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Nutrient, chlorophyll, and water clarity relationships in Baltic Sea nearshore coastal waters with comparisons to freshwater lakes Barlinek Gorzów Landscape Park (North-West Poland)

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ABSTRACT

Models relating chlorophyll to nutrients and Secchi depth to chlorophyll using data from nearshore coastal waters of Baltic Sea were successfully developed. The models suggest that phosphorus is the primary limiting factor for phytoplankton in the nearshore coastal waters of Baltic Sea and that total phosphorus concentration accounts for 65% of the variance in chlorophyll concentration. The models also show that chlorophyll is the dominant factor determining Secchi depth in nearshore coastal waters of Baltic Sea and that chlorophyll concentrations account for 38% of the variance in Secchi depth. On the basis of the analysis of research in the Western and Northern Polish Lakes summer macrozoobenthos it can be concluded that in the lakes Barlinek-Gorzów Landscape

Park (Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake) very intensively develop Oligochaeta. While the larvae of Chironomidae subdominants status in the period under review amounting to water, developed in other lakes much more intensely, acting mostly the main ingredient of benthic fauna. The results obtained have revealed that the ecological condition of the water in the lakes Barlinek-Gorzów Landscape Park (Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake) is very bad.

***Keywords*:** Nutrient, chlorophyll, Baltic Sea, total phosphorus, total nitrogen, freshwater lakes, Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake

1. INTRODUCTION

Urbanization is the cause of many changes which are taking place in the environment, including those found in the catchment. With this in mind, it is an important issue to properly protect water reservoirs and also take action to counter the adverse effects of human activities on the natural environment, including water bodies [5-8,10-15,33-35].

Water has always been the foundation of human existence. Once man's survival depended on access to water, however, along with the development of civilization, human reliance on water changed. Humans started treating water as a common good, assuming its resources to be limitless. This line of thought has resulted in degradation of waters constituting a reserve of drinking water for future generations [5-9,13,15].

Strong relationships between phosphorus, chlorophyll, and water clarity have been observed and reported for freshwater systems around the world [1-4,32].

Research conducted in various research centers show that phosphorus as the primary nutrient limiting primary production in many, if not most, freshwater systems [1-4,32].

The generality of the relational data coupled with the experimental findings has lead to the development of empirical loading models to predict in-lake phosphorus concentrations as a function of annual phosphorus load, adjusting for differences in lake morphometry and hydraulic residence time [33,35].

With regard to lakes, phosphorus concentrations are typically calculated with phosphorus loading models, and the calculated phosphorus concentrations are, in turn, used in regression models to estimate chlorophyll concentrations. As chlorophyll concentrations are, in many cases, strongly related to water clarity as measured by Secchi depth, the chain of relations allows for a determination of how much nutrient needs to be controlled to achieve a specified reduction in chlorophyll and concomitant increase in water clarity [5,7,10-15,33,34].

2. MATERIAL

The Baltic Sea is a relatively shallow inland sea in north-east Europe, bounded by the coastlines of Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russian Federation and Sweden. The catchment area is 1 650 000 km^2, more than four times the area of the sea itself. Almost 80 million people live within the catchment area [14,15].

The shallow sounds between Sweden and Denmark provide a limited water exchange with the North Sea. There is a clear salinity gradient from the almost oceanic conditions in the northern Kattegat to the almost freshwater conditions in the northern Gulf of Bothnia. Most of the water input comes from rivers, with marked seasonal and also long-term variability. The freshwater generates an outflowing low-salinity surface current towards the Skagerrak and North Sea, and an inflowing bottom current of higher salinity from the Skagerrak to the Baltic Sea. Persistent westerly winds can generate large short-term inflows of higher salinity. The interval between such episodes may be several years, but they can have significant ecological effects. The distribution of plant and animal species is profoundly influenced by variations in the salinity and stratification of the water [14,15].

The tidal amplitude is small (8-18 cm) and it takes 25-35 years for all the water in the Baltic to be replenished by water from the North Sea and beyond (Baltic Sea Environment web site).

The Baltic Sea has marked stratification between low-salinity surface water and the more saline water at a depth of about 40-70 m. This salinity barrier prevents the exchange of oxygen and nutrients between the two layers, and large parts of the seabed are lifeless because of oxygen depletion. The size of seabed with impaired conditions varies from year to year and may reach 100 000 km^2 (Baltic Sea Environment web site) [14-15].

Annual mean temperature increases gradually from north and east to south and west. The northern part of the Gulf of Bothnia (Bothnian Bay) and the coastal zone down to the Åland Sea and the inner parts of the Gulf of Finland and Gulf of Riga usually become completely ice-covered in January. At depths more than 50 m the average annual temperature is 3-4 degrees Celsius.

The Baltic is a young sea, formed after the last glaciation as the ice retreated some 10 000 years ago. Geological uplifting of land after the glaciation continues, especially in the northern part where the uplift causes the coastline to retreat noticeably within a human generation [14,15]. Freshwater lakes: Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake.

- Barlineckie Lake: The area of the Lake covers 260 hectares, the depth reaches 18 m, max length is 3.8 km Lake is located in the North. Barlineckie parts of the Park, at a height of 57 m above sea level and is part of the Myśliborskie [14,15].
- Glebokie Lake: The surface of the Lake Glebokie in Barlinek is: 4.65 ha, maximum depth-8 m [14,15].
- Lubiszewko Lake: The surface of this Lake covers 52 ha, depth, width is 11.8 m dating back to 520 m, length up to 2100 m. Lake is located at a height of 63.3 m above sea level [14,15].
- Przyleg Lake: The surface of the Lake is 43.2 ha, depth to 5.9 m, 650.0 m width, the length of 1,100 m [14,15].

The Barlinek-Gorzów Landscape Park was established in 1991. Forests, lakes, meandering rivers and numerous streams are its scenic and natural values. The area of the Park spread over the outwash plain, created by the waters running off from the melting glacier. The surfce of the plain is not flat – it is crossed with glacial tunnels and depressions.

The vegetation in the Barlinek-Gorzów Landscape Park is luxuriant. It covers a total of 639 species of ferns and flower plants and 138 lichen species. Forty one of them are acknowledged in Poland as dying species [14,15].

Among 142 species of birds living in this region, as many as 105 nest within the park boundaries. One may encounter many rare bird species covered with species protection: whitetailed eagle, osprey, lesser spotted eagle, red and black kite, eagle-owl, crane, goldeneye, common kingfisher, woodpeckers and others [14,15].

3. METHODS

Map 1. Location of 50 Baltic Sea nearshore coastal sites sampled three times between September 2012 and July 2013.

Between September 2012 and July 2013, surface water (0.5 m) samples were collected on three separate dates (for most sites) from 50 sites located around the entire coast of Baltic

Sea (Map. 1). All sampling sites were located within 2 km of shore. On each date and at each sampling station, dissolved oxygen concentration (mg·L^{-1}), temperature (°C), and salinity (‰) were measured in situ with a hand-held meter. Water clarity was also measured on each visit with a Secchi disk (m), and the actual water depth was recorded. Surface water samples were collected in acid-cleaned bottles and transported on ice to the laboratory where they were analyzed for total phosphorus (μg·L^{-1}), total nitrogen (μg·L^{-1}), chlorophyll (μg·L^{-1}), and color (Pt-Co units). Following persulfate digestion (Menzel and Corwin 1965), total phosphorus concentrations were determined using the procedures of Murphy and Riley (1962). Total nitrogen concentrations were determined from whole water samples by oxidizing water samples with persulfate and determining nitratenitrogen concentrations with a Bran-Luebbe autoanalyzer with a cadmium column reduction method [18-24,26]. Surface water chlorophyll concentrations were measured by filtering water through a 47-mm type A/E glass-fiber filter in the field. Subsequently, filters were stored over silica gel desiccant and then frozen before analysis. Chlorophyll was extracted with a hot ethanol method described by Sartory and Grobbelarr (1984), and chlorophyll concentrations were determined spectrophotometrically [18-24,26]. Color was determined spectrophotometrically on filtered water samples [18-23,26].

4. RESULTS AND DISCUSSION

The 50 sites sampled for this project covered almost all of the nearshore coastal waters around Baltic Sea (Map. 1). All of the sites were within about 2 km of land with an average depth of 4.1 m (Table 1). The average salinity at the sites was 24‰, and average salinity was less than 10‰ at only 3 of the 50 sites. Samples were collected during both winter (2012) and summer (2013) periods, and as expected, there was a wide range in average temperatures among the sites (3.6– 20.9°C). Mean oxygen concentrations were always greater than 4.8 mg·L–1. Color was generally low, averaging only 7 Pt-Co units. Secchi depth readings averaged 2.0 m. Total phosphorus and total nitrogen concentrations averaged 17 μg·L^{-1} and 227 μg·L^{-1}, respectively (Table 1), which is less than the averages of 19 μg·L^{-1} and 370 μg·L^{-1} reported for Barlinek Gorzów Landscape Park (North-West Poland) lakes [5,13].
Chlorophyll concentrations averaged 3.1 μg·L^{-1}, which was also less than the average of 25 μg·L^{-1} reported for Barlinek Gorzów Landscape Park (North-West Poland) lakes [5,13].

Table 1. Mean, standard error, and minimum and maximum values for physical and chemical parameters estimated for 50 nearshore sites in the coastal waters Baltic Sea.

Parameter	No. samples	Mean	Minimum	Maximum	Standard error
Depth (m)	50	4,1	0,4	13,6	0,2
Salinity (‰)	50	24,7	0,5	27,1	0,3
Temperature (°C)	50	18,6	3,5	20,9	0,2
Oxygen (mg·L^{-1})	50	4,8	3,6	19,6	0,1

Total phosphorus ($\mu g \cdot L^{-1}$)	50	24	3	98	1
Total nitrogen ($\mu g \cdot L^{-1}$)	50	285	81	980	7
Chlorophyll ($\mu g \cdot L^{-1}$)	50	3,1	0,2	25,7	0,2
Secchi (m)	50	2,0	0,4	6,3	0,1
Color (Pt-Co units)	50	7	0	71	1

Total phosphorus alone accounted for 65% of the variance in chlorophyll concentrations of nearshore coastal Baltic Sea waters, whereas nitrogen alone accounted for only 38% of the variance in chlorophyll concentrations (Table 2). These percentages are similar to those reported for Barlinek Gorzów Landscape Park (North-West Poland) lakes (Table 2), where total phosphorus alone accounted for 65% of the variance in chlorophyll concentrations and total nitrogen accounted for only 36% of the variance in chlorophyll concentrations.

Table 2. Empirical models and summary statistics describing the association of annual average nutrient and chlorophyll concentrations, Secchi depth and chlorophyll, and color (Pt-Co) and total phosphorus values using data from the nearshore coastal waters of Baltic Sea and freshwater lakes (Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake) [5,13]

Model	**N**	**F**	**p > F**	**r^2**
Baltic Sea coastal waters				
log10CHL = –1.13 + 1.17log10TP 300 1297 <0.01 0.81	50	980	<0.01	0.65
log 10 CHL = –2.99 + 1.38log10TN	50	274	<0.01	0.38
log 10 Secchi = 0.48 – 0.48log10CHL	50	371	<0.01	0.59
log 10 Secchi = 0.55 – 0.41log10Color	50	195	<0.01	0.38
log 10 Secchi = 1.04 – 0.59log10TP	50	428	<0.01	0.47
For lakes (Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake)				
log10CHL = –0.37 + 1.05log10TP	70	1270	<0.01	0.65
log10CHL = –2.42 + 1.21log10TN	70	398	<0.01	0.36

Freshwater lakes with average color				
log10Secchi = 0.65 – 0.43log10CHL	45	586	<0.01	0.72
log10Secchi = 0.76 – 0.43log10Color	45	79	<0.01	0.29
log10Secchi = 0.88 – 0.48log10TP	45	241	<0.01	0.58

Note: CHL, chlorophyll ($\mu g \cdot L^{-1}$); TP, total phosphorus ($\mu g \cdot L^{-1}$); TN, total nitrogen ($\mu g \cdot L^{-1}$); Secchi, Secchi depth (m).

Thus, the phosphorus–chlorophyll models presented for Baltic Sea nearshore coastal waters (Table 2) are as robust as those developed for lakes and suggest that phosphorus accounts for more variance in chlorophyll than in nitrogen in both systems.

Chlorophyll accounted for 59% of the variance in Secchi depth for Baltic Sea nearshore coastal waters, whereas color accounted for only 38% of the variance in Secchi depth (Table 2). Color has the potential to impact water clarity more in Barlinek Gorzów Landscape Park (North-West Poland) lakes than in coastal waters because color values are generally higher in the lakes, as we indicated earlier. Therefore, to compare chlorophyll–Secchi and color–Secchi relationships for the nearshore coastal waters of Baltic Sea and Barlinek Gorzów Landscape Park (North-West Poland) lakes, we selected a set of Barlinek Gorzów Landscape Park (North-West Poland) lakes (n = 45) that averaged color values less than 30 Pt-Co units. We selected a maximum of 32 Pt-Co units for the lake data because 90.5% of the nearshore coastal sites had color values less than 32 Pt-Co units.

4. CONCLUSIONS

In conclusion, it appears that the general principles applied successfully to the control of eutrophication in freshwaters can be applied to coastal marine systems in Baltic Sea. In this study, we successfully developed models relating chlorophyll to nutrients and Secchi depth to chlorophyll using data from nearshore coastal waters of Baltic Sea. The models suggest that phosphorus is often the primary limiting factor for phytoplankton production in the nearshore coastal waters of Baltic Sea and that phosphorus can account for 65% of the variance in chlorophyll concentrations. The models also show that chlorophyll is the dominant factor determining Secchi depth in nearshore coastal waters of Baltic Sea and that chlorophyll can account for 59% of the variance in Secchi depth.

The eutrophication models that we developed using data from nearshore coastal waters of Baltic Sea are similar to models developed for freshwater lakes in Baltic Sea, but the amount of chlorophyll per unit of phosphorus and Secchi depth per unit of chlorophyll are both significantly less. This suggests that the chlorophyll to biovolume ratios in the nearshore coastal waters of Baltic Sea are less than those in freshwater systems of Baltic Sea.

Therefore, chlorophyll to phosphorus and Secchi depth to chlorophyll models developed for freshwater systems are probably ill suited for use in marine systems.

In comparison with other lakes Western and Northern Polish in the lakes Barlinek-Gorzów Landscape Park is a large number of taxa, however, as a result of the distribution of non-harmonic doesn't translate to the indicator value of biodiversity index PIE [5].

On the basis of the analysis of research in the Western and Northern Polish Lakes summer macrozoobenthos it can be concluded that in the lakes Barlinek-Gorzów Landscape Park (Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake) very intensively develop Oligochaeta. While the larvae of Chironomidae subdominants status in the period under review amounting to water, developed in other lakes much more intensely, acting mostly the main ingredient of benthic fauna [5].

The results obtained have revealed that the ecological condition of the water in the lakes Barlinek-Gorzów Landscape Park (Barlineckie Lake, Glebokie Lake, Lubiszewko Lake, Przyleg Lake) is very bad [5].

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