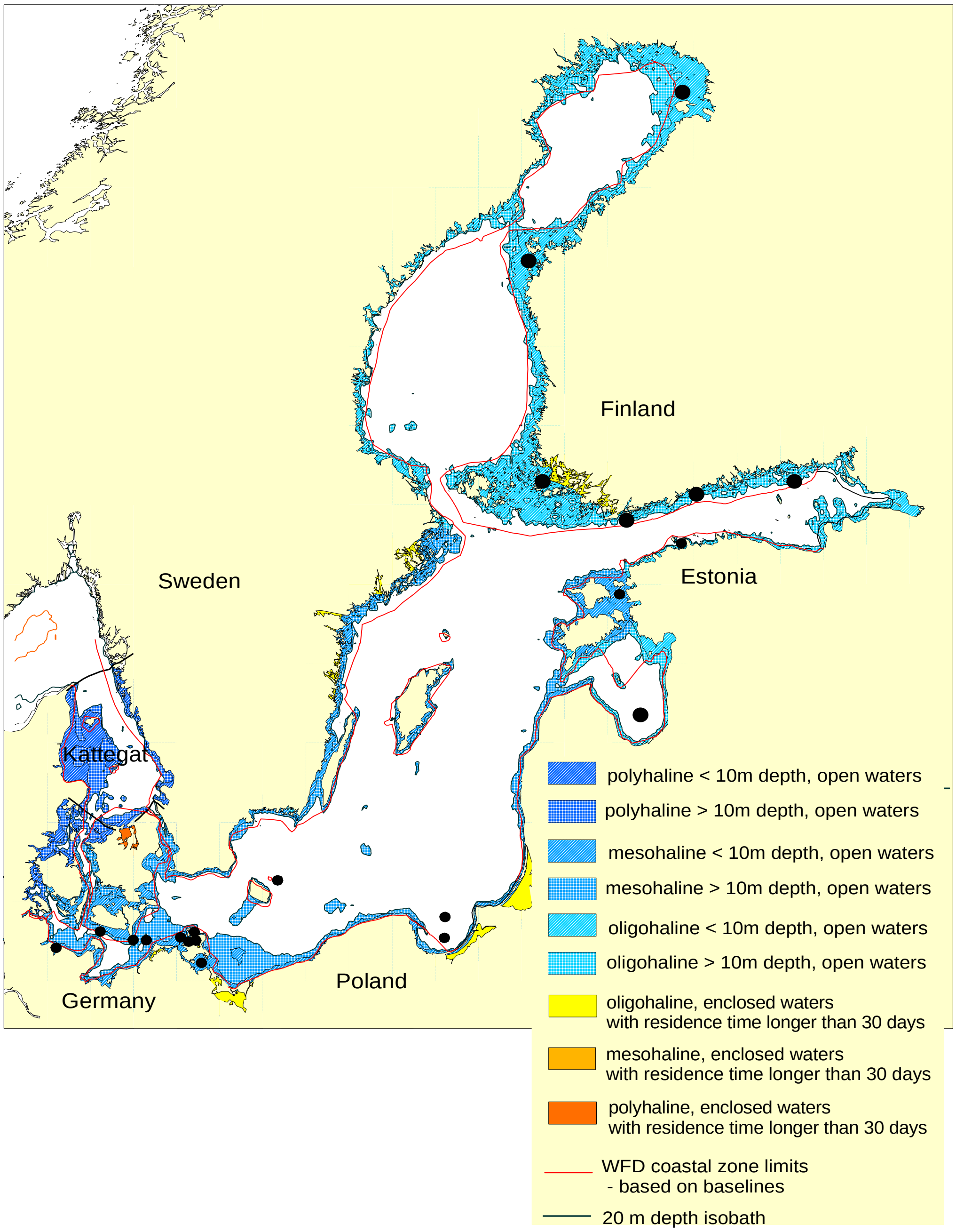

Figure 2. *Distribution of coastal physical types in the Baltic Sea, with the locations of the study areas (black dots) covered in this report (map provided by M. Wielgat & G. Schernewski, Baltic Sea Research Institute, Warnemuende, Germany).*

1. Historical composition and abundance of phytoplankton taxa

The first historical investigations of phytoplankton composition started already in early 19th Century (1800's). Most of these early studies were limited to short period of the year (summer or spring) and did not cover the full seasonal cycle, and included only few samples from spatially limited areas/ stations. In most cases the historical reports and publications include total species lists for a distinct area only. Abiotic parameters, seasonal linkage, biovolume or abundance values are missing in most cases. The list of historical studies of phytoplankton composition and abundance in the Baltic Sea is presented in **Appendix 1.**

Without information on the frequency of the species or in cases where the number of species is clearly underestimated, the species lists cannot be used for reconstruction of reference conditions. Only if the results of the more recent studies or monitoring data would be evaluated in the light of methodological approaches of the earlier investigators, comparisons could be made. However, calibration of historical methods would require execution of seasonal studies using past sampling and analytical methods to be carried out parallel to current monitoring programs, which is beyond the scope of the CHARM project. However, expert evaluation of the historical studies suggest that there are only very few and hardly significant long-term changes in the phytoplankton species lists detectable. On the other hand this does not mean that the species composition and / or bloom intensities (biomasses) are unchanged. To evaluate this effect, quantitatively analysed samples should have been recorded also in the past.

Although there is a relative large number of investigations and results available on phytoplankton composition from the early part of the 20th century, the applicability of this data is likely not to be very promising with respect of the big effort required. Extensive data input into data banks, recalculations and taxonomical rearrangements would be necessary but never satisfying (e.g. taxonomical rearrangement will fail for species that were split into several species or merged with other species recently).

However, the expert evaluation of the historical data and publications will provide valuable information to supplement the evaluation of the likelihood of phytoplankton reference conditions derived using some other available methods. The 'educated analysis' carried out by a phytoplankton expert will give valuable insights of the possible changes in the composition of phytoplankton during the past decades. However, this should always be supplemented with some other kind of analysis, for instance using hind-casting or modelling to extrapolate/ simulate past phytoplankton composition and biomass.

1.1. Germany

Systematic phytoplankton studies for **quantitative** analyses have been carried out in the Baltic Sea for more than hundred years. A first monitoring programme was coordinated by the International Council for the Exploration of the Sea (ICES) after 1902, with 4 cruises per year covering more or less the whole Baltic proper. The recent HELCOM monitoring programme is in principle based on this old ICES strategy. During those early days, ICES promoted a semi-quantitative method of estimating the relative abundance according to a scale of 5 classes. This method was much more subjective than the method of actually counting the cell numbers; and the data from different locations and different seasons could not be compared quantitatively (Apstein, 1904). Therefore, the early German phytoplanktologists still carried out quantitative analysis (see **Appendix** 1: Apstein 1906, Driver 1908, Kraefft 1910, Merkle 1910), providing valuable data for comparison with the recent quantitative phytoplankton data. Besides the open sea monitoring, some research campaigns were also carried out in coastal waters, which are of special interest in respect of the WFD, for instance in Greifswald Bodden (Fraude 1907, Abshagen 1908) and Kiel Fjord (Lohmann 1908, Busch 1916-1920). References are listed in Appendix 1.

In these early stages, different methods for quantitative sampling were used. The general problem was the enrichment of the samples for microscopy. This problem was solved by most of the researchers by net sampling. The net gauze was, however, not well defined and in all cases small cells were lost. Therefore, quantitative species information is not available for the pico- and nanoplankton fraction. However, Lohmann (1908) already used centrifugation and filtration to concentrate the whole phytoplankton community for microscopical analysis.

The data for microplankton are highly variable due to both, high natural variability and methodological insufficiencies. The general problem of undersampling still exists but the quantitative analysis of phytoplankton has improved especially due to use of the Utermöhl method and counting of samples under an inverted microscope. The Utermöhl method was first used in Kiel Bight by Gillbricht (1951). Later on this method became as routine application for all quantitative phytoplankton analyses. It was applied by Kell (1972) in the Mecklenburg Bight and the Arkona Sea and by Nasev (1976) in the Darss-Zingst Bodden chain.

Mainly because of these methodological improvements, comparisons of early and recent studies are difficult. Also historical studies seldom covered sufficient spatial or seasonal scales to allow comparison with current investigations. Single data points cannot be used for the reconstruction of reference conditions if natural variability in time is not considered.

Therefore we conclude that irrespective of the fact that data about phytoplankton from e.g. the beginning of the 20th century or the thirties are available in the form of hand-written protocols, the possible results of an analysis using such data are likely not to be very promising with respect of the big effort required. Extensive data input into data banks, recalculations and taxonomical rearrangements would be necessary but never satisfying (e.g. taxonomical rearrangement will fail for species that were split into several species or merged with other species recently).

The phytoplankton data collected in the frame of the HELCOM monitoring program date back to 1979. However, inorganic nutrient concentrations in the Baltic Sea were already elevated at that time (Larsson et al. 1985), thus the conditions in 1970's cannot be considered to reflect "background conditions". Nevertheless, significant changes in phytoplankton species composition occurred even in this 25-years period. The most prominent was the strong and statistically significant decline of diatoms in the spring blooms in the Baltic Sea (Wasmund and Uhlig, 2003), indicated also by reduced silicate consumption in the spring period (Wasmund et al., 1998). This was compensated by a significant increase of dinoflagellates in the spring bloom. These trends suggest that in early 1980's, the typical spring bloom in the Baltic Sea was dominated by diatoms. A shift from the diatom dominated spring blooms to dinoflagellate spring blooms has occurred thereafter. Systematically taken data series in the frame of the HELCOM monitoring date back to 1979, and do not reflect "background conditions". Nevertheless, significant changes in phytoplankton species composition occurred even in this 25-years period. The most prominent was the strong decline of diatoms in the spring blooms in the Baltic Sea, proved also by reduced silicate consumption in the spring period (Wasmund et al., 1998) and by statistical tools (Wasmund and Uhlig, 2003). This was compensated by a significant increase of dinoflagellates in the spring bloom. These trends suggest that the typical spring bloom in the Baltic Sea should be dominated by diatoms, as found in the 1980s, whereas a shift from this “normal” diatom spring blooms to dinoflagellate spring blooms indicates a deviation from the “reference conditions”.

1.2. Poland

The earliest nutrient observations in the Gulf of Gdansk concern only phosphates and their regular measurements started in 1948. A clear increase in phosphate concentrations has been observed since the beginning of 1970s (**Fig. 3**). Regular phytoplankton monitoring program using up-to-date methodologies started much later, in 1984. Therefore the phytoplankton reference conditions cannot be found in the materials collected during last decades in the Gulf of Gdansk.

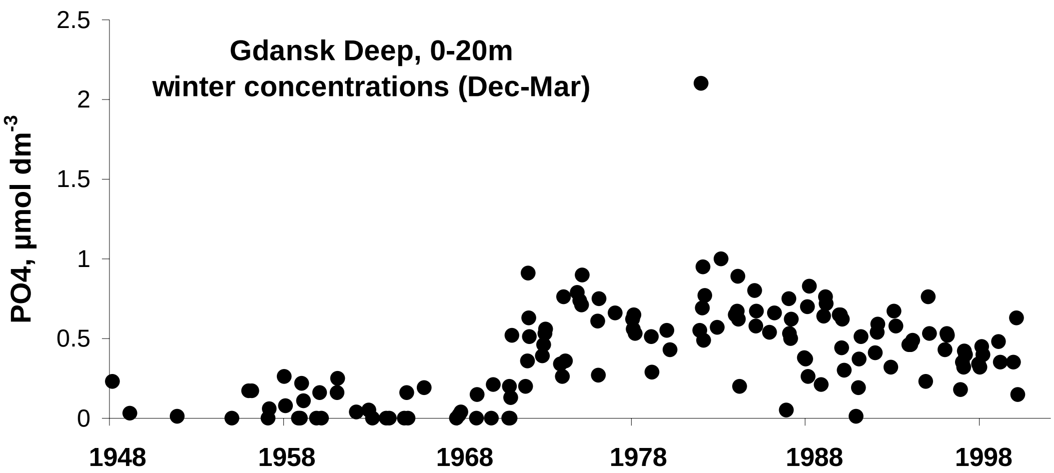

Figure 3. Winter phosphate concentrations in the Gulf of Gdansk since 1948.

The first studies of species composition in the Gulf of Gdansk can be found in the papers by Apstein (1906), Lakowitz (1907, 1927, 1929), Namyslowski (1924), Schulz (1926) and Woloszynska (1928, 1935). Most of the early investigators applied qualitative analysis and enumerated selected phytoplankton species or some groups only. Only Namyslowski (1924) presented a complete list of species. The first seasonal study including semi-quantitative phytoplankton analysis was carried out by Rumek (1948) in the Gdansk Deep and in the inner part of the Gulf of Gdansk in 1946-1947. Rumek reported the monthly phytoplankton composition with qualitative evaluation of the dominance of each species using such terms like "dominant", "abundant" and 'scarce". The second semi-quantitative analysis of phytoplankton composition was done by Ringer (1970, 1973). Her results were based on materials collected in 1956, 1959, 1967-68. Unfortunately, her major sampling area was the open sea, with only one site in the Gdansk Deep. Rumek as well as Ringer collected phytoplankton samples using the Copenhagen type net (No 25, with ca. 60µm mesh-size).

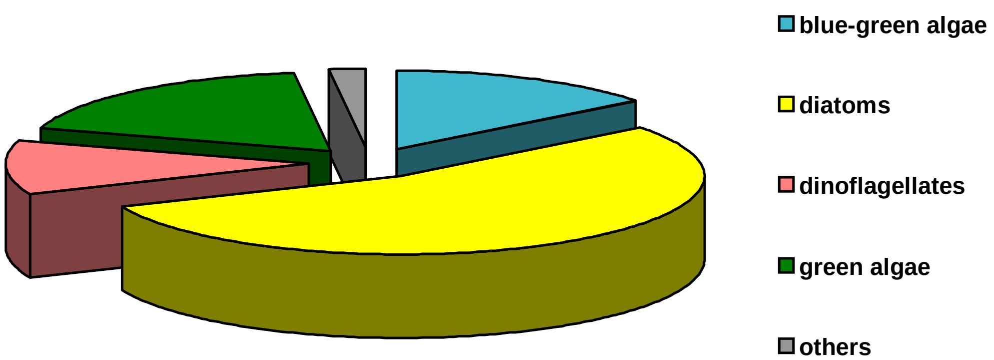

Figure 4. *The percentage of the phytoplankton species belonging to major groups in the Gulf of Gdansk and the Gdansk Deep (during the years 1923-24, 1946-47, 1956, 1959, 1967-68), based on surveys of Namylowski (1924), Rumek (1948), Ringer (1970, 1973).*

The list of phytoplankton species determined by Namyslowski (1924), Rumek (1948) and Ringer (1970, 1973) is presented in **Appendix 2**. They identified totally 355 phytoplankton species from the Gulf of Gdansk and the Gdansk Deep. The share of the species number belonging to the main phytoplankton groups in their material is presented in **Fig. 4**. The number of diatoms was the highest (54%), while the number of species belonging to other groups, such as green-algae (18%), blue-green algae (14%) and dinoflagellates (11%), was lower.

The results of Rumek covered the inner part of the Gulf of Gdansk as well as the Gdansk Deep in each season over the years 1946-47. A list of phytoplankton species, which she defined as "dominant" during the different seasons, is shown in **Table 1.** Most of the dominant species belonged to diatoms.

Table 1. *Phytoplankton species defined as "dominant" during different seasons in 1946-47 in the Gulf of Gdansk and the Gdansk Deep (Rumek, 1948).*

spring (1)	summer (2)	autumn (3)	winter (4)
Cyanobacteria			
	Aphanizomenon flos-aquae		
	Nodularia spumigena		
Diatoms			
Bacillaria paxillifera	*Chaetoceros eibenii*	*Bacillaria paxillifera*	*Actinocyclus octonarius*
Chaetoceros eibenii	*Coscinodidcus oculus-iridis*	*Chaetoceros eibenii*	*Melosira moniliformis*
Chaetoceros pseudocrinitus	*Diatoma tenuis*	*Coscinodidcus oculus-iridis*	*Skeletonema costatum*
Diatoma tenuis		*Melosira moniliformis*	
Melosira lineata		*Skeletonema costatum*	
Melosira moniliformis			
Melosira nummuloides			
Melosira varians			
Skeletonema costatum			
Tabellaria fenestrata			
Tabellaria flocculosa			
Fragilaria islandica			
Dinoflagellates			
		Dinophysis acuminata	
Green algae			
	Botryococcus braunii		
Others			
Dinobrion balticum			
Dinobryon sertularia			

Table 2. *Phytoplankton species defined as "abundant" and frequent (occurring at 4 out of 5 stations) in spring, summer and autumn in 1946-47 in the Gdansk Bay and the Gdansk Deep (Rumek, 1948).*

spring (1)	summer (2)	autumn (3)
Cyanobacteria		
Gomphosphaeria aponina	*Aphanothaece microscopica*	*Aphanizomenon flos-aquae*
Aphanizomenon flos-aquae	*Anabaena baltica*	*Nodularia spumigena*
	Anabaena flos-aquae	
	Anabaena spiroides	
	Nodularia litorea	
Diatoms		
Actinocyclus octonarius	*Chaetoceros danicus*	*Chaetoceros danicus*
Asterionella formosa	*Chaetoceros wighamii*	*Coscinodidcus radiatus*
Chaetoceros danicus	*Coscinodidcus radiatus*	*Fragilaria crotonensis*
Chaetoceros holsaticus	*Diploneis didyma*	*Thalassiosira baltica*
Chaetoceros wighamii	*Fragilaria crotonensis*	
Coscinodidcus radiatus	*Melosira moniliformis*	
Fragilaria crotonensis	*Thalassiosira baltica*	
Synedra ulna		
Thalassiosira baltica		
Dinoflagellates		
Dinophysis acuminata	*Dinophysis acuminata*	*Dinophysis rotundata*
Dinophysis rotundata	*Dinophysis norvegica*	*Dissodinium pseudolunnula*
Kolkwitziella acuta	*Dinophysis rotundata*	*Protoceratium reticulatum*
Peridiniella catenata	*Dissodinium pseudolunnula*	*Protoperidinium steinii*
Peridinium grenlandicum	*Protoceratium reticulatum*	
Protoperidinium bipes	*Protoperidinium deficiens*	
Protoperidinium granii		
Protoperidinium pellucidum		
Protoperidinium steinii		
Green algae		
Oocystis pelagica	*Chlamydocapsa planctonica*	
Pediastrum kawrayski	*Chlorangiella pygmae*	
Trochiscia clevei	*Oocystis pelagica*	
	Oocystis submarina	
	Pediastrum boryanum	
	P. boryanum v. longicorne	
	Pediastrum duplex	
	Pediastrum kawrayski	
	Sorastrum americanum	
	Trochiscia clevei	
	Sorastrum spinulosum	
Others		
	Ebria tripartita	

In **Table 2** a list of species, which were defined as "abundant" and occurred in most (4 out of 5) of the stations is presented. Most of the abundant species were diatoms and dinoflagellates in spring, while in summer most of the abundant species were green algae.

Based on the results of Rumek, the relative abundance of each phytoplankton species in her publications was assessed by using three categories: (3) "dominant", (2) "abundant", and (1) "scarce". The relative abundance score of each phytoplankton group shown in **Figure 5**. Diatoms had the highest score for all seasons. This suggests that diatoms dominated the microphytoplankton fraction during all seasons in 1946-47. The current Polish phytoplankton monitoring data (1994-2001) from CHARM database was filtered to be comparable with the data of Rumek (1948), and compared with the scores from the 1946 - 47 (**Figure 5).**

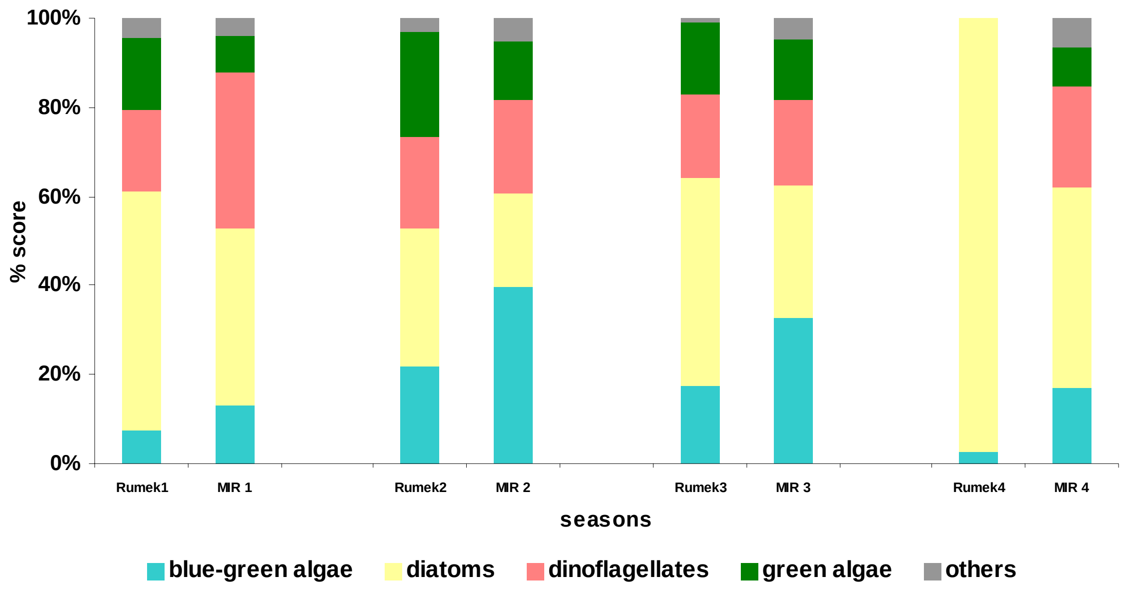

Figure 5. *Comparison of the relative abundance scores of the major phytoplankton groups in the Gulf of Gdańsk in 1946-47, based on results of Rumek (1948), and the current Polish monitoring data (MIR; 1994-2001). See text for the detailed explanation of the calculation of score values. Seasons: 1 - Spring, 2 - Summer, 3 - Autumn, 4 - Winter.*

In order to do this, all phytoplankton species, which occur in single cells larger than 20µm, and all colonial cyanobacteria from the current monitoring database were included in the analysis. Also species with single cells and smaller than 20µm (for example *Heterocapsa rotundata*, *Scenedesmus* spp.) had to be excluded from the Rumek's species lists, in order to make the samples comparable. Thereafter the biovolume of the current monitoring data were scored according to the criteria below, because score 2 was the most frequent in the Rumek's list.

Score	% of total biovolume
1:	0-1%
2	1-50%
3	75-100%

When the current data is compared to the data material of Rumek, remarkable decrease of scores of diatoms throughout the all seasons could be observed (Figure 5). Also the scores of cyanobacteria in the current data had clearly increased.

Part of the difference is probably partly caused by different identification methods For instance, Rumek used acid cleaning to separate the diatom frustules into single valves and bands free from organic material. However, when counting procedure is carried out using Utermohl technique (1958), determination to the species level is impossible or difficult (especially for Pennate diatoms) However, the increase in the share of cyanobacterial species (which generally form chains or aggregates larger than 60 µm) in the recent monitoring material cannot be only due to methodological differences, but could reflect the changes in the trophic status of the Gulf of Gdansk.

Some of diatoms and dinoflagellates species present in the 'historical' list are currently typical only in the Western part of the Baltic Sea. Those have not been recorded to occur in the Gulf of Gdansk after 1984. For example, diatoms *Chaetoceros affinis*, *C. brevis*, *C. curvisetus*, *C.debilis*, *C. diadema*, *C. eibenii*, *C. laciniosus* and *C. socialis* were only observed before 1970. Also dinoflagellates *Protoperidinium curvipes*, *P. deficiens*, *P. stenii* and *Preperidinium meunieri* have not been recorded over the last twenty years. The more abundant occurrence of these species between 1950's and 1970's was probably related to the higher salinity and temperature, as well as the lower oxygen levels in the deep waters (Fonselius 1969, Matthaus 1978, 1984). In the 1950s the composition of the phytoplankton (Mańkowski 1951, Ringer 1973), zooplankton (Mańkowski 1951, 1963), and zoobenthos (Żmudziński 1968) communities were more oceanic in the southern Baltic. In the Gulf of Gdansk, a regular phytoplankton monitoring program started only after 1984. Between the years 1981 and 1990, the Baltic Sea deep layer salinity continued to decreased gradually as started as already in the mid-1970s (Matthaus and Carlberg 1990). The same trend was observed also in the Gdansk Deep (Matthaus et al. 1990b, Wojewódzki 1991). The disappearance of these marine and oceanic species, indicates that these changes in the hydrological conditions (mostly decrease in salinity and long-term stagnation) have probably had an impact on phytoplankton composition in the southern Baltic Sea.

1.3. Latvia

Phytoplankton investigations in the Gulf of Riga started already in the beginning of the 19th century (Grindel, 1803; Goebel, 1857; Buchse, 1866; Braun, 1886). Unfortunately, these publications are no more available in the public libraries and they are rarely referred in the literature of early 20th century, so it is difficult to judge their scientific value. Numerous publications are describing phytoplankton development in the Gulf of Riga from 1976-2003, when the monitoring programme was initiated, but there are only 10 other publications, covering the time period from 1908-1976, what could be used for definition of reference conditions.

Early works of Krabbi (1913a, b; as reviewed by Nikolajev 1953) gives us insight in to phytoplankton species composition in the Gulf of Riga during summers 1908 and 1909. The analysis, based on few samples only, shows dominance of the cyanobacteria, *Aphanizomenon flos-aquae* and *Nodularia spumigena*, all around the Gulf of Riga. More detailed results as a translation of the paper by Nikolajev (1953) are presented in the Appendix 3. In July 1910 Taube took some samples from the Gulf of Riga by the way to Saaremaa Island (as reviewed by Nikolajev, 1953). In the report he mentioned occurrence of only 3 species- *Aphanizomenon flos-aquae, Nodularia spumigena, Thalassiosira baltica*, with the remark, that *Aphanizomenon* formed so dense bloom all over the Gulf, that "…*looked like green porridge. It was easy to observe the green scum even from fast moving ship*".

In 1925, Rappoprort (1930) carried out the phytoplankton research in the coastal zone of the Gulf of Riga. He surveyed 10 stations along a transect from Kolka to the River Daugava and to Ainaži. He took qualitative samples monthly from the surface layer.

Few years later, Berzinsh (1932) described the spring phytoplankton composition in the coastal zone of the Gulf, giving detailed list of species. All the mentioned species are common in the Gulf of Riga also nowadays during summer and spring times. In both publications, there are no biomass estimations, neither proportions of species mentioned. *What about Rapoport (1929) ?: [annual cycle in 1925]*

During the years 1946-1947, Nikolajev (1953; 1957) carried out comprehensive analyses of the composition, abundance and biomass of phytoplankton in the Gulf of Riga using phytoplankton net and quantitative vertical profile samples with Nansen bottles. Samples were collected during different seasons in 1946 and 1947, in the different parts of the Gulf of Riga. .

Based on these studies, Nikolajev described the general seasonal cycle of phytoplankton development in the Gulf, presenting a very detailed list of phytoplankton species with a description of their ecology, and compared the Gulf of Riga with open Baltic Sea and Gulf of Finland, as well as with other sea areas. He also included estimates of the average phytoplankton biomasses during the different seasons in 1947. The only drawback was that his biomass values are given as average for the whole gulf without any sampling station specific values. The results of Nikolajev (1953; 1957) are translated to English and summarized in the **Appendix 3**.

Two other publications are dealing with seasonal cycles of phytoplankton in the Gulf of Riga (Rudzroga, 1974, Kalveka, 1980). During the years 1968-1971 Rudzroga (1974) carried out quantitative phytoplankton sampling both in the coastal zone at mouth of river Lielupe and Daugava, at Bolderaja and Vecaki. These results are summarized in **Appendix 4**. Further Kalveka (1980) carried out quantitative phytoplankton sampling at two stations in the southern Gulf of Riga during the seasonal cycle in 1976. These results are summarized in **Appendix 5**. The complete list of phytoplankton taxa observed and identified in the Gulf of Riga between 1908 and 1971 are listed in **Appendix 6**. In the next step, it will be analysed, how well these results can be applied to reconstruct both qualitative & quantitative reference conditions, which can be compared with present day data from the same type areas.

1.4. Estonia

Regular studies of phytoplankton in Estonian coastal waters date back only to 1970s. Some areas investigated 20-30 years ago are not monitored anymore during the past years, this makes direct comparison of species information difficult. The analysis of phytoplankton from the Moonsund area (Estonian west coast) during 1970-1980s and 2000 has not indicated any shifts in the general succession of community structure and the biomass values obtained have been similar as well (Piirsoo, 1984; Jaanus, 2003).

Phytoplankton moniroting results from Tallinn Bay (southern Gulf of Finland) may be divided into two periods (Table 3). These periods cannot be compared directly due to some methodical differences and numerous taxonomic changes that have taken place during the last decades. However, the dominating phytoplankton species in spring are the same. In the summer period, the interannual variability of the phytoplankton communities has been variable and influenced by the meteorological conditions and/or on some hydrodynamical events, such as upwellings.

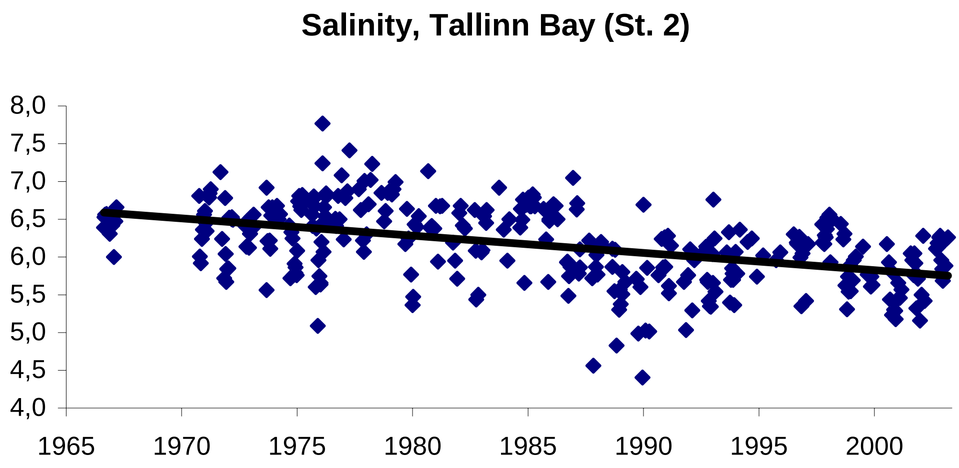

Figure 6. *Variability of the mean surface layer (from 0 to 10 m) salinity in Tallinn Bay during the period from 1967 to 2003.*

Upwelling as any short term natural variability has a relatively local and short-term effect on the phytoplankton communities, these events could have been obscuring changes caused by increased level of eutrophication. On the other hand, some information might have been missed due to insufficient taxonomic identification during the earlier period.

The changes in the phytoplankton community structure may partly be due to decreased salinity, especially during the autumn period. Figure 6 indicates the decline in the upper mixed layer (0-10 m) salinity of about 0.8 units from the early 1970s to the beginning of the current decade in Tallinn Bay. This is probably related to the disappearance of some diatom (*Coscinodiscus granii, Chaetoceros danicus*) and

Table 3. *The predominant phytoplankton species according to wet weight biomass (mean values for the period) in Tallinn Bay. Stations 2 and 57a represent the open and inner parts of the bay, respectively, during the two periods in 1979-91 and 1993-2003.*

1979-1991	**1993-2003**
Station 2, May	
Achnanthes taeniata	*Scrippsiella hangoei*
Skeletonema costatum	*Achnanthes taeniata*
Peridiniella catenata	*Peridiniella catenata*
Station 57a, May	
Achnanthes taeniata	*Achnanthes taeniata*
Skeletonema costatum	*Peridiniella catenata*
Peridiniella catenata	*Scrippsiella hangoei*
Station 2, August	
Cryptomonadales	*Heterocapsa triquetra*
unidentified flagellates	*Aphanizomemon flos-aquae*
Aphanizomemon flos-aquae	*Cryptomonadales*
Station 57a, August	
Cryptomonadales	*Heterocapsa triquetra*
Eutreptiella sp. (Euglenales)	*Aphanizomemon flos-aquae*
unidentified flagellates	*Nodularia spumigena*
Station 2, October	
Coscinodiscus granii	*Coscinodiscus granii*
Cryptomonadales	*Woronichinia spp.*
Dinophysis norvegica	*Mesodinum rubrum*
Station 57a, October	
Coscinodiscus granii	*Coscinodiscus granii*
Cryptomonadales	*Actinocyclus octonarius*
Woronichinia spp.	*Woronichinia spp.*

dinoflagellate (*Dinophysis norvegica*) species from the dominant species list. The diatom *C. granii* formed dense autumn blooms during the 1980s (with the only exceptions in 1984 and 1987). At the same time, the autumn diatom blooms have became more rare, the last being recorded in 1998 and 2000 in the Central Gulf of Finland and in the North-Eastern Gulf of Riga, respectively.

1.5. Finland

In the Finland's coastal waters as well as in the whole Baltic Sea, there are probably few or no sites, which have only minor anthropogenic impacts. There are some physico-chemical and phytoplankton data originating from the 1960s, which are mainly included in the database of the Finnish Environment Institute (SYKE). The data is spatially extensive and covers both summer and winter periods. In addition, a few intensive monitoring data in the outer archipelagos from the 1970s is available in the monitoring database of the Finnish Institute of Marine Research (FIMR).

The oldest phytoplankton investigations cover the period from the late 1890s till the early 1970s. In the beginning of the 1900s, Levander (1900, 1901, 1913, 1914, 1915) made observations of phytoplankton and hydrography four times a year at several sites in the coastal Gulf of Finland. With the "Müller-Gaze" net, he was able to identify approximately one hundred phytoplankton species, of which only some tens occurred regularly. The most abundant species in his lists were *Aphanizomenon flos aquae*, *Nodularia spumigena*, *Thalassiosira baltica* and *Chaetocera bottnicum*. He also mentioned mass occurrences of *A. flos aquae* in mid-summer.

Leegaard (1920) extended cruises from the open Gulf of Finland to cover the Bothnian Sea in May 1912. Besides studying basic hydrography he also identified a number of phytoplankton species, collected according to "Gran's method". Välikangas (1926, 1932) studied seasonal and areal distribution of phytoplankton in the Helsinki sea area in 1919-1920 and 1932 by using net sampling. According to his studies e.g. *Achnanthes taeniata* occurred abundantly in spring, *Skeletonema costatum* in June, and *Aphanizomenon flos aguae* and *Oscillatoria agardhii* in August. The number of sampling sites in these early studies varied from 3 to 11, the sampling time ranging generally from May to December. These authors reported qualitative observations including the list of dominating species or species lists. Consequently, these results are not directly comparable to the present phytoplankton monitoring data. In the 1940's and 50's, Halme (1944) and Halme and Mölder (1958) studied phytoplankton composition and biomass in the archipelago regions of the Western Gulf of Finland. Information on phytoplankton in the 1960s includes the studies of Bagge and Niemi (1971) in the archipelago of Loviisa, the Gulf of Finland, the studíes of Melvasalo (1971) and Melvasalo and Viljamaa (1975) in the sea area of Helsinki-Espoo, and the study of Niemi *et al*. (1970) in the western coastal Gulf of Finland. In these studies Utermöhl method has been used, and the total biomass has been estimated. Dominating species and species lists are usually also presented.

The literature of phytoplankton in the early 1970s includes the studies of Kononen and Niemi (1986) and Forskåhl (1978) in the Gulf of Finland, and the studies of Niemi and Ray (1975, 1977) and Valtonen *et al.* (1978) in the Gulf of Bothnia. In these studies also Ütermöhl method was used, and the results include information on total biomass and dominating species. In the studies of Niemi and Ray (1975, 1977), species list and results of physico-chemical analyses are also presented. Finni *et al*. (2001) published the long term analysis on plankton assemblages in the sea area of Helsinki in the 20th century, but no numerical data are presented in the evaluation.

The historical literature is generally not very useful for establishing the reference conditions, because of the methodological differences, lack of information on phytoplankton biomass and uncertainty in the completeness of the species lists.

2. Paleo – ecological reconstruction of reference conditions

The applicability of paleo-ecological reconstruction of reference conditions for the past composition of phytoplankton is limited to sediment accumulation areas. In many coastal areas (such as the German coastal waters) large scale sediment transport processes prevent recent accumulation of sediments. In such areas studies dealing with sediments from the *Mya*-stage of the Baltic are not possible.

Recently, a promising approach is being developed by another EU-project *Molten (Monitoring long-term trends in eutrophication and nutrients in the coastal zone:*

Creation of guidelines for the evaluation of background conditions, anthropogenic influence and recovery[1], 2001-2004), which is currently carrying out comprehensive paleoecological studies for development for reconstruction of past nutrient conditions (N). The Molten project is carrying out sediment sampling and analysis of sediment and water column diatom composition in relation to nutrient concentrations to establish transfer functions that can be applied in the calculation of past nutrient conditions as well as phytoplankton biomass (as chlorophyll *a*). Such studies have been carried out in several coastal locations in Denmark, Sweden and Finland.The combined and harmonized dataset produced by the *Molten* project can be applied for nutrient conditions reconstruction at the European scale.

The diatom transfer functions enable reference conditions to be established for total nitrogen (TN), total dissolved nitrogen (TDN) and chlorophyll a. Some of the *Molten* results are now published in Andersen *et al*. 2004, Clarke *et al*. (2003, 2004), Conley *et al*. (2003), Kauppila *et al*. (2004), Vaalgamaa (2004) and Weckström *et al*. (2002, 2003).

One of the case studies of *Molten* project is the Laajalahti Bay, close to Helsinki city in the central Gulf of Finland, representing an urban estuary, which has recovered from excess nutrient pollution after the termination of functioning of the local municipal treatment plant in the mid-1980s. At present, the bay receives practically no external loading, but is still affected by internal loading of nutrients from the sediments. Paleoecological analyses on sediment geochemistry and diatom community structure suggested that Laajalahti Bay was relatively pristine in the late 1800s and in the early 1900s (Kauppila *et al.* 2004). The decrease in the dominance of benthic diatoms and the changes in sediment chemistry indicate that the human disturbance started between 1915 and 1955. At present, the annual levels of chlorophyll *a* (ca. 20 µg l^{-1}) and total nitrogen(ca. 900 µg N $l^{-}1$) are clearly higher than the reference concentrations (ca. 10 µg Chlorophyll a l^{-1} and 600 µg N l^{-1}) in the late 1800s and the early 1900s (Kauppila *et al.* 2004). In the Laajalahti Bay, total nitrogen explained 91% of the variation of phytoplankton biomass (chlorophyll *a*), which suggests that phytoplankton primary production is limited by nitrogen.

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[1] http://craticula.ncl.ac.uk:8000/Molten/jsp/index.jsp

The composition and structure of phytoplankton in the sediment cores is indicative to changes in nutrient conditions, but cannot be used to estimate changes in the phytoplankton composition or biomass in the water column, since only some species with siliceous frustules or cysts remain in the sediments, representing only a fraction of the species that have occurred in the water column during those times. Therefore the major objective of the *Molten* project is to produce an approach for definition of the time period when reference conditions may have occurred in the coastal areas. Based on this information and the reconstructed nutrient conditions, it may be possible to apply predictive modeling for estimation of reference status for biological quality elements, such as phytoplankton.

3. Historical phytoplankton biomass and chlorophyll

The main problem for the estimation of the historical phytoplankton biomass and chlorophyll concentrations is that the methodology for determination of these parameters has changed several times in the past. Without any calibration between the current and previous methodologies has been, it is very difficult to compare historical data with the present situation. In most cases, the recent methods for both parameters were introduced in the late 1960's and finally established in 1970's or 1980's. **Mostly comparable methods of phytoplankton** biomass have been applied since the late sixties; and chlorophyll concentrations since the beginning of the seventies (**Appendix 1)**. However, as the temporal and seasonal coverage of the earlier studies is often restricted, limiting the possibilities of deriving reliable reference conditions in comparison to more recent monitoring results. The approach discussed in this chapter is the applicability of long-term monitoring data sets and trends in biomass and composition changes of phytoplankton for hind-casting phytoplankton reference conditions.

3.1. Latvia

The first values of phytoplankton biomass during the seasonal cycle in the Gulf of Riga were estimated by Nikolajev (1957) already in the 1940's. Later in 1960's and 1970's the seasonal cycle of phytoplankton biomass was studied in the coastal zone (Rudzroga,

1974) and in the central part of the Gulf of Riga (Kalveka, 1980). In order to allow comparison of the earlier results of Nikolajev with the more recent monitoring data, average monthly phytoplankton biomass values were calculated pooling the results from all coastal stations currently monitored. The years with the most complete coverage of the seasonal cycle were selected for the comparison. However, there were no marked

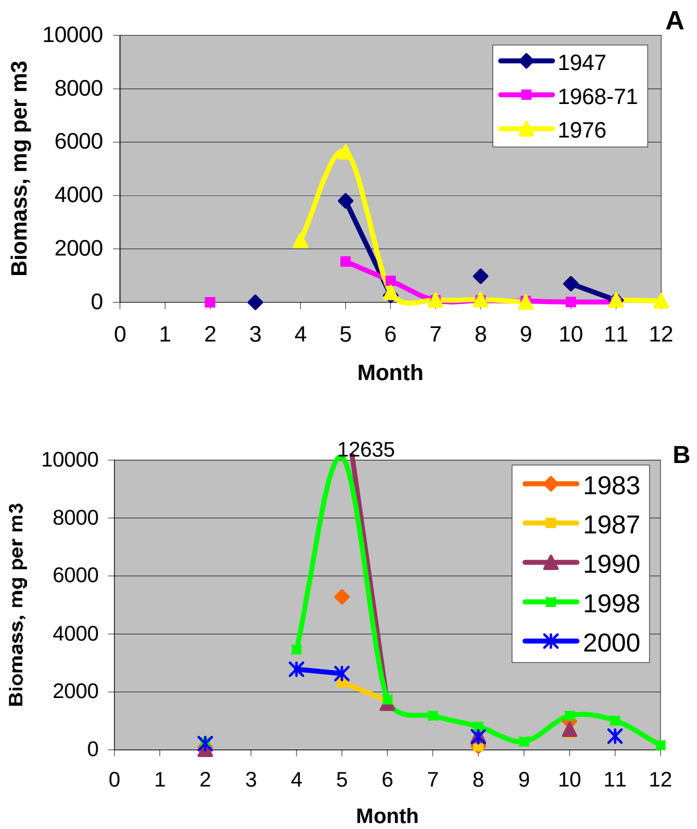

Figure 7. *The average monthly phytoplankton biomass in the Gulf of Riga, Baltic Sea (averaged over several sampling/ monitoring stations in the Gulf) during the years 1947, 1968-71, 1976 (A) and randomly selected more recent monitoring years (B).*

differences in the total average phytoplankton biomass in different years between 1947 and 2001 (**Fig. 7**).

Spring and autumn diatom blooms show considerable fluctuations between the years, but not any clear trends. Only clear difference can be observed during summer blooms. Early researchers (Krabbi, 1913ab; Rappoport, 1929; Nikolajev, 1953; Nikolajev, 1957) reported heavy blooms of *Aphanizomenon flos-aquae*, accompanied by

Nodularia spumigena during July-September, with the biomass maximum in August. Nikolajev (1957) reported *Aphanizomenon flos-aquae* blooms in every summer between 1946 and 1956. However, Rudzroga (1974) and Kalveka (1980) never reported observations of *Aphanizomenon* blooms during summers 1968-1976, despite the favourable weather conditions. During those years, the summer phytoplankton composition was dominated by *Gomphosphaeria lacustris* and chlorophytes (Kalveka, 1980). Comparing the literature values with the data at the CHARM phytoplankton database, generally a lower level of N_2-fixing cyanobacteria (*Aphanizomenon flos-aquae* and *Nodularia spumigena*) biomass prevailed between 1960's and 1980's. However, in 1990's higher biomass levels of cyanobacteria appeared, (**Fig. 8**). It is difficult to find some explanations for this increase, since no significant changes in the nutrient loading from rivers has been observed in 1990s, despite that there has been an extensive reduction in the use of mineral fertilisers and in the numbers of livestock in the Baltic States between 1987 and 1996 (Stålnacke et al. 2003).

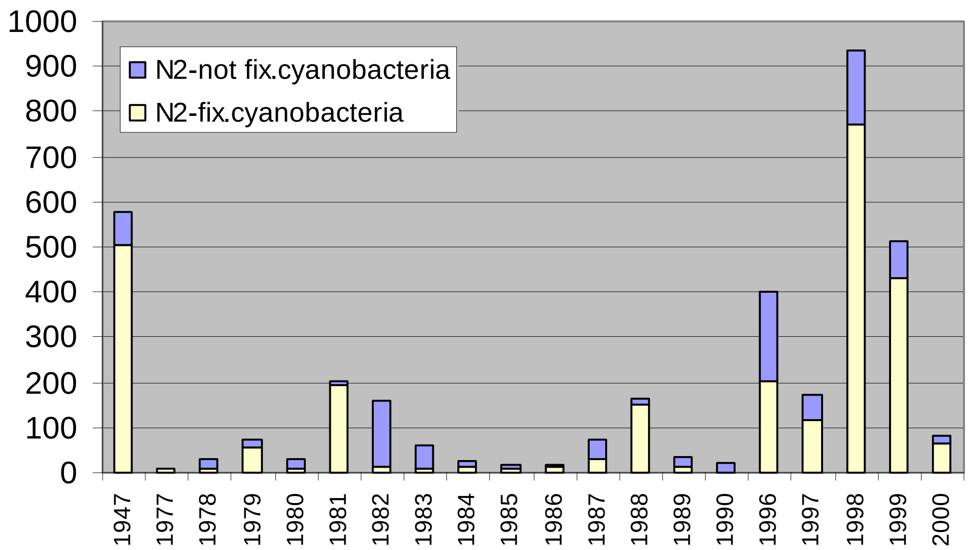

Figure 8. *Changes in mean cyanobacteria biomass (mean values for summer period July-September; mg wet weight l^{-1}) in the Gulf of Riga during 1947-2000.*

3.2. Estonia

Regular chemical and biological measurements in the Estonian coastal waters started only in the late 1970s. Some nutrient data from Tallinn Bay (PO_4-P, NO_2-N) are also available from the earlier period (since 1967), justifying the use of the Tallinn Bay as a case area. The data from other sites are less representative, based only on three seasonal samplings each year.

As in many other coastal areas around the Baltic Sea, water quality in the vicinity of municipal and industrial centres some decades ago does not reflect reference conditions. On the other hand, even if temporal coverage is regular, the data, especially phytoplankton biomass, are not directly comparable to present day data. Although the sedimentation method (Utermöhl technique) has become a standard since 1960s in quantitative phytoplankton studies, the use of fixed volume sedimentation chambers was not widespread. An alternative was the sedimentation of bigger (mostly 1 litre) volume and subsequent transference of settled material into the counting chamber with a pipette (Kiselev, 1969). The major source of variation was probably due to uneven sedimentation onto the bottom of sample container.

Cell concentration, expressed as the number of individuals per counting units per litre, is rather inadequate for the estimation of phytoplankton biomass. However, a bulk of historical data (Olenina et al. in prep.) consist only abundance numbers or relative abundances based on a scale of 5 classes from very sparse to dominant. The phytoplankton biomass has to be derived from the abundance using a biovolume factor, specific for each species and moreover, for each size-classes within a species. The standardized biomass estimation procedure for the Baltic Sea area has been developed very recently (**HELCOM, 1988**) and even the data collected some years ago need thorough revision.

The variation of total phytoplankton biomass in Tallinn Bay in different seasons is presented in **Figure 9**. The database was divided into two parts representing “historical” untreated biomass values (1979-91) and revised (updated for the changes in taxonomy, and for some biomass estimations) recent monitoring data (1993-2003), respectively. Despite the season, the variation in the phytoplankton biomass in the earlier observations was remarkably larger. At the same time, the dominant species have changed only in

August (see **Table 3**). This indicates that the biovolume factors need to be checked when analyzing earlier data. The summer biomass decline from early 1980s to the recent years is most probably due to biovolume overestimation of some phytoplankton species or groups, especially small flagellates in the earlier data. On the other hand, spring and autumn communities comprise many large-sized species leading to a larger variation in biomass.

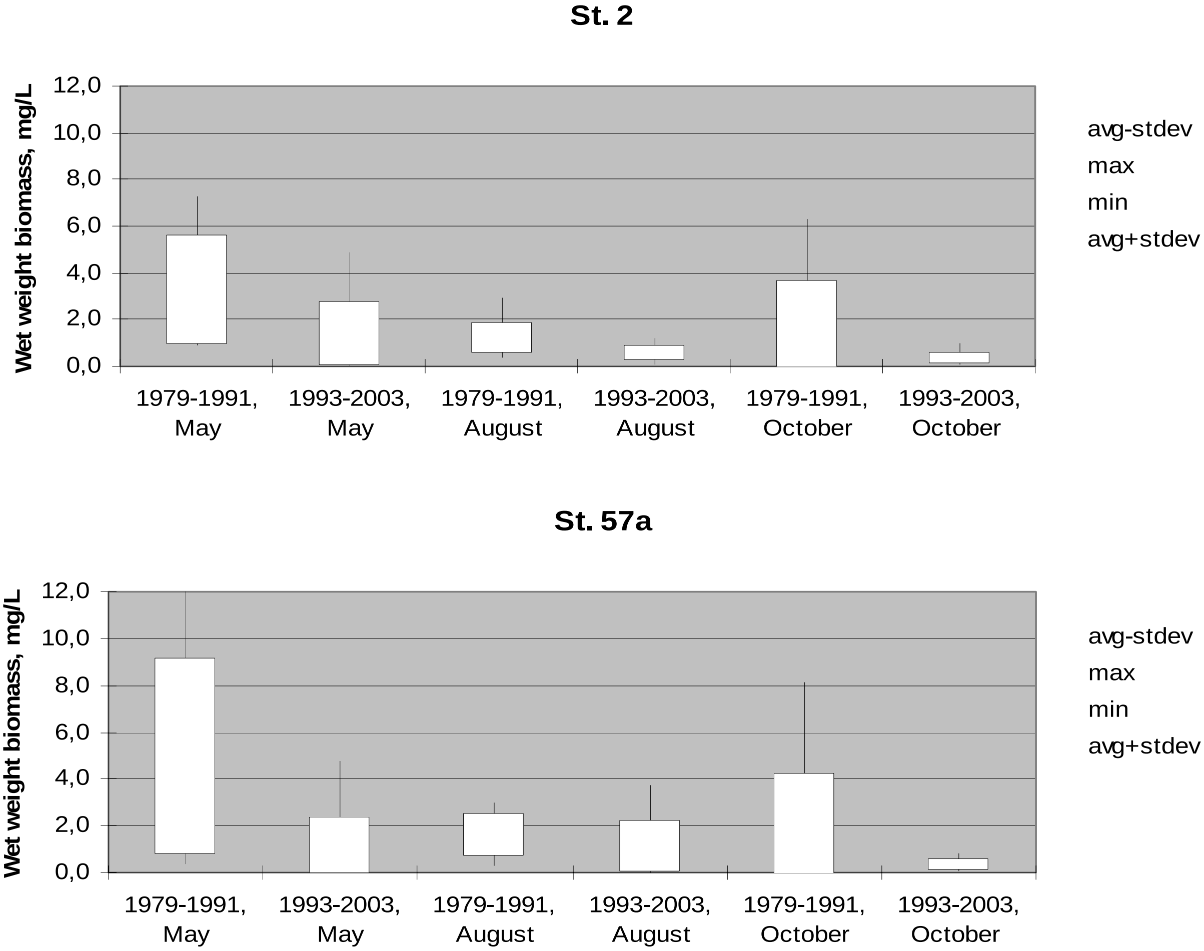

Figure 9. Seasonal variation in phytoplankton biomass (mg/L) in the open (upper panel) and inner (lower panel) parts of Tallinn Bay, central Gulf of Finland.

The higher biomass values in the 1980s may also explained by the higher nutrient (total nitrogen) concentrations (**Fig. 10**). Total nitrogen measured along the ferry route between Tallinn and Helsinki on the monthly basis and averaged for the period 1997-2003, seems to be a good indicator of water quality, as it is shown to be strongly related to the frequency of blooms (Carstensen *et al.*, 2003). In June, which is generally the period of phytoplankton summer minimum biomass in the Gulf of Finland, the correlation coefficient between these two parameters was very high (r=0.99; **Fig. 11**). This indicates that during this period any increase of phytoplankton biomass is strictly related to availability of nitrogen, which is mostly limiting phytoplankton production in summer (Kivi et al. 1993).

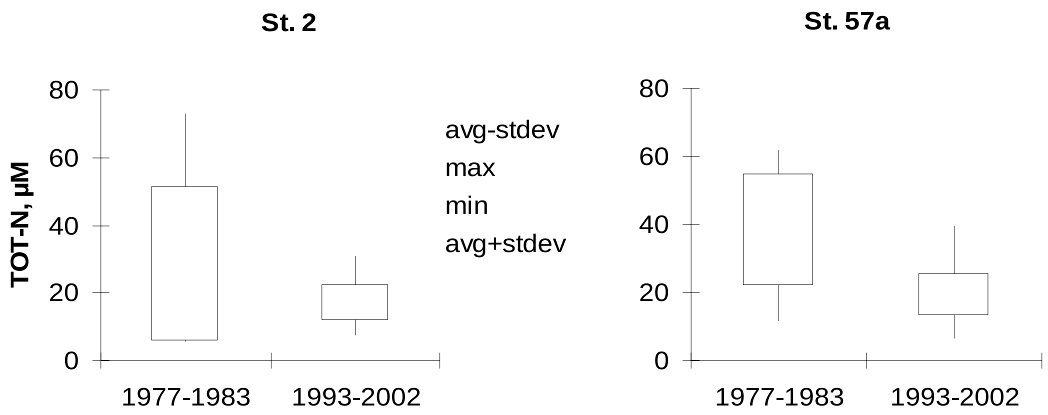

Figure 10. Comparison between variability of total nitrogen concentrations (µM; June-September) in two monitoring stations in Tallinn Bay (averaged values for the upper 10 m layer).

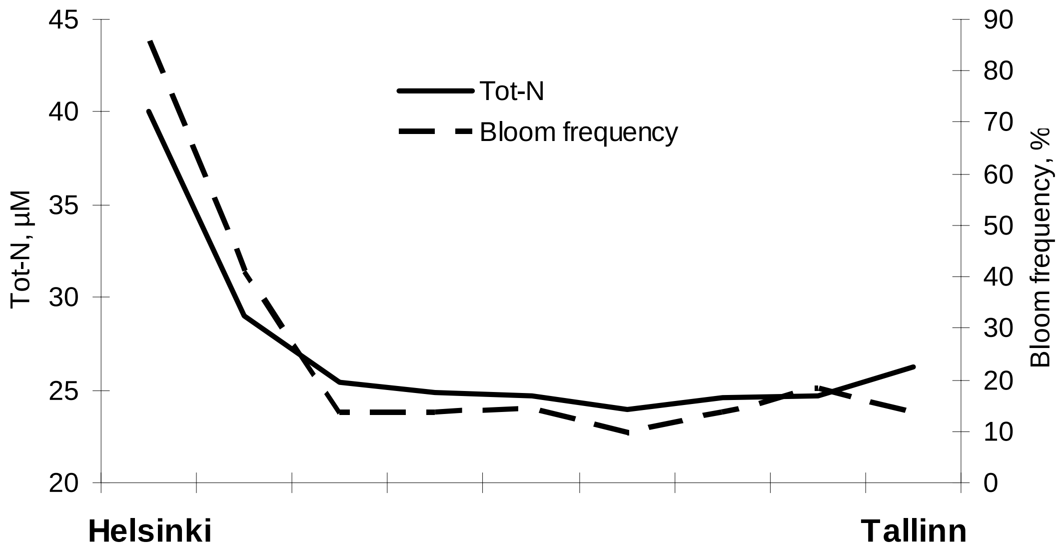

Figure 11. *Averaged frequency of phytoplankton bloom (calculated according to Carstensen et al. (2003)) vs. monthly average concentrations of total nitrogen (µM) measured in June along the ferry route between Helsinki and Tallinn between 1997 and 2003.*

3.2. Finland

Long-term monitoring of chemical and biological water quality started in the 1960's and 1970s in the Finnish coastal waters. However, the sparse data from the 1960s is unlikely to be representative for reference conditions at least in inner coastal areas , because trophic levels off many municipal and industrial areas were higher in the 1960s than at present (e.g. Pitkänen *et al.*, 1987, Kauppila *et al.*, 2004). This was due to poor purification techniques of the wastewater treatment plants. By contrast, chlorophyll a concentrations in the open sea areas even in the 1970s were usually lower than in the 1990s (Pitkänen *et al*. 1987; Kauppila and Lepistö, 2001). However, the historical values from the open sea and the outer coastal areas, which are usually outside the direct influence of land-derived anthropogenic loading, may not be applicable as reference conditions for nutrients for inner coastal areas, which may have had natural higher trophic levels due to shallowness and proximity to river influence.

In order to evaluate the applicability of the Finnish monitoring data to set the reference conditions for supporting chemical quality elements in the coastal waters, the monitoring data on nutrients and phytoplankton chlorophyll a was compiled from 19 stations in the outer archipelago and open sea areas between the years 1966 and 1976. The mean and median concentrations were calculated for total nitrogen (TN), total phosphorus (TP), nitrate nitrogen (NO_3-N), Nitrite-nitrogen (NO_2-N, ammonium-nitrogen (NH_4-N), phosphate phosphorus (PO_4-P), phytoplankton chlorophyll a and secchi depth for winter (February to March) and summer (July to September) periods. The inter-annual and spatial variability of nutrients and phytoplankton biomass (as chlorophyll a and biovolume) in the late 1960s and early 1970s was compared with the trends in some intensive sampling stations (Pitkänen *et al.* 2001, Kauppila and Lepistö 2001).

In the Gulf of Finland, the average nutrient concentrations (331 mg TN m^{-3} and 24 mg TP m^{-3} in winter) in the 1960s and early 1970s were corresponding to the levels in the outer archipelago of Helsinki (station Länsi-Tonttu) in the late 1970s (**Appendix 7**, **Fig. 12**). In general, nutrient concentrations in the 1960s and early 1970s were lowest in the open western Gulf (**Fig. 12**). The level TP seemed to be even higher in the late 1960s than in the early and mid-1970s.

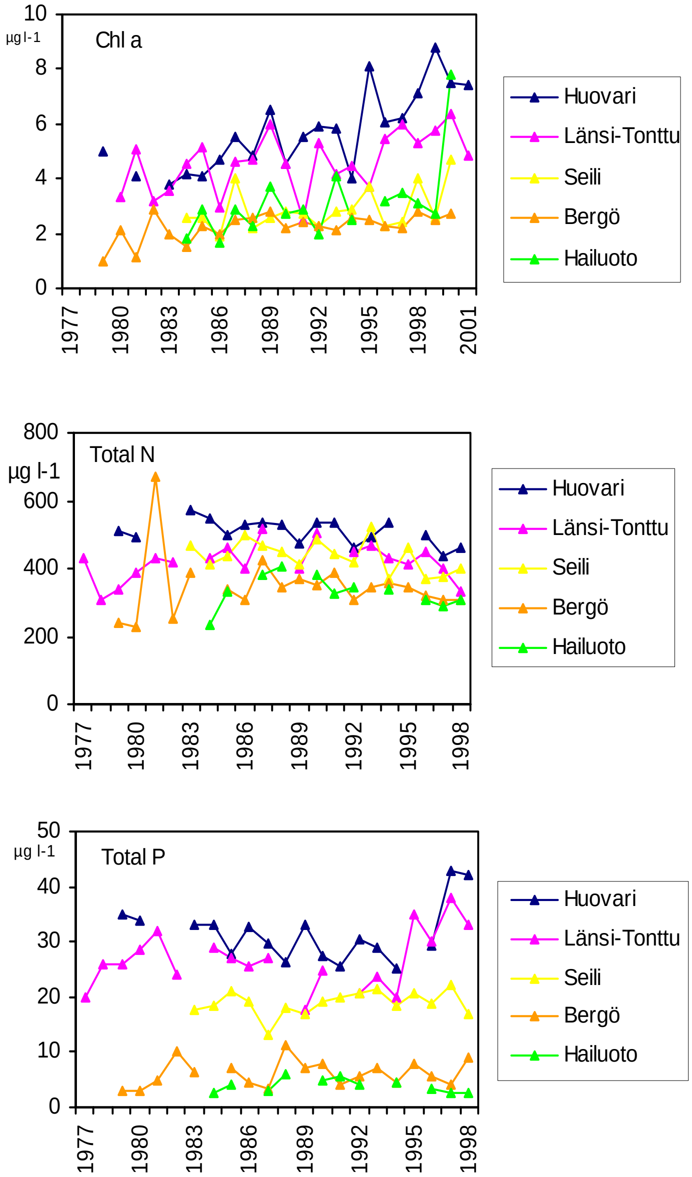

Figure 12. *Average annual concentrations of chlorophyll a (µg l^{-1}; upper panel) in summer (July-September), total nitrogen (µg l^{-1}; middle panel), and total phosphorus (µg l^{-1}; lower panel) in early spring (February-March) at five sampling stations along the Finnish coast between 1977 and 1998 (see Figure 13, for location of the sampling stations). Modified from Pitkänen et al. (2001).*

Contrary to nutrients, the concentrations of chlorophyll a (2.5 mg m^{-3} on average) in the 1960s and early 1970s were clearly lower than at the end of the 1970s (**Appendix 7**, **Fig. 12**). In fact, the boundary of slightly eutrophied area (3 mg Chlorophyll a m^{-3}) in the gulf has moved westward since the 1970s (Pitkänen *et al.* 1987, Kauppila and Lepistö 2001), which can be explained by the weakening of vertical stability and an increase of nitrogen concentrations (Perttilä *et al.* 1996). The status of the open Gulf of Finland in the 1960s and early 1970s can be classified as good on the basis of the criteria of the general classification for coastal waters (see Antikainen *et al.* 2000).

<u>In the Archipelago Sea</u>, the level of nutrients (240 mg TN m^{-3} and 18 mg TP m^{-3} in winter) in the 1960s and early 1970s were lower than observed at Seili in the beginning of the 1980s, but chlorophyll *a* values were on the similar level (**Appendix 7**, **Fig. 12**). On the basis of the criteria of the general classification for coastal waters (Antikainen *et al.* 2000), the middle and outer Archipelago Sea were classified to be at least in a good status in the 1960s and early 1970s. Summertime chlorophyll a was on average 2.3 mg m^{-3}, TP 15 mg m^{-3} and secchi depth 5 m, in respectively.

<u>In the Bothnian Sea</u>, the average nutrient concentrations (median 265 mg TN m^{-3} and 16 mg m^{-3} in winter) in the 1960s and early 1970s corresponded to the level at Bergö at the end of the decade (**Appendix 7**, **Fig. 12**). The values of chlorophyll a and secchi depth (on average 1.4 mg m^{-3} and 4.9 m, respectively) revealed excellent status according to the criteria of the general classification for coastal waters given in Antikainen *et al.* (2000). On the basis of TP concentrations, the status was good.

Similarly, the oldest data of nutrient concentrations (358 mg TN m^{-3} and 12 mg TP m^{-3}) <u>in the</u> <u>Bothnian Bay</u> were close to those observed at Bailout in the late 1970s (**Appendix 7**, **Fig. 12**). On the basis of TP and chlorophyll a (ca. 2 mg m^{-3} at Bailout in the mid-1980) the status from the 1960s to the early 1980s was between excellent and good.

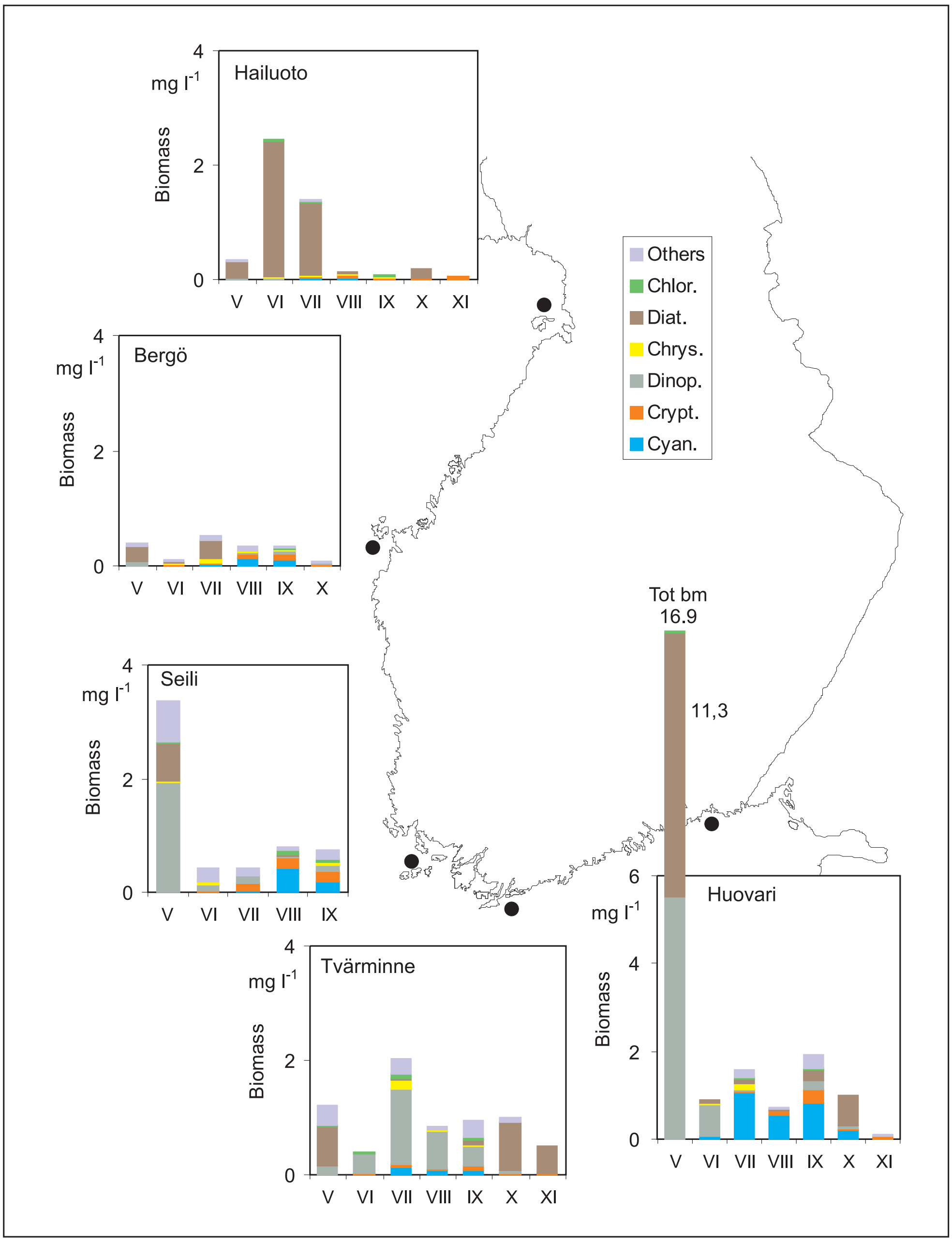

Figure 13. Contribution of major taxonomic groups to mean total phytoplankton biomass (wet weight; mg l^{-1}) in the Eastern Gulf of Finland, the Western Gulf of Finland, the Archipelago Sea, the Northern Bothnian Sea, and the NE Bothnian Bay from May to November in 1998. (V= May, VI= June, VII= July, VIII= August, IX= September, X= October, XI= November; modified from Kauppila and Lepistö, 2001).

Phytoplankton biomasses and species composition have large seasonal and areal variability in the Finnish coastal waters (Fig. 13, Kauppila and Lepistö, 2001). Such variability has to be considered when establishing reference conditions for the Northern Baltic Sea. The only monitoring station where long-term changes in phytoplankton biomass and composition have been observed is from the Eastern Gulf of Finland. There the total phytoplankton biomass has increased and the community structure has also clearly changed since the late 1970s due to increased trophic status of the area (**Fig. 14,** Kauppila and Lepistö, 2001). In the late 1970s and early 1980s, phytoplankton community was mainly dominated by *Dinophysis acuminate,* while in 1990s cyanobacteria have become more dominant.

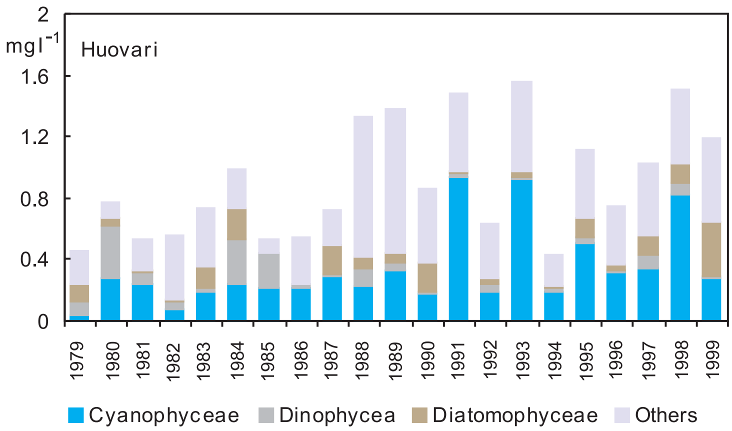

Figure 14. Contribution of major taxonomic groups to mean total phytoplankton biomass in the Hoover monitoring station in the Eastern Gulf of Finland during the late summer period in between 1979 and 1999 (Kauppila and Lepistö, 2001).

Based on the existing monitoring and assessment system of the Finnish coastal waters, the outer coastal waters can be classified to be good in the 1960s and 1970s (Appendix 7, cf. Personnel *et al.* 1995, Monika 2001). In the outer Bothnian Bay, trophic conditions seemed to have been nearly excellent in the 1960s. However, the data is relatively scarce and the results can be only considered to be indicative for the actual coastal status at those days.

4. Application of transparency for reconstruction of historical phytoplankton conditions

In contrast to the measurement of chlorophyll and biomass, the measurement of the transparency conditions as Secchi-depths started already in the early thirties in the Baltic area (Sanden & Håkansson, 1996). There are several investigations that show a very good relationship between secchi-depth and chlorophyll a (Fig. 16). Secchi-depth measurement is a relatively simple procedure: a white disc with a specified diameter is lowered in the water column and the depth of the disappearance of the disc is recorded. It generally gives a good estimation of the intensity of phytoplankton biomass, although also other particles such as mineral turbidity influence visibility.

The reconstruction of historical chlorophyll a concentrations was tried by recalculating the chlorophyll a values from historical Secchi-depths using some data from the German coastal waters as an example. The basis of these recalculations is a correlation of actual values of both parameters which was found for several water bodies (compare Sanden and Håkansson 1996, **Fig. 15**). Only few historical measurements from inner coastal waters of Germany were found. The given Secchi depths, single values from July 1932 to July 1933 (Gessner 1937), and August, September, October 1936 (Trahms 1937) are compared with recent values in **Figure 15**. Whereas the Secchi-depths of Libben and Großer Jasmunder Bodden (high-eutrophic water bodies) are comparable to actual measurements from the nineties, the historic data of Kleiner Jasmunder Bodden (since beginning of 20th century hypertrophic) are lower than actual values.

Irrespective of significant correlations for the German coastal waters (Fig 16) a backward calculation of chlorophyll a values was not possible, because of the marginal numbers of available historic Secchi-depths.

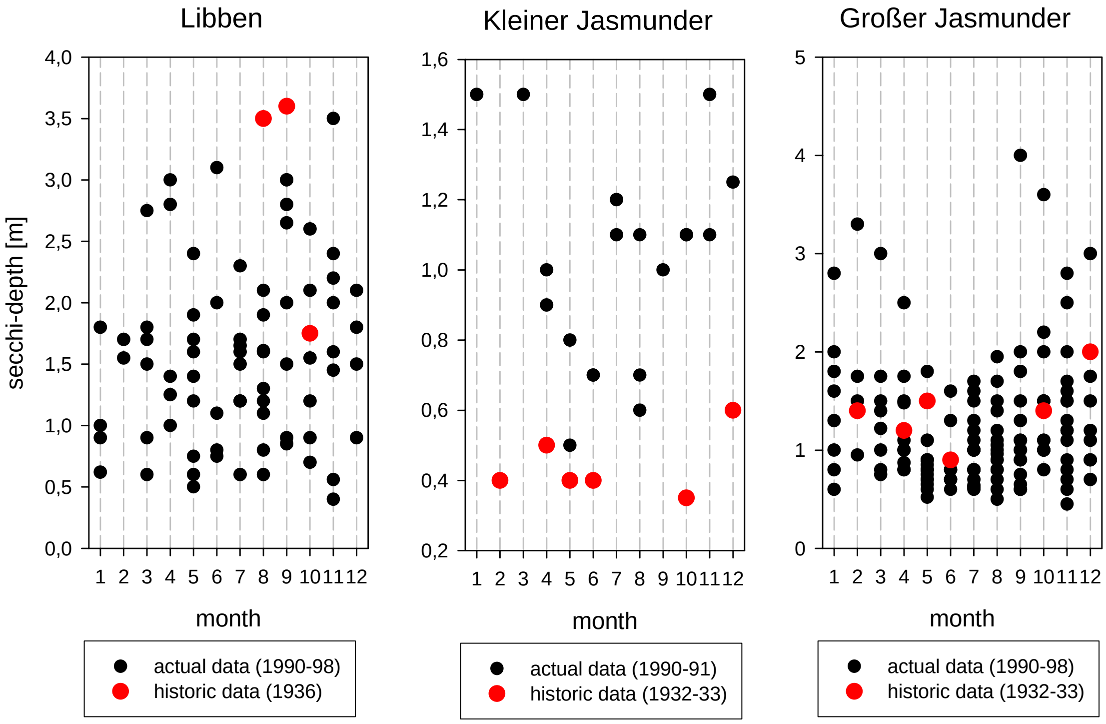

Figure 15. *Comparison of historic and actual Secchi-depths for three inner coastal waters of Germany.*

However, in areas where more historical Secchi-depth measurements are available, there might be a good possibility to apply the relationships between transparency and chlorophyll a for approximation of historical phytoplankton biomasses. Secchi depth also appears to be good predictor of the depth limits of some macrophytes, such as eel grass (Nielsen et al, 2002), and should also be tested for prediction of phytoplankton biomass values using data from several coastal areas.

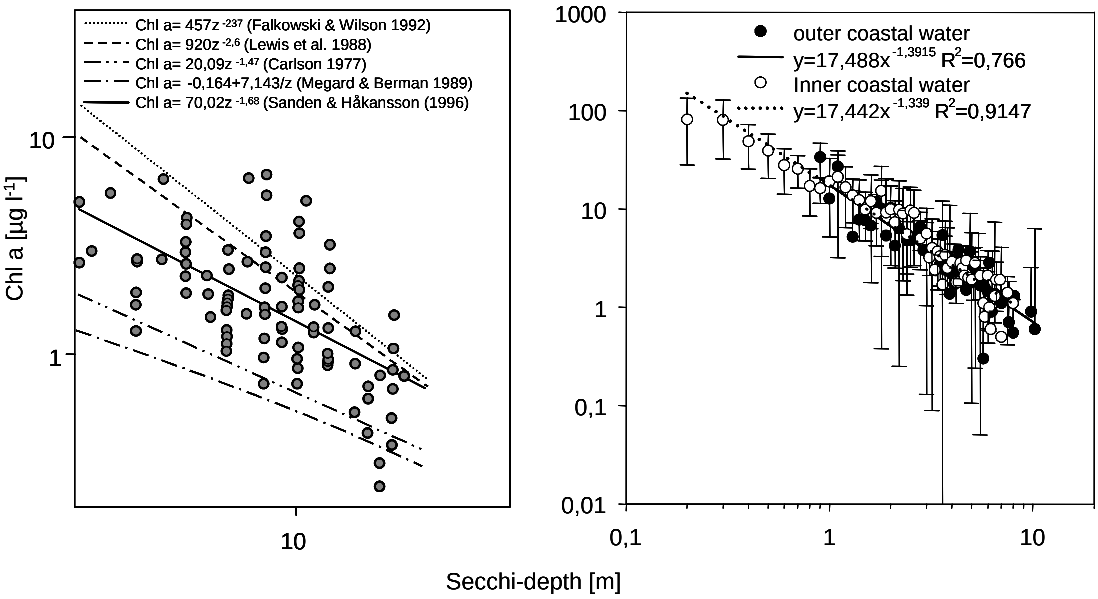

Figure 16. *Correlation of Secchi-depth and chlorophyll a. Left: Figure from Sanden and Håkansson (1996). Right: Correlations of Secchi-depth versus chlorophyll a concentration for various coastal waters of Germany. All data were summarised from monthly measurements between June and August from 1990 up to 1998. The bars give standard deviations of average values.*

In the estuaries of the Finnish coast, dependence between chlorophyll *a* and secchi depth was weaker than in the coastal waters of Germany as a whole. Chlorophyll a and TP accounted 41 and 53% of the variation in secchi depth, respectively (Kauppila, 2004). Thus, most of the TP was bound to algae, but extinction of particle scattering also had an effect on the optical properties of the sea water. An alternative model for secchi depth was obtained as a function of TP and mean depth (R^2=0.55), which illustrated the impact of resuspension to water transparency in the shallow Finnish estuaries. The applicability of the relationship between chlorophyll a and secchi depth in establishing reference conditions for the outer coastal waters of Finland has not yet been tested. It is possible that the relationship is stronger in the deeper areas outside the direct influence of river waters, which are strongly colored by humic substances.

5 Modeling of phytoplankton reference conditions

Development of three-dimensional coupled ecological -physical models (such as presented in Neumann et al. 2002) can potentially provide new additional tools for reconstruction of past phytoplankton conditions. Such models summarize the current understanding of the functioning of the lower trophic levels of the pelagic ecosystems, and provide tools to simulate functioning of the current nutrient dynamics and biomass production of the Baltic Sea since those are validated using recent monitoring data. If applied for simulations of past conditions, the inevitable presumption is that the climatological and hydrodynamic forcing has been the same in the past as nowadays, and that the structure and functioning of the ecosystem in the past was similar to present state. However, these conditions, as well as the structure of the food web may have been different in the past so that direct interpolations may be slightly misleading. However, such ecological-physical models will provide an advanced tool to construct alternative scenarios of the past conditions using available information on the atmospheric and nutrient loading to the coastal areas.

The 3D-coupled biological chemical physical model of the Baltic Sea (Neumann et al. 2002) was used to derive past nutrient and phytoplankton biomass conditions in the coastal areas of the Baltic Sea by Schernewski & Neumann (**2003**). The model was used to simulate pre-industrial (early 1900) conditions of coastal waters using past information and data on riverine nutrient loading to the Baltic Sea. Calculations of the past chlorophyll a concentrations along the outer German coast using the dynamic model of Schernewski & Neumann (**2003**) the following reference values for chlorophyll a (mg m^{-3}) were obtained.

	Annual average	Summer maximum
Kiel Bight	1,9	2,7
Lübeck Bight	1,5	2,0
Mecklenburg Bight	1,5	2,3
Oder Bight	3,0	4,5

However, these values are in the same range than the actual measured ones, which would led to the conclusion that these areas are still in pristine conditions with respect to chlorophyll a. Because this conclusion seems to be unlikely, a careful evaluation of the model applied is highly recommended. Alternatively, chlorophyll might be not very useful for classification, because it is masking composition changes as well as changes in the phytoplankton succession.

In addition, modelling of rough phytoplankton composition is probably possible after evaluating of the model by means of recent data sets (Gerald Schernewski, pers. comm.). The primary production in the model is provided by three major phytoplankton groups: diatoms, cyanobacteria and flagellates, having different growth rates and assimilation rates for nutrients, in addition to cyanobacteria being able to fix atmospheric nitrogen. After validation of the results of model calculations with recent data an attempt to extrapolate the annual biomass succession of Diatoms, N-fixing cyanobacteria and flagellates during e.g. the late 18th century could be attempted. However, such work is beyond the scope of the CHARM project.

In general, advanced models, when combined with other information (such as simple relations between secchi-depth and chlorophyll a or historical information on phytoplankton composition), may provide a useful tool to support expert evaluation of the past conditions. In some cases the expert opinion may be biased to ‘earlier it was always better quality waters’-type of conceptions. If the model simulations provide results that for instance the biomass cyanobacteria may increase as result of nutrient loading reductions (Neumann et al. 2002), the ‘expert opinion’ that increased intensity of cyanobacterial blooms is a clear indication of eutrophication of coastal waters may need to revised and critically evaluated as well.

6. Frequency and intensity of plankton blooms

The sampling frequency in the historical data is generally not sufficient to allow estimation of the historical periodicity and intensity of phytoplankton blooms. As a part of the CHARM project a statistical method to define the bloom and to analyse likelihood of the occurrence of blooms (Carstensen et al. 2003) has been tested using data from several coastal areas (Henriksen et al., in prep.). This approach seems promising, but it still remains to be tested, if reference condition values of the potential bloom frequencies can be developed by using this approach and the data available in the CHARM phytoplankton database.

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Acknowledgement

The Authors wish to thank Johanna Rissanen (SYKE) for compiling the historical references from the Finnish coastal waters, and Magdalena Wielgat (IOW) for providing a map of the Baltic Sea with the CHARM draft typology of the Baltic Sea indicated. We gratefully acknowledge the possibility to use the phytoplankton data from the Algaline (Finnish Institute of Marine Research) in our analysis. This study is supported by the European Commission (CHARM-EVK3-CT-2001-00065).

List of Appendixes

Appendix 1: List of the historical literature of phytoplankton species composition/ abundance in the Baltic Sea in chronological order

Years of studied	Sampling location and period	Measured data; method	Author /Reference
1800's	Gulf of Riga, and the coastal zone of Baltic Sea	Species identification; method unknown	Grindel D., 1803. Botanisches Taschenbuch für Liv-, Kur- und Ehstland. Algae. Riga. Goebel A., 1857. Der heilsame Meeresschlamm an den Küsten der Insel Oesel. Arch.Naturk. Liv-, Ehst- u. Kurlands, 1.Ser., I. Buchse F.B., 1866. Algen des Rigaschen Meerbusens. Correspondenzbl. Naturf.-Ver., Riga, N15. Braun M., 1886. Über mikroskopische pelagische Tiere aus der Ostsee. Zool. Anzeiger, N235.
1900-1901	Greifswald Bodden. June 1900 - June 1901	Abundance; plankton net	Abshagen, G. (1908): Das Phytoplankton des Greifswalder Boddens. – Diss. Greifswald 1908
1903	Southern Baltic Sea: Kiel Bight to Lithuanian waters. Feb. - Nov.	Sedimented volume and abundance; different nets and "plankton tube"	Apstein, C. (1906): Plankton in Nord- und Ostsee auf den deutschen Terminfahrten, 1. Teil (Volumina 1903) – Wissenschaftliche Meeresuntersuchungen / Neue Folge /Abt. Kiel/ 9: 1-27
1905	Greifswald Bodden	Abundance; plankton net Including review of previous investigations of different authors	Fraude, H.P.A. (1907): Grund- und Plankton-Algen der Ostsee. - X. Jahresbericht der Geographischen Gesellschaft zu Greifswald: 223-350
1905	Southern Baltic Sea: Kiel Bight to Lithuanian waters. Feb.- Nov.	Abundance; plankton net	Driver, H. (1908): Das Ostseeplankton der 4 deutschen Terminfahrten im Jahr 1905. - Wissenschaftliche Meeresuntersuchungen / Neue Folge /Abt. Kiel/ 10: 106-128
1906	Kieler Förde Apr. 1905 - May	Abundance; water samples enriched by filter and/or centrifuge, some samples caught by net	Lohmann, H. (1908): Untersuchungen zur Feststellung des vollständigen Gehaltes des Meeres an Plankton. - Wissenschaftliche Meeresuntersuchungen / Neue Folge/Abt. Kiel/ 10: 129-370
1906	Skagerrak, Kattegat and Southern Baltic Sea: Kiel Bight to Gulf of Gdansk. Spring period	Abundance; different nets and "plankton tube"	Kraefft, F. (1910): Über das Plankton der Ost- und Nordsee und den Verbindungsgebieten mit besonderer Berücksichtigung der Copepoden. - Wissenschaftliche Meeresuntersuchungen /

			Neue Folge /Abt. Kiel/ 11: 29-108
1907	Skagerrak to Northern Baltic proper. July - Aug.	Sedimented volume and abundance; plankton net	Merkle. H. (1910): Das Plankton der deutschen Ostseefahrt Juli-August 1907. – Wissenschaftliche Meeresuntersuchungen / Neue Folge /Abt. Kiel/ 11: 321-346
1900's	Gulf of Gdansk	Monograph, phytoplankton composition	Lakowitz, K. (1907): Die Algenflora der Danziger Bucht. Danzig.
1908-09	Gulf of Riga	Abundance; plankton net	Krabbi A.I., 1913a. Plankton of the Baltic Sea from the expedition in 1908. Proceeding of the Russian Baltic expedition, vol.2 (in Russian). Krabbi A.I., 1913b. Report on the plankton of the Baltic Sea, collected by the Baltic expedition in August and November 1909. Proceeding of the Russian Baltic expedition, vol.2 (in Russian).
1910	Gulf of Riga July	Abundance; plankton net	Taube, E., 1911. Zur Kenntnis des Planktons der Kielkond. Bucht auf Osel. Arbeiten der Naturforschungen. Ver. Zu Riga, N.F.13.
1910-11	Fehmarnbelt. April 1910 - March 1911	Abundance; plankton net	Büse, T. (1915): Quantitative Untersuchungen von Planktonfängen des Feuerschiffes „Fehmarnbelt" vom April 1910 bis März 1911. - Dissertationes philosophicae Kilonienses 1914-1916: 230-279
1912	Finnish waters. May	Abundance; plankton net	Leegaard, C. (1920): Microplankton from the Finnish waters during the month of may 1912. - Acta Societatis scientiarum Fennicae 48; 1916.20; Helsingfors 1920; 1-44
1889-1915	Gulf of Finland and Åland Sea. Oct. and Dec. 1989, August and Nov. 1911, March, Juni August 1912, Juni-August in 1913-1914,	plankton lists, five classes to describe abundance, plankton net	Levander 1900-1915: Levander, K.M. 1900. Uber das Herbst- und Winter-Plankton im finnishen Meerbusen und in er Ålands-See 1898. Acta Soc. Fauna Flora Fenn, XVIII, N:o 5. Levander, K.M. 1901. Zur Kenntnis des Planktons und der Bodenfauna einiger seichten Bracwasserbuchten. Acta Soc. Fauna Flora Fenn, XX, N:o 5. Levander, K.M. 1914. Zur Kenntnis der Bucht Tavastfjärd in hydrobiologischer Hinsicht. Meddelanden af Societas pro Fauna et Flora Fennica h. 40 (1913-1914). Levander, K.M. 1915. Zur Kenntnis der Bodenfauna und des Planktons der Pojowiek. – Fennica 35(2): 1-39.

1912-13	Kiel Fjord. March 1912 - May 1913	Abundance; plankton net	Busch, W. (1916-1920): Über das Plankton der Kieler Föhrde im Jahre 1912/13. - Wissenschaftliche Meeresuntersuchungen / Neue Folge /18: 25-144
early 1920s and early 1930s	open Gulf of Finland, open Bothnian Sea, May-June 1912	Abundance, plankton net	Välikangas, I. 1926. Planktologishe Untersuchungen um Hafengebiet von Helsingfors. Acta Zool. Fenn. 1: 1-298. Välikangas, I. 1932. Biological and hydrographical studies on the pollution of the Helsinki sea area in summer 1932 and observation of possible changes that has taken place since 1919-1920. Unpublished report. (In Finnish)
1919	Gulf of Finland, Port of Helsinki, April-Oct.	Abundance (semi-quantitative); plankton net	Välikangas, I. (1926): Planktologische Untersuchungen im Hafengebiet von Helsingfors. - Acta Zoologica Fennica 1: 1-298
1923-24	Gulf of Gdansk	Abundance (semi-quantitative); plankton net	Namyslowski, B. (1924): Fitoplankton Małego Morza. Roczniki Nauk Rolniczych, T. XII, 419-461.
1925	Gulf of Riga. Jan. – Dec.	Abundance; water samples enriched by gauze	Rapoport, M. (1929): Das Oberflächenplankton der Küstengewässer Lettlands im Jahre 1925. – Folia Zoologica et Hydrobiologica 1: 63 - 104
1917-25	Gulf of Gdansk	Sediment sample, glacial and postglacial sediments	Schultz, P. (1926): Die Kieselalgen der Danziger Bucht. Bot.Archiv. Bd. 13,149-327.
1927-28	Gulf of Gdansk, Dębki-coastal station Seasonal studies	Abundance (semi-quantitative); plankton net	Woloszynska, J. (1928): Dinoflagellatae polskiego Bałtyku i błot nad Piaśnicą. Archiwum Hydrobiologii i Rybactwa. T. III, 153-251.
1920's	Gulf of Gdansk	Monographs, phytoplankton composition	Lakowitz, K. (1927): Die Cyanophyceen (Schizophyceen), Blautange der Ostsee. Bericht des Westpreussischen Botanisch-Zoologischen Vereins. Bd. 49. Lakowitz, K. (1929): Die Algenflora der gesamten Ostsee. Danzing.
1928	Gulf of Riga. May	Abundance; plankton net	Bruno, V. and A. Berzins (1932): Das Plankton der lettischen Terminfahrt im Frühjahr 1928 (Rigascher Meerbusen und Baltisches Meer). - Folia Zoologica et Hydrobiologica 4: 68 - 102
1928	Gulf of Riga. May	Abundance; plankton net and water samples enriched by filter	Bruno, V. and A. Berzins (1932): Das Plankton der lettischen Terminfahrt im Frühjahr 1928 (Rigascher Meerbusen und Baltisches Meer). - Folia Zoologica et Hydrobiologica 4: 68 - 102

1930, 1934	Gulf of Gdansk Jun-July	Phytoplankton composition; plankton net	Woloszynska, J. (1935): Bemerkungen uber eine seltene Plankton-diatomee des Brackwassers Attheya decora West. Bull. de l' Acad. Pol. Ser B. Cracovie 1935, 65-67. Woloszynska, J. (1935): Uber eine wasserblute von Cyanophyceen in der Danziger Bucht und eine Wucherung der Diatomee Chaetoceros eibenii Grun. Bull. de l' Acad. Pol. Ser B. Cracovie 1935, 102-114.
1936	Waters around Island of Rügen. July - Nov.	Abundance (semi-quantitative); plankton net or "plankton tube"	Thrams, O.-K. (1938): Zur Kenntnis der Salzverhältnisse und des Phytoplanktons der Hiddenseer und der Rügenschen Boddengewässer. - Archiv für Hydrobiologie 32: 75-90
1936-37	Fehmarnbelt to western Gotland Sea with special respect to coastal stations at the southern Baltic coast. May 1936 - Oct. 1937	Abundance; water sample enriched by gauze	Brandes, C.-K. (1939): Über die räumlichen und zeitlichen Unterschiede in der Zusammensetzung des Ostseeplanktons.- Mitteilung aus dem Hamburgischen Zoologischen Museum und Institut 48: 1 – 47
1937-38	Darss sill region. April 1937 - Mai 1938	Abundance; plankton net and water samples	Bandel, W. (1940): Phytoplankton- und Nährstoffgehalt der Ostsee im Gebiet der Darsser Schwelle. - Internationale Revue der gesamten Hydrobiologie und Hydrographie 40, 3/4: 249-304
1938	Gulf of Gdansk to Öland, spring 1938. Southern Baltic proper to northern Baltic proper, summer 1938. Bornholm Sea, autumn 1938	Abundance; water sample	Rothe, F. (1941): Quantitative Untersuchungen über die Planktonverteilung in der östlichen Ostsee. - Berichte der deutschen wissenschaftlichen Kommission für Meeresforschung / Neue Folge 10: 291-368
1940's	Western Gulf of Finland, Tvärminne archipelago, Pojo Bay	Biomass and species composition.	Halme, E. 1944. Planktonlogische Untersuchungen in der Pojo-Bucht und angrenzenden Gewässern. I. Milieu und Gesamtplankton. _ Ann. Zool. Soc. 'Vanamo' 10(2): 1-180. Halme, E. & Mölder, K. 1958. planktologische Untersuchungen in der Pojo-Buch und angrenzenden Gewässern. III. Phytoplankton. – ann. Bot. Soc. 'Vanamo' 30(3): 1-71.
1946-47	Gulf of Riga	Abundance, biomass,	Nikolajev I.I., 1953. Phytoplankton of the Gulf

	Season cycle	phytoplankton net (1947), nansen bottles (1947)	of Riga. In: Proceedings of the Fisheries research in the Baltic Sea, Issue 1, Riga (in Russian). Nikolajev I.I., 1957. Biological seasons of the Baltic Sea. In: Proceedings of the Fisheries research in the Baltic Sea, Issue 2, Riga (in Russian).
1946-47	Gulf of Gdansk, Gdańsk Deep Seasonal studies	Abundance (semi-quantitative); plankton net	Rumek, A. (1948): Lista gatunków fitoplanktonu powierzchniowego Zatoki Gdanskiej (List of surface phytoplankton species in the Gulf of Gdansk). Biul. Mor. Lab. Ryb., Gdynia, 4, 139-141.
1949-50	Kiel Bight. June 1949 - June 1950	Abundance; water samples	Gilbricht, M. (1951): Produktionsbiologische Untersuchungen in der Kieler Bucht. – Diss. Kiel
1954-1955	Gedser Rev to Bornholm Sea.	Abundance; water sample enriched by gauze	Waldmann, J. (1959): Quantitative Planktonuntersuchungen in der mittleren Ostsee 1954/55. - Zeitschrift für Fischerei und deren Hilfswissenschaften 8: 371-436
1956, 1959, 1967-68	South Baltic Proper, Gdańsk Deep Seasonal studies	Abundance (semi-quantitative); plankton net	Ringer, Z. (1970): Sklad fitoplanktonu poludniowego Baltyku w latach 1967-1968 (Phytoplankton composition in the southern Baltic Sea from 1967-1968). Stud. Mater. Mor. Inst. Ryb., Gdynia, ser. A nr 7. Ringer, Z. (1973): Fitoplankton poludniowego Baltyku na tle warunków hydrologicznych (The southern Baltic Sea phytoplankton against a background of hydrological conditions). Stud. Mater. Mor. Inst. Ryb., Gdynia, ser. A nr 11.
1968	Western Gulf of Finland, Tvärminne archipelago August 1968	Biomass (Utermöhl method).	Niemi, A., Skuja, H., Willen, T. (1970): Phytoplankton from the Pojoviken-Tvärminne Area, S. coast of Finland. - Memoranda Societatis pro Fauna et Flora Fennica 46: 14-28
late 1960s to early 1970s	Western Gulf of Finland, Tvärminne area. Finnish coastal waters. Open water period.	Species composition and biomass. Ruttner sampler, Ütermöhl method	Niemi, Å. 1973. Ecology of phytoplankton in the Tvärminne area, SW coast of Finland. I, dynamics of hydrography, nutrients, chlorophyll a and phytoplankton – Acta Bot. Fennica 100: 1-68. Niemi, Å. & Ray, I.L. 1975. Phytoplankton production in Finnish coastal waters. Report ;. Phytoplankton biomass and species composition in 1972. – Meri 1: 24-40. Niemi, Å. & Ray, I.L. 1977. Phytoplankton production in Finnish coastal waters. Report ;. Phytoplankton biomass and species

			composition in 1972. – Meri 4: 2-22.
1966-1970	Sea area of Helsinki and Espoo, April-October.	Species composition and biomass, Ruttner sampler or a Tube, Ütermöhl method.	Melvasalo, T. 1971. Observations on phytoplankton species and biomass in the sea area of Helsinki and Espoo in 1966-1970. Reports of the Water Conservation Laboratory, Helsinki.
1968-71	Southern Gulf of Riga	Abundance, biomass; water samples	Rudzroga A.I., 1974. Distribution of plankton algae in the littoral part of the Gulf of Riga. In: Biology of the Baltic Sea, vol.1, eds. G.Andrushaitis, R.Laganovska, A.Kumsare, M.Matisone, Riga, Zinatne, 175-766 (in Russian, abstract in English).
early 1970's	Helsinki sea area. Open water period.	Species composition and biomass, Ruttner sampler, Ütermöhl method.	Melvasalo, T. & Viljamaa, H. 1975. Plankton composition in the Helsinki sea area. Merentutkimuslait. Julk. 239: 301-310.
1976	Central Gulf of Riga	Abundance, biomass; water samples, bathometer "Bios"	Kalveka B.J., 1980. On the seasonal cycles of phytoplankton development in the open part of the Baltic and in the Gulf of Riga in 1976. In: Proceedings of the Fisheries research in the Baltic Sea, Issue 15,eds. L.M.Vail, E.M.Kostrichkina, M.N.Lishev, E.M. Malikova, V.I.Pechatina, M.P.Poljakov, E.J.Rimsh, C.V.Smirnova, B.I.Shlimovitch, Riga, Avots, 36-45 (in Russian, abstract in English).

Appendix 2: The historical phytoplankton species composition in the Gulf of Gdansk

Data compiled in 1923-24, 1946-47, 1956, 1959, 1967-68 based on Namyslowski (1924), Rumek (1948) and Ringer (1970, 1973).

Species marked with asterisk (*) are not present in the HELCOM Baltic Sea phytoplankton species list anymore, but they exist in the older literature.

Diatoms
Achnanthes bevies
Achnanthes longipes
Achnanthes taeniata
Actinocyclus normanii
Actinocyclus octonarius
Amphiprora alata
Amphiprora paludosa
Amphora coffeaeformis
Amphora commutata
Amphora ovalis
Amphora perpusilla
Aneumastus tusculus
Asterionella formosa
Attheya decora
Aulacoseira granulata
Aulacoseira granulata v. angustissima
Aulacoseira islandica
Aulacoseira italica
Bacillaria paxillifera
Brebissonia lanceolata
Caloneis amphisbaena
Campylodiscus bicostatus
Campylodiscus clypeus
Campylodiscus echeneis
Campylodiscus hibernicus
Cavinula lacustris
Chaetoceros affinis
Chaetoceros borealis
Chaetoceros brevis
Chaetoceros curvisetus
Chaetoceros danicus
Chaetoceros densus
Chaetoceros debilis
Chaetoceros decipiens
Chaetoceros diadema
Chaetoceros eibenii
Chaetoceros gracilis
Chaetoceros holsaticus
Chaetoceros laciniosus
Chaetoceros pseudocrinitus
Chaetoceros similis
Chaetoceros socialis
Chaetoceros subtilis
Chaetoceros wighamii
Cocconeis disculus
Cocconeis neodiminuta
Cocconeis pediculus
Cocconeis placentula
Cocconeis placentula v. euglypta
Cocconeis scutellum
Coscinodiscus centralis
Coscinodiscus concinus
Coscinodiscus commutatus
Coscinodiscus granii
Coscinodidcus oculus-iridis
Coscinodidcus radiatus
Coscinodidcus subbulliens
Cosmioneis pusilla
Craticula ambigua
Craticula halophila
Ctenophora pulchella
Cyclotella comensis
Cyclotella krammeri
Cyclotella meneghiniana
Cyclotella socialis
Cylindrotheca closterium
Cymatopleura elliptica
Cymatopleura solea
Cymbella amphicephala
Cymbella lanceolata
Diatoma tenuis
Diatoma vulgaris
Diatoma vulgaris v. producta
Diploneis didyma
Diploneis elliptica
Diploneis interrupta
Diploneis interrupta

Diploneis ovalis
Diploneis puella
Diploneis smithii
Ellerbeckia arenaria
Epithemia adnata
Epithemia argus
Epithemia frickei
Epithemia sorex
Epithemia turgida
Fallacia pygmaea
Fragilaria bidens
Fragilaria capucina
Fragilaria crotonensis
Fragilaria nitzschioides
Fragilaria striatula
Fragilaria vaucheriae
Fragilariforma virescens
Gomphonema olivaceum
Grammatophora marina
Gyrosigma acuminatum
Gyrosigma eximium
Hantzschia amphioxys
Lauderia annulata
Licmophora abbreviata
Licmophora ehrenbergii
Martyana martyi
Mastogloia baltica
Mastogloia braunii
Mastogloia exigua
Mastogloia smithi v. amphicephala
Mastogloia smithii
Melosira arctica
Melosira lineata
Melosira moniliformis
Melosira nummuloides
Melosira varians
Navicula menisculus
Navicula peregrina
Navicula platystoma
Navicula protracta
Navicula reinharditii
Navicula rhynchocephala
Navicula viridula v. rostellata
Neidium affine
Neidium binodis
Nitzschia capitellata
Nitzschia dissipata
Nitzschia fasciculata
Nitzschia frigida

Nitzschia hybrida
Nitzschia palea
Nitzschia paleacea
Nitzschia sigma
Nitzschia sigmoidea
Nitzschia umbonata
Opephora mutabilis
Paralia sulcata
Petrodiction gemme
Petroneis humerosa
Pinnularia major
Placoneis plancentula
Pleurosigma elongatum
Pleurosigma salinarum
Rhizosolenia setigera
Rhoicosphaenia abbreviata
Rhopalodia gibba
Skeletonema costatum
Stauroneis anceps
Stauroneis phoenicenteron
Stauroneis spicula
Staurosira construens
Surirella biseriata
Surirella elegans
Surirella linearis
Surirella minuta
Surirella ovalis
Surirella striatula
Synedra acus
Synedra amphicephala
Synedra berolinensis
Synedra ulna
Tabellaria fenestrata
Tabellaria flocculosa
Tabularia fasciculata
Tabularia tabulata
Thalassionema nitzschioides
Thalassiosira baltica
Thalassiosira eccentrica
Thalassiosira lacustris
Thalassiosira leptopus
Thalassiosira nordenskioeldi
Tryblionella circumsuta
Tryblionella gracilis
Tryblionella hungarica
Tryblionella litoralis
Tryblionella punctata
*Amphiprora lineolata**

*Berkeleya fennica**
*Biddulphia święcickiana**
*Caloneis fasciata**
*Caloneis latiuscula v. subholstei**
*Caloneis zachariasi**
*Campylodiscus parvulus**
*Cocconeis dirupta**
*Coscinodiscus curvatulus**
*Diploneis marginestriata**
*Epithemia reichelti**
*Epithemia sorex v. gracilis**
*Fragilaria islandica**
*Mastogloia lanceolata**
*Melosira humerosa**
*Navicula liber**
*Navicula viridis**
Pleurosigma affine
Synedra gailionii
Thalassiosira subtilis
Blue-green algae
Aphanocapsa incerta
Aphanothaece castagnei
Aphanothaece microscopica
Chroococcus limneticus
Chroococcus minutus
Chroococcus turgidus
Coelosphaerium dubium
Coelosphaerium naegelianum
Gloeocapsopsis crepidinum
Gomphosphaeria aponina
Snowella lacustris
Merismopedia affixa
Merismopedia glauca
Merismopedia punctata
Merismopedia tenuissima
Microcystis aeruginosa
Microcystis flos-aquae
Microcystis ichthyoblabe
Microcystis pseudofilamentosa
Microcystis viridis
Pleurocapsa fulginosa
Anabaena affinis
Anabaena baltica
Anabaena crassa
Anabaena cylindrica
Anabaena flos-aquae

Anabaena oscilarioides
Anabaena spiroides
Anabaena torulosa
Aphanizomenon flos-aquae
Jaaginema subtilissima
Lyngbia planctolyngbia
Nodularia harveyana
Nodularia litorea
Nodularia spumigena
Oscilatoria limosa
Oscillatoria margaritifera
Phormidium splendidum
Spirulina baltica
Trichodesmium lacustre
*Aphanocapsa pulchella**
*Aphanocapsa (Microcystis) stagnalis**
*Aphanothaece tuberculosa**
*Calothrix scopulorum**
*Lyngbia semiplena**
*Nostoc pruniforme**
*Oscillatoria nigro-viridis**
*Pelagothrix clevei**
*Phormidium foveolarum**
*Rivularia atra**
*Spirulina pimator**
Dinoflagellates
Alexandrium ostenfeldii
Amphidiniopsis kofoidii
Amphidinium operculatum
Amphidinium semilunatum
Amylax triacantha
Ceratium tripos
Dinophysis acuminata
Dinophysis norvegica
Dinophysis rotundata
Diplopsalis lenticula
Dissodinium pseudolunnula
Gonyaulax helensis
Gonyaulax spinifera
Gymnodinium rhomboides
Hemidinium nasutum
Heterocapsa rotundata
Katodinium asymetricum
Kolkwitziella acuta
Oblea rotunda
Peridiniella catenata
Peridiniopsis balticum

Peridinium grenlandicum	*Pediastrum boryanum v. longicorne*
Peridinium inconspicuum	*Pediastrum boryanum v. undulatum*
Preperidinium meunieri	*Pediastrum duplex*
Prorocentrum balticum	*Pediastrum duplex v. asperum*
Prorocentrum cassubicum	*Pediastrum duplex v. pulchrum*
Protoceratium reticulatum	*Pediastrum duplex v. rugulosum*
Protoperidinium achromaticum	*Pediastrum integrum*
Protoperidinium bipes	*Pediastrum kawrayski*
Protoperidinium brevipes	*Pediastrum simplex*
Protoperidinium curvipes	*Pediastrum tetras*
Protoperidinium deficiens	*Raphidionema cryophilum*
Protoperidinium granii	*Scenedesmus acuminatus*
Protoperidinium pellucidum	*Scenedesmus obliguus*
Protoperidinium steinii	*Schizochlamys gelatinosa*
*Diplopsalis minor v. sphaerica**	*Schroederia setigera*
*Peridinium aciculiferum**	*Sorastrum americanum*
*Peridinium pellucidum v.spinulosa**	*Sphaerocystis schroeteri*
*Peridinium sub-curvipes**	*Tetraedron incus*
	Tetraedron minimum
Green algae	*Tetraselmis cordiformis*
Ankistrodesmus falcatus	*Trochiscia brachiolata*
Botryococcus braunii	*Trochiscia clevei*
Chlamydocapsa planctonica	*Trochiscia multispinosa*
Chlorangiella pygmae	*Actinastrum rhaphidioides**
Closterium kuetzingii	*Ankistrodesmus nitzschioides**
Coelastrum microporum	*Botryococcus proturberans**
Coelastrum reticulatum	*Chlorosarcina minor**
Desmodesmus communis	*Eudorina charcowiensis**
Desmodesmus dispar	*Gloeocystis riparia**
Desmodesmus maximus	*Pediastrum duplex v. subgranulatum**
Desmodesmus spinosus	*Pediastrum integrum v. perforatum**
Dictyosphaerium ehrenbergianum	*Scenedesmus bernardi**
Dictyosphaerium pulchellum	*Scenedesmus bijugatus**
Eudorina elegans	*Sorastrum spinulosum**
Gonium pectorale	*Staurastrum crenulatum**
Gonium sociale	*Trochiscia sierpinkiana**
Oocystis borgei	
Oocystis lacustris	**Others**
Oocystis pelagica	*Ebria tripartita*
Oocystis solitaria	*Dinobrion balticum*
Oocystis submarina	*Dinobryon sertularia*
Pachysphaera pelagica	*Coccosphaera atlantica*
Pandorina morum	*Discosphaera tubifer*
Pediastrum angulosum	*Hexasterias problematica*
Pediastrum angulosum v.asperum	*Askenasyella chlamydopus**
Pediastrum boryanum	*Prymesium parvulum**
Pediastrum boryanum v. brevicorne	
Pediastrum boryanum v. divergens	

Appendix 3: Description of historical phytoplankton records from the Gulf of Riga, Baltic Sea

Reviewed by Nikolajev (1953; 1957)
Translated & summarized by I.Purina

First qualitative and quantitative investigations of the phytoplankton in the Gulf of Riga were carried out during Russian-Baltic expedition in ***1908-1909*** (Krabbi, 1913a,b, as reviewed by Nikolajev, 1953). In July 1908 expedition reached Gulf of Riga, where they spend only two days. Researchers took only 5 phytoplankton samples from the different sites- at the entrance of the gulf, in the northern part, 2 samples at the mouth of river Daugava and at the Ruhnu Island. In the phytoplankton samples dominated *Aphanizomenon flos-aquae, Anabaena sp., Nodularia spumigena, Merismopedia elegans, Pediastrum sp., Dinobryon sp., Chaetocerus sp., Actinocyclus ehrenbergii, Melosira sp., Fragillaria sp., Asterionella gracillima, Sceletonema costatum, Thalassiosira baltica*. From these species *Asterionella gracillima, Sceletonema costatum, Thalassiosira baltica*, *Pediastrum sp.* and *Melosira sp.* were found only at the mouth of river Daugava.

Quantitative analysis shows dominance of *Aphanizomenon flos-aquae* ($4*10^6$ cells per m^3), followed by *Nodularia spumigena* ($158*10^3$ cells per m^3) and *Anabaena* sp. ($90*10^3$ cells per m^3). Phytoplankton biomass was distributed evenly over the entire gulf, except at the mouth of river Daugava.

In the next year, samples were taken on 13 of August only in the Irbe strait. Dominant species was *Aphanizomenon flos-aquae, Nodularia spumigena, Coelosphaerium naegelianum, Peridinium pellucidum, Dinophysis acuminata, Thalassiosira baltica, Actinocyclus ehrenbergii, Chaetocerus holsaticus.*

In May **1928** Berzinsh collected phytoplankton samples from 14 stations in the coastal zone of the Gulf of Riga (Berzinsh, 1932, as reviewed by Nikolajev, 1953). He found 33 species, characteristic for phytoplankton spring bloom: *Aphanizomenon flos-aquae, Melosira helvetica, M.moniliformis, M.italica, Sceletonema costatum, Thalassiosira baltica, Coscinodiscus sp., Chaetocerus danicus, Ch.crinitus, Fragillaria crotonensis, F.capucina, Asterionella gracillima, Synedra spp., Achnanthes taeniata, Navicula vanhoffenii, Nitzschia frigida, N.spp., Dinobryon divergens, D.pellucidum,* *Gonyaulax catenata, Peridinium achromaticum, P.pellucidum, Merismopedia glauca, Oocystis spp., Pediastrum boryanum, P.duplex, Dinophysis ovum, D.rotundatum, D.norvegica.* Dominant species were *Sceletonema costatum, Chaetocerus wighamii, Achnanthes taeniata, Thalassiosira baltica,Gonyaulax catenata.*

Nikolajev (1953; 1957) carried out analyses of the composition, abundance and biomass of phytoplankton. Samples were collected in May 1946, in July-October 1946, in November 1946, in March 1947, in May-June 1947 and in August 1947, in the open part of the Gulf of Riga at 144 stations, in the near shore area at Lielupe (18 stations), Bulduri (12 stations) and Ainazi (3 stations), as well as in the mouth of rivers Lielupe, Daugava, Salaca, Parnu (12 stations). Samples were taken with phytoplankton net for qualitative analysis (in 1946) and with Nansen bottles from different layers (0m, 10m, 20m, 30m, 40m, 50m, in 1947) for quantitative analysis. Based on these studies, Nikolajev described the general seasonal cycle of phytoplankton development in the Gulf,

Winter (December-March) is characterized by low phytoplankton biomass. Despite the high nutrient concentrations, the growth of phytoplankton is inhibited due to light limitation (ice cover). Winter phytoplankton species belong to 2 groups, late autumn species- *Aphanizomenon flos-aquae, Chaetocerus danicus, Thalassiosira baltica, Coscinodiscus granii, Chaetocerus wighamii*, and early spring species *Melosira arctica, Gonyaulax catenata, Nitzschia frigida, Achnanthes taeniata*.

Spring (April-June) begins with the break of ice cover, mixing of water and substantial enrichment with nutrients. **Table 1** shows the spring phytoplankton species composition during 3 different years as described by Nikolajev (1953; 1957). There were no great differences from year to year indicating stability in the composition of the spring phytoplankton community in the Gulf of Riga. Many of these species belong to arctic species complex. They are widely distributed in the arctic seas. Others are eurithermal species, distributed in temperate waters, however, they are developing in cold water. Length of vegetation can vary significantly for different species. Arctic species disappears from the phytoplankton community already at the beginning of June, but eurithermal species remains in the water column (mainly at the estuaries) till the middle of summer and some of them, like *Thalassiosira baltica* and *Chaetocerus wighamii*, give the second, autumn, bloom.

Table 1. *Phytoplankton species composition in spring 1928, 146, and 1947, according to Nikolajev (1953; 1957). *- arctic species.*

Species	1.-25. May 1928 coastal stations Ainzi– Daugava-Kolka	24 June 1946 4 coastal stations at Kolka	20 May 1947 3 coastal stations at Ainazi
*Achnanthes taeniata**	+	+	+
Sceletonema costatum	+	+	+
*Gonyaulax catenata**	+	+	+
Thalassiosira baltica	+	+	+
*Melosira arctica**	+	+	+
*Nitzschia frigida**	+	+	+
Nitzschia longissima	+	+	+
Chaetocerus wighamii	+	+	+
Chaetocerus radicans	-	+	+
*Navicula vanhoffenii**	+	-	+
*Navicula granii**	-	+	+
Fragilaria oceanica	-	+	+
*Fragilaria islandica**	-	-	+
Diatoma elongatum	+	+	+
*Dinobryon pellucidum**	+	+	+
Thalassiosira nana	-	+	+
Peridinium granii	-	-	+

Summer (end of June- September) could be characterized by expressed thermal stratification and low nutrient concentrations. At the beginning of June arctic species vanished from the phytoplankton community, while other cold-water species prevailed until the end of June (**Table 2**). In July, cold water species disappeared and typical summer species appeared. August was the most typical summer month (**Table 3**) characterised by:

1) Dominance of *Aphanizomenon flos-aquae*;
2) Diversity of cyanobacteria, dinoflagellates and chlorophytes;
3) Few diatom species;
4) Total vanishing of spring species;

Table 2. *Phytoplankton species composition in June 1946 and 1947 according to Nikolajev (1953; 1957).*

Species	
Chaetocerus wighamii	Dominant
Diatoma elongatum	
Sceletonema costatum	
Thalassiosira nana	
Thalassiosira baltica	
Gomphosphaeria lacustris	Abundant
Coscinodiscus sp.	
Peridinium finlandicum	
Melosira italica	
Chaetocerus danicus	
Aphanizomenon flos-aquae	
Nodularia spumigena	Rare
Anabaena baltica	
Anabaena lemmermanii	
Dinophysis baltica	
Peridinium pellucidum	
Diplopsalis minor	
Oocystis submarina	
Actinocyclus ehrenbergii	
Merismopedia tenuissima	
Scenedesmus quadricauda	
Phalacroma rotundatum	
Minusculum minor	

Table 3. *Phytoplankton species composition in August 1946 and 1947 according to Nikolajev (1953; 1957).*

Species	
Aphanizomenon flos-aquae	Dominant
Anabaena baltica	Abundant
Anabaena flos-aquae	
Nodularia spumigena	
Oocystis submarina	
Actinocyclus ehrenbergii	
Gomphosphaeria lacustris	
Merismopedia tenuissima	
Dinophysis baltica	
Peridinium pellucidum	
Diplopsalis minor	
Chaetocerus wighamii	
Phalacroma rotundatum	Rare
Melosira granulata	
Gomphosphaeria aponina	
Pediastrum boryanum	
Oocystis pelagica	
Coscinodiscus sp.	
Coscinodiscus granii	
Chaetocerus danicus	
Chaetocerus wighamii	

In the coastal zone freshwater species were present, like *Microcystis minutissima, Scenedesmus quadricauda, Asterionella formosa, Pediastrum boryanum, Dictiosphaerium pulchellum, Dictiosphaerium ehrenbergianum, Melosira granulata, Melosira italica*. In September no significant changes in species composition were observed. At the end of September vanished thermofilic species, like *Actinocyclus ehrenbergii, Gomphosphaeria aponina, Diplopsalis minor, Merismopedia minutissima, Peridinium pellucidum, Prorocentrum micans,* but *Coscinodiscus granii, Chaetocerus danicus, Thalassiosira baltica* increased in number and biomass

Autumn (October- November, **Table 4**) thermal stratification broke and complete mixing of water column began. Decrease of water temperature till 10-12ºC caused disappearance of thermophilic cyanobacteria *species Merismopedia tenuissima, Microcystis* spp., *Anabaena baltica, Gomphosphaeria* sp. and chlorohytes. *Aphanizomenon flos-aquae* still remained, but gradually decreased to grow.

Table 4. *Phytoplankton species composition in October 1946 according to Nikolajev (1953; 1957).*

Species	
Aphanizomenon flos-aquae	Abundant
Chaetocerus danicus	
Chaetocerus wighamii	
Thalassiosira baltica	
Dinophysis baltica	
Diatoma elongatum	
Nodularia spumigena	
Coscinodiscus granii	
Anabaena lemmermanii	Rare
Gomphosphaeria lacustris	
Microcystis spp.	
Melosira islandica	
Peridinium finlandicum	
Coscinodiscus sp.	
Pediastrum boryanum	

At the end of November number of species in the phytoplankton community was low. Only *Chaetocerus danicus, Chaetocerus wighamii, Aphanizomenon flos-aquae, Thalassiosira baltica, Coscinodiscus granii* and *Gomphosphaeria lacustris* could be observed in the water.

According to Nikolajev (1953; 1957) the Gulf of Riga could be divided horizontally in three subregions: 1) Central part; 2) Outer part - from western coast till Ruhnu Island, including northern part and Irbe strait- influenced by more saline Baltic Sea water; 3) Coastal zone- southern and eastern coast of the Gulf, with entrances of all major rivers. Features of the central part were discussed in previous chapters. In this chapter will be mentioned only distinctive features for other regions.

In the **outer part** of the gulf can be find species characteristic for more saline Baltic Sea water, like *Distephanus speculum, Dinophysis norvegica, Dinobryon pellucidum, Protoceratium reticulatum, Ceratium longipes*. These species do not proliferate in the Gulf, but are transported by currents. From other hand, in this region can not be find such freshwater species as *Asterionella formosa, Melosira granulata, Melosira italica, Ceratium hirundinella, Pandorina morum, Eudorina elegans, Dinobrion divergens*.. **Coastal zone (Table 5)** can be characterised by higher species diversity, due to incoming freshwater species, and the highest productivity.

Table 5. *Typical phytoplankton species composition of the coastal zone according to Nikolajev (1953; 1957).*

Species	
Aphanizomenon flos-aquae	Freshwater species
Melosira granulata	
Melosira italica	
Melosira islandica	
Merismopedia tenuissima	
Merismopedia glauca	
Gomphosphaeria lacustris	
Dictiosphaaerium ehrenbergianum	
Cyclotella meneghiniana	
Nodularia spumigena	***Marine species***
Chaetocerus danicus	
Chaetocerus wighamii	
Thalassiosira baltica	
Coscinodiscus sp.	

Estimations of the **average phytoplankton biomasses** during the cruises in 1947 in the vertical samples taken by Nikolajev (1953; 1957) are presented in **Tables 6-10**.

Table 6. Average phytoplankton biomass in the beginning of March 1947 (mg/m^3).

Species	0m	5m	10m	20m
Achnanthes taeniata	0.08	0.12	+	-
Gonyaulax catenata	0.1	0.13	+	-
Sceletonema costatum	0.06	0.02	+	-
Melosira arctica	0.03	0.06	+	-
Nitzschia frigida	0.04	0.1	+	-
Nitzschia longissima	+	+	-	-
Thalassiosira baltica	0.12	0.16	+	+
Diatoma elongatum	0.04	0.05	+	+
Navicula vanhoffenii	0.01	0.04	+	-
Aphanizomenon flos-aquae	+	+	-	-
Varia	0.08	0.13		
Total	0.56	0.81		

Table 7. Average phytoplankton biomass in May 1947 (mg/m^3).

Species	0m	10m
Achnanthes taeniata	860	920
Gonyaulax catenata	880	740
Sceletonema costatum	310	120
Nitzschia frigida	98	80
Thalassiosira baltica	720	1050
Diatoma elongatum	225	300
Navicula vanhoffenii	18	35
Chaetocerus wighamii	64	15
Varia	630	656
Total	3805	3916

Table 8. Average phytoplankton biomass in June 1947 (mg/m^3).

Species	0m	10m	20m	30m	40m
Aphanizomenon flos-aquae	26	5	-	-	-
Gomphosphaeria lacustris	10	2	+	-	-
Sceletonema costatum	18	26	30	27	+
Thalassiosira nana	8	15	5	+	-
Diatoma elongatum	40	130	170	102	60
Chaetocerus wighamii	105	216	104	15	+
Varia	49	94	74	34	12
Total	256	488	383	178	72

Table 9. Average phytoplankton biomass in August 1947 (mg/m^3).

Species	0m	10m	20m	30m	40m
Aphanizomenon flos-aquae	395	140	61	16	+
Nodularia spumigena	46	30	12	2	-
Gomphosphaeria lacustris	38	23	18	8	+
Anabaena (lemmermanii+baltica)	38	12	9	+	-
Merismopedia (minutissima +glauca)	24	23	12	2	-
Chaetocerus wighamii	42	60	54	14	4
Chaetocerus danicus	41	58	48	27	2
Actinocyclus ehrenbergii	39	42	41	12	+
Coscinodiscus granii	37	70	35	23	8
Coscinodiscus sp.	20	25	20	17	4
Ebrya tripartita	28	42	17	6	+
Dinophysis baltica	16	24	20	14	8
Peridinium pellucidum	14	19	12	6	7
Diplosalis pillula	12	8	2	-	-
Varia	187	138	86	35	8
Total	977	714	447	182	41

Table 10. Average phytoplankton biomass in October and November 1947 (mg/m^3).

Species	1-15 October	13-16 November
Aphanizomenon flos-aquae	180	21
Gomphosphaeria lacustris	13	2
Coscinodiscus granii	131	8
Thalassiosira baltica	8	4
Nodularia spumigena	24	4
Chaetocerus wighamii	64	10
Chaetocerus danicus	120	15
Varia	159	17
Total	699	81

Appendix 4: Phytoplankton species composition and total biomass in the Gulf of Riga in 1968-1971

According to Rudzroga (1974).
Samples collected in the coastal zone of at mouth of river Lielupe and Daugava, at Bolderaja and Vecaki, at 0, 5, 10, 20, 30m depth horizons.

	February	May	June	July-August	September	October-November
Dominant		*Achnanthes taeniata*	*Sceletonema costatum*	*Aphanizomenon flos-aquae*	*Chaetocerus wighamii*	
		Sceletonema costatum		*Nodularia spumigena*	*Thalassiosira baltica*	
				Anabaena baltica	*Diatoma elongatum*	
Abundant		*Nitzschia frigida*	*Achnanthes taeniata*		*Aphanizomenon flos-aquae*	*Chaetocerus wighamii*
		Gonyaulax catenata	*Nitzschia frigida*			*Thalassiosira baltica*
			Gonyaulax catenata			*Diatoma elongatum*
Rare	*Melosira arctica*	*Melosira arctica*	*Aphanizomenon flos-aquae*	*Phalacroma rotundatum*		*Aphanizomenon flos-aquae*
	Sceletonema costatum	*Thalassiosira baltica*	*Nodularia spumigena*	*Gomphosphaeria lacustris*		
	Gonyaulax catenata		*Caetocerus danicus*			
	Pediastrum boryanum		*Chaetocerus wighamii*			
			Dinophysis baltica			
			Phalacroma rotundatum			
Total biomass (mg/m^3)	0.03-0.06	700-2360	360-1260	12-124	17- 69	11-20

Appendix 5: Phytoplankton species composition and total biomass in the Gulf of Riga in 1976

According to Kalveka (1980)
Samples were collected in stations 119 and 121 from April till December 1976, from 0, 10, and 20 m depth horizons with bathometer "Bios".

Species composition								
Month	**April**	**May**	**June**	**July**	**August**	**September**	**November**	**December**
Dominant	*Achnanthes taeniata (88%)*	*Achnanthes taeniata (95%)*	*Achnanthes taeniata (60%)*	*Chaetocerus wighamii (64%)*	*Gomphosphaeria lacustris*	*Dinoflagellates (species???)*	*Chaetocerus wighamii*	
			Gonyaulax catenata				*Chaetocerus danicus*	
							Thalassiosira baltica	
Abundant	*Chaetocerus wighamii*	*Chaetocerus wighamii*		*Cyanobacteria*	*Dinopysis baltica*		*Coscinodiscus granii*	
	Thalassiosira baltica	*Thalassiosira baltica*		*Chlorophyta*				
Rare					*Aphanizomenon flos-aquae*	*Aphanizomenon flos-aquae*		*Chaetocerus wighamii*
								Chaetocerus danicus
								Thalassiosira baltica
								Coscinodiscus granii
Total biomass (mg/m^3)								
Month	**April**	**May**	**June**	**July**	**August**	**September**	**November**	**December**
Station 119	2321	5640	375	93	103	16	143	42
Station 121	2695	1625	430	92	122	16	91	53

Appendix 6: List of phytoplankton species found in the Gulf of Riga during 1908-1971

According to Nikolajev (1953) and Rudzroga (1974)
Occurrence of species: 1-very rare, 2- rare, 3- frequent, 4- common, high biomass, 5- very common, blooms.

Original species name	Season	Occurr ence	Reference
Cyanophyta			
Dactylococcopsis acicularis	2	1	Rudzroga, 1974
Dactylococcopsis fascicularis	2	2	Rudzroga, 1974
Microcystis aeruginosa	2	3	
Microcystis ichtioblabe	2	1	Rudzroga, 1974
Microcystis pulverea	2	3	Rudzroga, 1974
Aphanothece stagina	2	2	Rudzroga, 1974
Aphanothece clathrata	2	3	
Gleocapsa turgida	2	3	
Gleocapsa limnetica	2	2	
Merismopedia tenuissima	2	4	
Merismopedia elegans	2	3	
Merismopedia glauca	2	3	
Merismopedia glauca f. mediterranea	2	1	Nikolajev, 1953
Coelosphaerium minutissimum	2	3	Nikolajev, 1953
Gomphosphaeria lacustris	2-3	4	
Gomphosphaeria aponina	2-3	3	
Gomphosphaeria litoralis	2	2	Nikolajev, 1953
Woronichinia naegeliana	2	3	
Anabaena baltica	2	2	Nikolajev, 1953
Anabaena flos-aquae	1-3	4	
Anabaena lemmermannii	2	3	
Anabaena spiroides	2	3	
Aphanizomenon flos-aquae	2-3	5	
Nodularia spumigena	2-3	4	
Nodularia spumigena v. litorea	2	3	
Nodularia spumigena v. major	2	3	
Oscillatoria margaritifera	2	1	Rudzroga, 1974
Oscillatoria tenuis	2	3	Rudzroga, 1974
Spirulina tenuissima	2	1	Rudzroga, 1974
Lyngbya limnetica	2	3	Rudzroga, 1974
Lyngbya aestuarii	2	1	Rudzroga, 1974
Bacillariophyta (now Heterocontophyta, Bacillariophyceae)			
Melosira moniliformis	1	4	

Melosira jurgensii	2	3	Rudzroga, 1974
Melosira varians	1	3	
Melosira granulata	2	3	
Melosira granulata var. angustissima	2	2	Rudzroga, 1974
Melosira islandica	2	2	
Melosira islandica subsp. helvetica	2	2	
Melosira italica	1-2	3	
Melosira italica var. tenuissima	1-2	2	Rudzroga, 1974
Melosira arenaria	2	1	
Melosira distans	2	3	Nikolajev, 1953
Melosira arctica	1	3	
Sceletonema costatum	1	5	
Cyclotella meneghiana	2	3	
Cyclotella meneghiana var. laevissima	2	1	Nikolajev, 1953
Cyclotella comta	2	3	
Stephanodiscus astraea	2	1	Rudzroga, 1974
Stephanodiscus astraea var. minutula	2	1	Rudzroga, 1974
Stephanodiscus hantzschi	2	3	Rudzroga, 1974
Thalassiosira baltica	1-4	4	
Thalassiosira levanderi	1-3	2	Nikolajev, 1953
Thalassiosira nana	1-3	2	
Coscinodiscus granii	3	4	
Coscinodiscus jonesianus	2	1	
Coscinodiscus lacustris	2	2	
Coscinodiscus oculus-iridis	2	1	
Actinocyclus ehrenbergii	2	4	
Actinocyclus ehrenbergii var. crassa	2	2	
Actinocyclus ehrenbergii var. ralfsii	2	2	
Leptocylindrus danicus	2	1	
Leptocylindrus minimus	2	1	
Rhizosolenia minima	2	1	Nikolajev, 1953
Chaetocerus crinitus	1	3	
Chaetocerus holsaticus	1	3	
Chaetocerus danicus	1-3	4	
Chaetocerus radians	1	1	
Chaetocerus gracilis	1	3	
Chaetocerus wighamii	2-3	4	
Diatoma elongatum	1-2	4	
Diatoma elongatum var. tenue	1-2	3	
Fragillaria capucina	2	2	
Fragillaria crotonensis	2	3	
Fragillaria oceanica	2	2	
Fragillaria islandica	2	3	
Fragillaria cylindricus	2	1	Nikolajev, 1953
Asterionella formosa	2	3	

Tabellaria fenestrata	2	3	
Achnanthes taeniata	1	5	
Navicula granii	1	2	Nikolajev, 1953
Navicula vanhofenii	1	2	Nikolajev, 1953
Nitzschia closterium	2	3	
Nitzschia longissima	2	3	
Nitzschia frigida	1	3	
Nitzschia acicularis	2	3	Rudzroga, 1974
Nitzschia filiformis	2	2	Rudzroga, 1974
Pyrrophyta (now Dinophyta)			
Exuviella baltica	2	3	
Prorocentrum micans	2	2	
Phalacroma rotundatum	3	3	
Dinophysis norvegica	3	2	
Dinophysis baltica	3	4	
Dinophysis acuminata	3	4	
Dinophysis arctica	3	2	
Goniodoma ostenfeldii	2	1	Nikolajev, 1953
Diplopsalis lenticula	2	2	
Diplopsalis pilula	2	2	
Gymnodinium aeruginosum	2	2	Rudzroga, 1974
Gymnodinium fissum	2	3	Rudzroga, 1974
Heterocapsa triqetra	2	3	Nikolajev, 1953
Protoceratium reticulatum	2	2	Nikolajev, 1953
Amphidiniopsis kofoidi	2	2	
Peridinium achromaticum	2	3	
Peridinium breve	1	3	
Peridinium granii	1	2	
Peridinium minusculum	2	2	
Peridinium pellucidum	2	4	
Peridinium subinerme	2	2	
Ceratium hirundinella	2	2	
Gonyaulax catenata	1	5	
Gonyaulax triacantha	2	3	
Ebria tripartita	1-3	4	
Chlorophyta			
Chlamidomonas angulosa	2	2	Rudzroga, 1974
Gonium pectorale	2	2	
Pandorina morum	2	3	
Eudorina elegans	2	2	
Botryococcus braunii	2	2	
Chlorangium stentorium	2	1	Nikolajev, 1953
Colacium vesiculosus	2	1	Nikolajev, 1953

Dictiosphaerium pulchellum	2	3	
Pediastrum simplex	2	3	Rudzroga, 1974
Pediastrum tetras	2	2	Rudzroga, 1974
Pediastrum duplex	2	2	
Pediastrum boryanum	1-3	3	
Oocystis submarina	2	3	
Oocystis solitaria	2	3	Rudzroga, 1974
Oocystis lacustris	2	2	Rudzroga, 1974
Ankistrodesmus acicularis	2	2	Rudzroga, 1974
Ankistrodesmus arcuatus	2	1	Rudzroga, 1974
Dictyosphaerium ehrenbergianum	2	2	
Dictyosphaerium braunii	2	3	Rudzroga, 1974
Coelastrum microporum	2	2	Rudzroga, 1974
Coelastrum sphaericum	2	2	Rudzroga, 1974
Crucigenia fenestrata	2	2	Rudzroga, 1974
Crucigenia tetrapedia	2	2	Rudzroga, 1974
Actinastrum hatzschii	2	3	Rudzroga, 1974
Scenedesmus obliquus	2	1	
Scenedesmus acuminatus	2	2	Rudzroga, 1974
Scenedesmus acuminatus var. biseriatus	2	1	Rudzroga, 1974
Scenedesmus bijugatus	2	3	Rudzroga, 1974
Scenedesmus bijugatus var. alternans	2	2	Rudzroga, 1974
Scenedesmus quadricauda	2	4	
Chrysophyta (now Heterocontophyta, Chrysophyceae)			
Uroglena volvox	2	1	Nikolajev, 1953
Synura uvella	1	2	
Malomonas producta	2	1	Nikolajev, 1953
Dinobryon divergens	2	2	
Dinobryon pellucidum	2	2	Nikolajev, 1953
Distephanus speculum	2	1	

Appendix 7: Basic statistics of the nutrients and chlorophyll a concentrations in the Finland's coastal waters 1966-76

Concentrations nutrients (mg m^{-3}) and chlorophyll *a* (mg m^{-3}) in the outer archipelago and open parts of Finland's coastal waters in the summer and winter 1966-76. N is number of stations; number of samples in parenthesis. Q1 and Q3 are the lower and upper quartiles. SD is the standard deviation.

		February to March		July to September					
Sea area		TN	TP	TN	TP	DIN	PO_4-P	Chl	Sec
Gulf of Finland	N	5 (43)	5 (42)	5 (52)	5 (52)	5 (52)	5 (52)	5 (10)	
	Median	300	26	260	12	11	1	2.4	
	Mean	331	24	277	12	17.6	1.1	2.5	
	Min	160	5.0	30	1.0	3	0	1.6	
	Max	760	36	650	28	63	6	3.4	
	Q1	255	20	210	9.0	7	0	2.0	
	Q3	350	31	320	15	25	2	3.0	
	SD	127	7.9	115	5.4	14.6	1.3	0.6	
Archipelago Sea	N	2 (12)	2(13)	3 (4)	3 (7)		.	3 (4)	3 (9)
	Median	230	17	295	15			2.3	4.7
	Mean	239	17.5	298	15			2.3	5
	Min	180	10	250	11			1.8	3.8
	Max	310	27	350	24			2.8	6.5
	Q1	205	15	257	12			1.8	4.5
	Q3	282	21	335	17			2.8	6
	SD	44.4	4.8	49.9	4.7			0.6	0.9
Bothnian Sea	N	7 (22)	7 (21)	3 (10)	3 (23)	.	.	1 (2)	3 (9)
	Median	265	16	285	20	.	.	1.4	4.7
	Mean	327	16	341	19	.	.	1.4	4.9
	Min	130	1	200	0	.	.	1.2	3.7
	Max	900	30	620	50	.	.	1.6	6.8
	Q1	200	13	248	10	.	.	1.3	3.7
	Q3	387	20	412	20	.	.	1.5	6.5
	SD	202	7.1	135	12.6	.	.	0.3	1.3
Bothnian Bay	N	4 (12)	4 (8)	3 (12)	3 (12)	.	.	.	3 (9)
	Median	310	13	315	16	.	.	.	2.2
	Mean	358	12	330	17.3	.	.	.	2.7
	Min	200	3	190	8	.	.	.	0.3
	Max	750	24	700	38	.	.	.	6.0
	Q1	245	6	272	11	.	.	.	2.1
	Q3	430	14	335	21	.	.	.	3.4
	SD	229	7	127	8.6	.	.	.	1.6

Mission of the JRC

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private of national.

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