CLIMATE CHANGE: HOW DOES THIS INFLUENCE ON HARMFUL ALGAL BLOOMS IN THE LAGOON OF THE BALTIC SEA?

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Fig. 1. Monitoring stations in the Baltic Sea, Vistula and Curonian Lagoons

MATERIAL AND METHODS

The researches (primary production, chlorophyll *a* (Chl), phytoplankton, nutrients and others) were carried out monthly from March-April to November at 12 stations in the Curonian Lagoon and at 9 stations in the Vistula Lagoon since 1991 to 2014. Location of this stations corresponds to hydrological and hydrochemical division and covers the Russian waters (Fig. 2). The database includes 3250 stations for the period from 1991 to 2014. Long-term data on the water temperature were estimated on the basis of daily observations at standard stations in the lagoons.

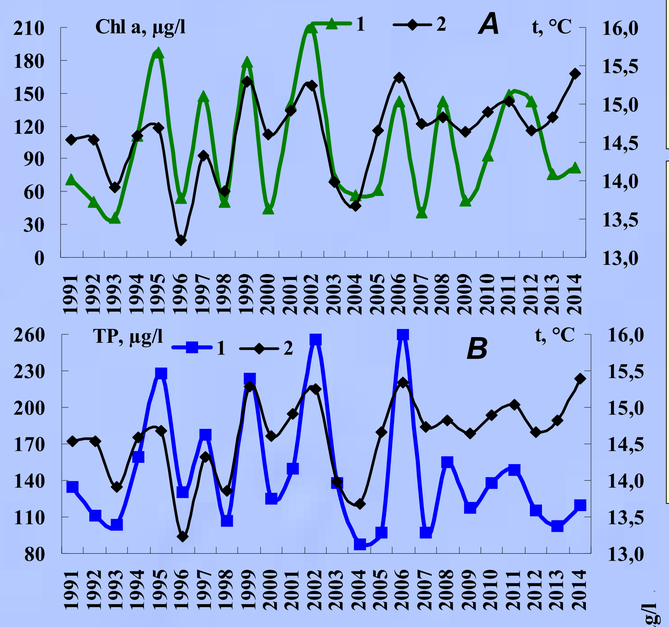

Fig. 5. The mean for the growing season (April - October) Chl "a" (A), total phosphorus (B) and temperature of water in the Curonian Lagoon

Mean annual primary production in 2010-2014 (≈600 gC·m^{-2}·year^{-1}) is considerable higher, than in the middle of 1970s (300 gC·m^{-2}·year^{-1}) in the Curonian Lagoon (Fig. 7). The local climate warming in the Baltic region caused ongoing eutrophication and harmful algae blooms in the Curonian Lagoon despite of significant reduction of nutrients loading.

Table 2. Effects of algal blooms in the Southeastern Baltic Sea (including coastal water, lagoons)

INTRODUCTION

The Curonian and Vistula Lagoons are the largest lagoons of the Baltic Sea. These Lagoons are similar in temperature regimes, however different in continental runoff and salinity. The Curonian Lagoon is choke mostly freshwater lagoon, while the Vistula Lagoon is restricted brackish water lagoon.

In XX century in the Baltic Sea and its coastal areas and lagoons the nutrients loading increased and warming trend is observed (Fig. 1). Reduction of industrial production and fertilizers during the economic crisis in Russia resulted in a decrease of the external nutrients loading by 3-4 times. However, in the Lagoons, unlike many inland and coastal marine waters, eutrophication of water continues.

Ongoing eutrophication is one of the most important problems for the lagoon. Eutrophication of the lagoons affects all trophic levels and primarily the intensity of phytoplankton development and also at benthic communities and fishery.

I) CURONIAN LAGOON

The Curonian Lagoon may be characterized as hypertrophic water body with "poor" water quality.

In this choked lagoon the water temperature is key environmental factor determining the level of primary production and algae blooms. Climate change in 1990s-2000s combined with other factors (freshwater conditions, slow-flow exchange, high nutrients concentrations) creates conditions for Cyanobacteria "hyperblooms" (Fig. 3, 4).

"Hyperblooming" of Cyanobacteria is observed at water warming-up to 20-22°C and the mean water temperature above 14.5 °C for the growing season. Small fluctuations of the mean summer water warming-up (in 2-3ºC) resulted in 2-4-fold variations of the trophic status indices and affected considerably the ecological state (Fig. 5, 6).

During the latest decades the trend towards increase number of "warm" years has been observed. The water temperature above 14.5°C, typical to "hyperblooming", was observed 3 times in 1970s, 4 times in 1980s, 6 times in 1990s, and 13 times in 2000s. So, the "hyperblooming" (Chl "a" > 100 µg/l) was observed during 3 years in 1980s in the period of the most intensive nutrients loading, while 11 years "hyperblooming" were observed in 1990s and 2000s when the nutrients loading from lagoon watershed area multiple decreased owing to the economic crisis in Russia.

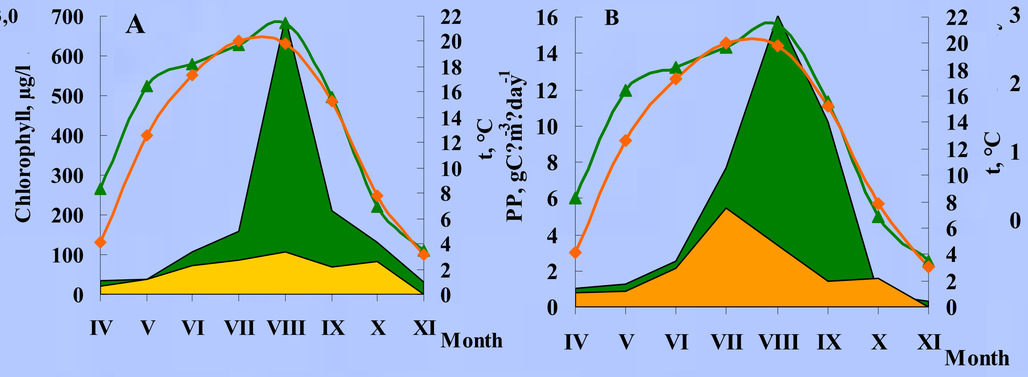

Fig. 6. The temperature of water and A) concentration of chlorophyll "a", B) primary production in 2002 (1, 3) and 2003 (2, 4)

Harmful algal blooms (*Aphanizomenon flos-aquae, Microcystis aeruginosa*) in July-October (Chl to 700-3400 µg/l) result in deterioration of the water chemical parameters, death of fish in the coastal zone of the Curonian Lagoon (Fig. 8, table 2). Algal toxins detected in water, mussels and fish, and the concentrations of microcystins (0.1-134 µg/l) may exceed safe level. Hyperblooms" of Cyanobacteria is the most dangerous for coastal towns (Polessk, Zelenogradsk) and tourist resorts (UNESCO National Park "Curonian Spit").

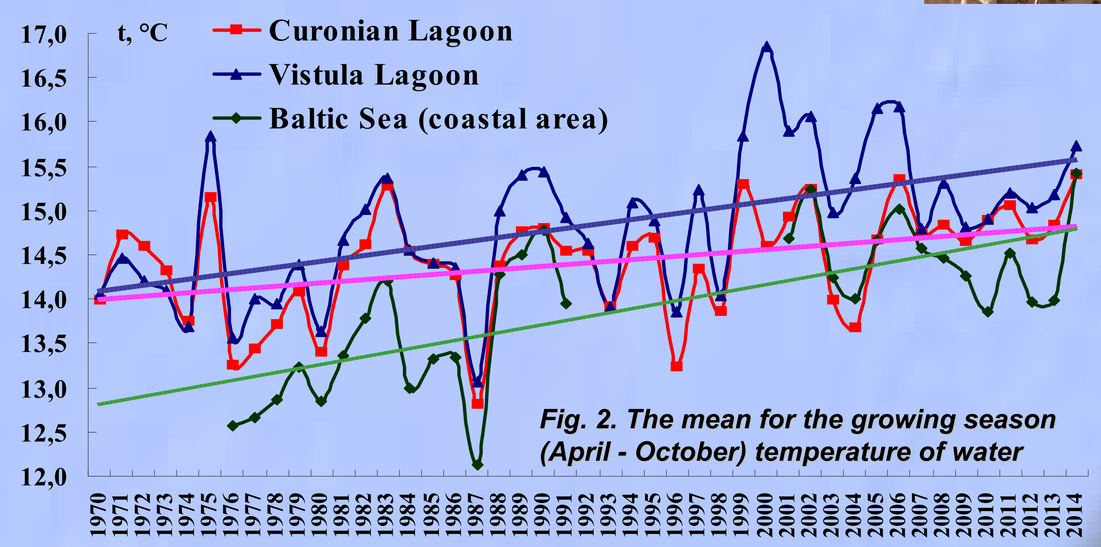

Fig. 2. The mean for the growing season (April - October) temperature of water

Fig. 2. CAUSES of HARMFUL ALGAL BLOOMS

The environmental factors determining level of biological production and the trophic status of the lagoon «close type» (Curonian Lagoon).

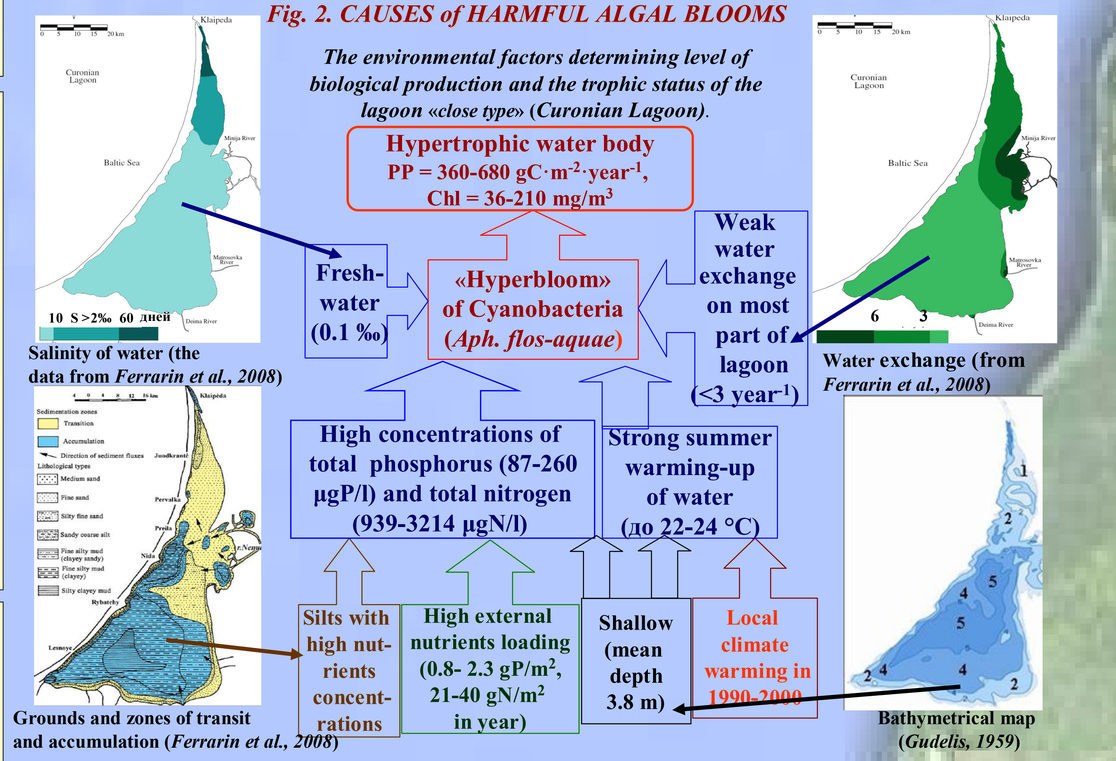

Fig. 3. The environmental factors determining level of biological production and the trophic status of the lagoon

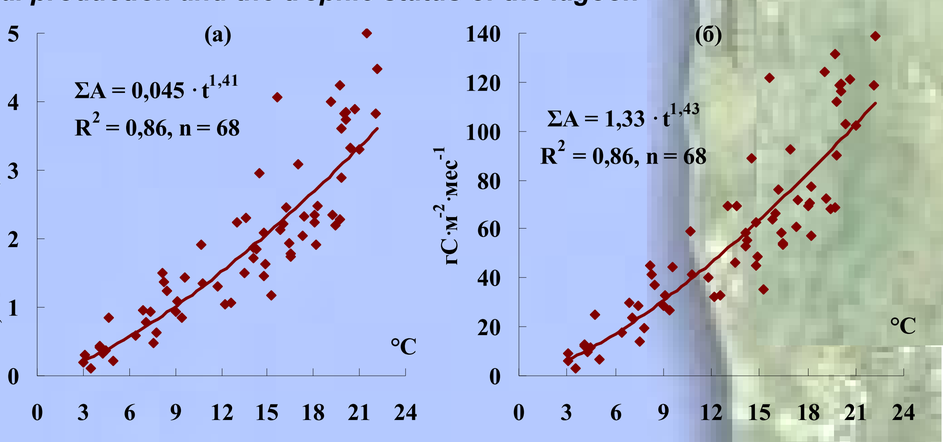

Fig. 4. Correlation primary production per day (a) and monthly (b) and average monthly water temperature

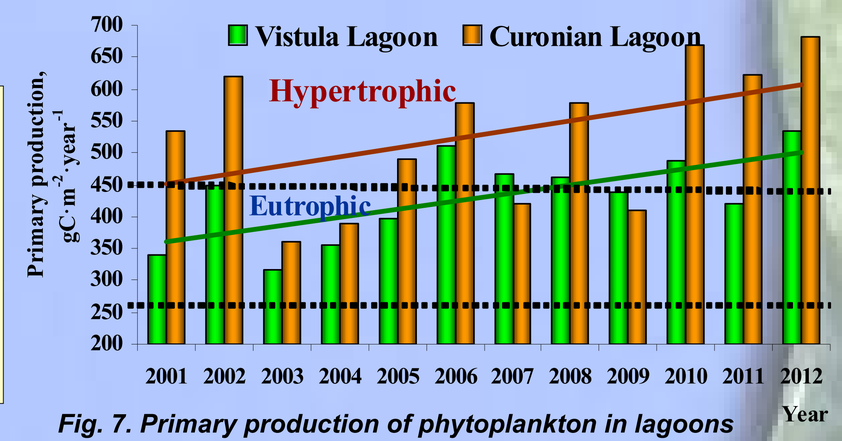

Fig. 7. Primary production of phytoplankton in lagoons

II) VISTULA LAGOON

Also, effects of climate change and eutrophication have been observed in restricted Vistula Lagoon (Fig. 7). Mean annual temperature increased by 1.4°C for 40 years, and water warming combined with other factors created conditions for phytoplankton "hyperblooms" (70-80 µg Chl/l) in 1995-2010. Mean annual primary production in 2000s (430 gC·m^{-2}·year^{-1}) is considerable higher, than in the middle of 1970s (300 gC·m^{-2}·year^{-1}). The climate warming was cause ongoing eutrophication and harmful algal blooms in summer in 1990-2010 despite of significant reduction of nutrients loading in the lagoon.

Table 1. Trophic classification for 1) Baltic Sea (including coastal waters) ([1]Wasmund et al., 2001) 2) lakes ([2]OECD, 1982), lagoons

Trophic status	[1]Chl *a* µg/l	[2]Chl *a* µg/l	PP, gC·m^{-2}·year^{-1}	Type
Oligotrophic	< 0.8	< 2.5	< 100	◆
Mesotrophic	0.8-4,0	2.5-8	100 – 200	▲
Eutrophic	4.1-10	8-35	250 – 400	●
Hypertrophic	10-100	35-100	> 400	■
Extremely hypertrophic	> 100	> 100		✥

Water body	Type	Trophic status	Effects of Eutrophication and Algal Blooms in the Baltic Sea
Curonian Lagoons	*Choked lagoon*	*Hyper-trophic*	1. Hyperblooming of freshwater Cyanobacteria is observed long period (July-October). Dominant species of Cyanobacteria is the toxic and the concentrations of toxins may exceed safe levels. 2. Accumulation and decomposition of Cyanobacteria results in oxygen deficiency and death of fish in the coastal zone. 3. The pathological changes in zooplankton and fish were similar to the symptoms of affected by toxins of Cyanobacteria. 4. Phytoplankton production (≈600 gC/(m^2·year) exceeds mineraliza-tion of organic matter (on 60%). In choked lagoon that leads to accumulation of organic matter in sediments and eutrophication. 5. Deterioration of hydrochemical parameters (exceeded MPC continually for BOD_5 and periodically local for nutrients).
Vistula Lagoon	*Restricted lagoon*	*Eutro-phic - hyper-trophic*	1. The blooming of brackish-water Cyanobacteria (sometimes to level of hyperblooming) is observed briefly in the summer. 2. Phytoplankton production (430 gC/(m^2·year)) exceeds mineraliza-tion of organic matter (on 50%). In restricted lagoon that leads outwelling organic matter in the adjacent marine waters. 3. Deterioration of hydrochemical parameters (exceeded MPC continually for BOD_5 and periodically local for nutrients).
South-Eastern Baltic	*Coastal zone*	*Eutro-phic*	1. The blooming of brackish-water Cyanobacteria is observed locally and briefly in the summer. The concentrations of toxins are small and have no effect on aquatic organisms. 2. Deterioration of hydrochemical parameters (exceeded MPC for BOD_5 in summer).
South-Eastern Baltic	*Offshore area*	*Meso-trophic*	1. Climate change (warming of water) leads to increased production and abundance of phytoplankton, zooplankton, benthic. In the deep waters near the bottom may be formed or expanded anoxic areas (benthic desert). 2. The concentrations of pollutants Cyanobacteria is about the same level and don't exceed MPC.

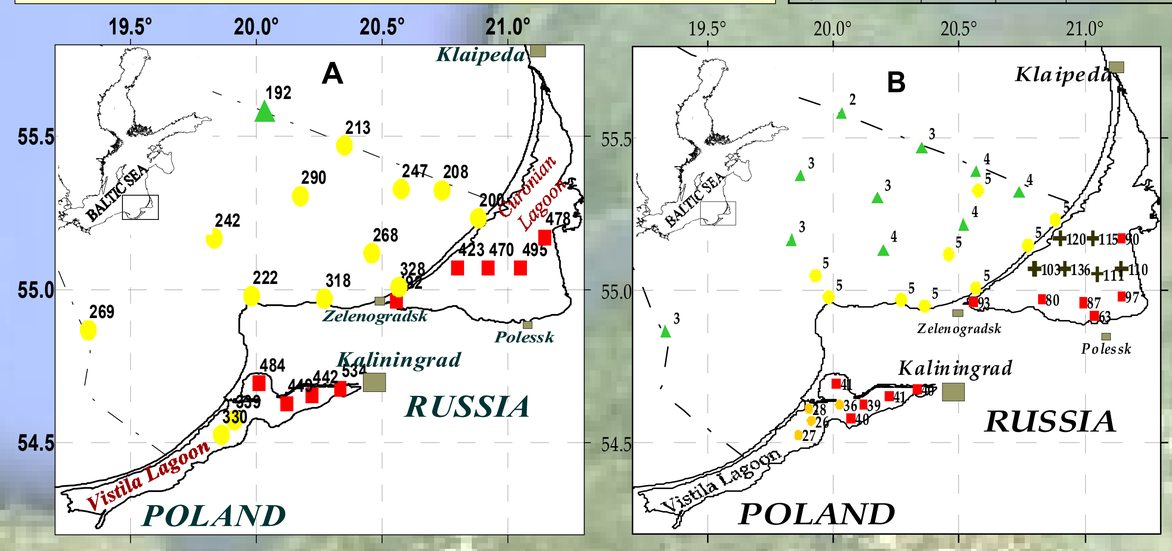

Fig. 8. Trophic status of the Curonian and Vistula Lagoons and the South-Eastern Baltic Sea based on: A) primary production, gC·m-2·year-1 B) mean for growing season (April - October) chlorophyll a (µg/l) in 2001-2014