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Positive and negative feedback loops in nutrient phytoplankton interactions related to climate dynamics factors in a shallow temperate estuary (Vistula Lagoon, southern Baltic)

Marek Kruk[a,*], Justyna Kobos[b], Lidia Nawrocka[c], Katarzyna Parszuto[a]

[a] University of Warmia and Mazury in Olsztyn, Poland
[b] University of Gdańsk, Poland
[c] The State School of Higher Professional Education in Elbląg, Poland

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ABSTRACT

This study aims to demonstrate that factors associated with climate dynamics, such as temperature and wind, affect the ecosystem of the shallow Vistula Lagoon in the southern Baltic and cause nutrient forms phytoplankton interactions: the growth of biomass and constraints of it. This occurs through a network of direct and indirect relationships between environmental and phytoplankton factors, including interactions of positive and negative feedback loops. Path analysis supported by structural equation modeling (SEM) was used to test hypotheses regarding the impact of climate factors on algal assemblages. Increased phytoplankton biomass was affected directly by water temperature and salinity, while the wind speed effect was indirect as it resulted in increased concentrations of suspended solids (SS) in the water column. Simultaneously, the concentration of SS in the water was positively correlated with particulate organic carbon (POC), particulate nitrogen (PN), and particulate phosphorus (PP), and was negatively correlated with the total nitrogen to phosphorus (N:P) ratio. Particulate forms of C, N, and phosphorus (P), concentrations of soluble reactive phosphorus (SRP) and nitrate and nitrite nitrogen (NO_3-N + NO_2-N), and ratios of the total N:P and DIN:SRP, all indirectly effected Cyanobacteria C concentrations. These processes influence other phytoplankton groups (Chlorophyta, *Bacillariophyceae* and the picophytoplankton fraction). Increased levels of SRP associated with organic matter (POC), which stemmed from reduced DIN:SRP ratios, contributed to increased Cyanoprokaryota and picophytoplankton C concentrations, which created a positive feedback loop. However, a simultaneous reduction in the total N:P ratio could have inhibited increases in the biomass of these assemblages by limiting N, which likely formed a negative feedback loop. The study indicates that the nutrients-phytoplankton feedback loop phenomenon can intensify eutrophication in a temperate lagoon, including increases of the biomass of Cyanobacteria and picophytoplankton. However, it can also constrain this increase.

1. Introduction

A number of studies conducted recently on the impact of climate on coastal marine ecosystems point to the functioning of a multifactor system of relationships and interactions among physical phenomena linked with climate and the biological responses of these ecosystems (Häder and Gao, 2015; Hense, 2007; Payn et al., 2014). This concerns in particular changes in phytoplankton production, including processes such as Cyanobacterial blooms (Kennish, 2002; Statham, 2012). The complexity of these relationships is noted particularly in shallow coastal waters, for example, in the Vistula Lagoon (southern Baltic Sea). In such water bodies, because of the shallow depth and the characteristics of the geological structure of the basin, waves can upraise bottom sediments, and nutrient inflow from the catchment area can occur (Kruk, 2012; Pliński, 2005).

Biogeochemical functioning, especially that related to biomass production and that linked to climate dynamics such as temperature, wind speed, and storms (causing tidal sediment mixing), changes in salinity, and catchment area inflow can be explained and predicted with suitable tools, such as mathematical models. These models rely on the recent increase of data availability derived from research and monitoring (Bruggemann and Bolding, 2014; Dzierzbicka-Głowacka et al., 2011a; Håkanson et al., 2007; Lopes et al., 2015; Payn et al., 2014). Increased phytoplankton production, including that of

* Corresponding author.
E-mail address: mkruk@uwm.edu.pl (M. Kruk).

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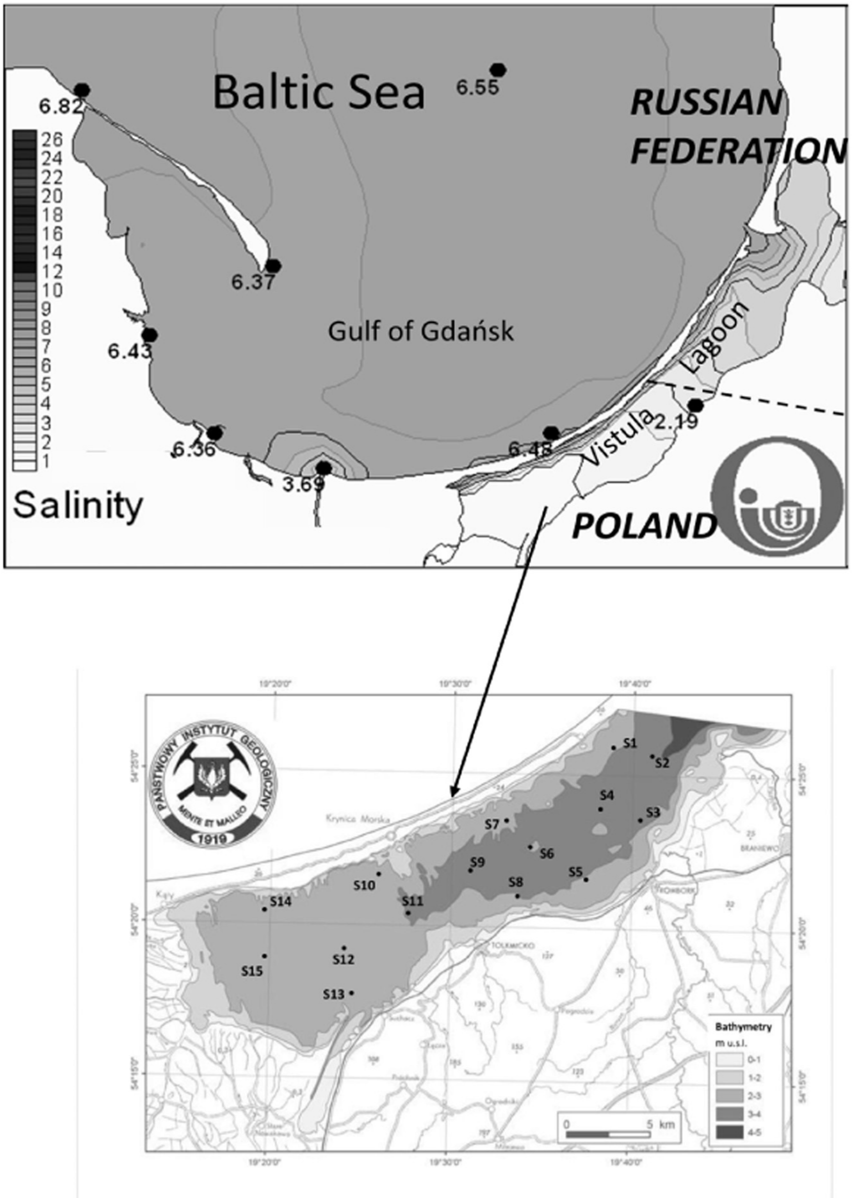

Fig. 1. The Vistula Lagoon location in the part of Baltic Sea with salinity map referred to October 2009 (Institute of Oceanography, Gdańsk University) and bathymetry map (Uścisłowicz and Zachowicz, 1996) with points of sampling: S1–S15.

Cyanobacteria, is attributed to the relationship between hypothetical physicochemical factors, and it is associated with combined bottom-up and top-down control (Arhonditsis et al., 2007). However, this can also be negative and prevailing positive feedback loops linked to the life cycle of Cyanobacteria, lead to excessive growth of these organisms that cause both economic and sanitary problems (Hense, 2007).

Available studies on climatic conditions in the region of the southern Baltic Sea based on Regional Climate Model (Hollweg et al., 2008) predictions indicate a possible increase in sea surface temperatures, including more frequent occurrences of maximum temperatures (Dzierzbicka-Głowacka et al., 2011a, 2011b; Neumann et al., 2012). It also concerns increased frequency of storms because extreme winds in the Baltic Sea can be related to the North Atlantic storm track and the NAO phase (Mölter et al., 2016).

Environmental factors that stem from the impact of the climate can be direct, such as air and water temperature or wind action, or indirect, such as factors that depend on local conditions. Certainly, strong winds combined with sea shallowness mix the particulate bottom sediments (Jeng, 2003), including organic deposits originating mainly from accumulated algal debris. This process is crucial to the transport of nutrients into the water column rendering them available to phytoplankton, which could contribute to progressively increasing trophic conditions in shallow coastal waters such as the Vistula Lagoon (Nawrocka and Kobos, 2011). Particulate organic matter (POM) is known to be the major carrier and source of nutrients C, N, and P for autotrophs in marine ecosystems, and their stoichiometric rate limits phytoplankton (Dzierzbicka-Głowacka et al., 2011b; Klausmeier et al., 2004; Martiny et al., 2014). In the context of the discussion of the N:P ratio (Hillebrand et al., 2013), relationships that are noteworthy are those between available N:P (DIN: SRP) and phytoplankton or the total N:P ratio. These ratios can indicate processes regulating stoichiometry in aquatic ecosystems (Persson et al., 2010).

This study aims to demonstrate that factors associated with climate dynamics in the shallow Vistula Lagoon, such as temperature and wind, affect the biogeochemistry of C, N, and P could impact phytoplankton, especially Cyanobacteria blooms. This could occur through the direct and indirect relationships among environmental and biological and biogeochemical factors, including interaction among these factors occurring via positive and negative feedback loops.

Two-stage path analysis of observable variables supported by