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THE IMPACT OF TEMPERATURE ON THE WATER QUALITY OF THE BALTIC SEA

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The article examines the impact of water temperature on the quality indicators of the Baltic Sea, including nitrogen and phosphorus compounds as well as biochemical oxygen demand (BOD_7). The relevance of the study is determined by climate change-induced warming of the Baltic Sea, which accelerates eutrophication processes and threatens ecosystem stability. The results revealed that rising water temperature significantly increased total nitrogen and phosphorus concentrations and intensified BOD_7 fluctuations, with 20 °C identified as the critical threshold for the most intensive chemical changes. These processes create favourable conditions for cyanobacterial blooms, accelerate eutrophication, and deteriorate the ecological status of the sea. The findings highlight that climate-driven water temperature rise is one of the key factors affecting the quality of Baltic Sea ecosystems.

Keywords: *Baltic Sea; water temperature; phosphorus; nitrogen; BOD_7; eutrophication; climate change.*

INTRODUCTION

The Baltic Sea is one of the most sensitive seas in the world, characterized by limited water exchange, a relatively shallow average depth, and high nutrient loads brought by rivers. Due to these features, it is particularly vulnerable to both local pollution and the impacts of global climate change. In recent decades, a consistent warming of the sea has been recorded, accelerating eutrophication processes and contributing to the expansion of “dead zones” (Ministry of Environment, 2023; Buslavičiūtė & Jukna, 2024).

One of the most significant ecological challenges in the Baltic Sea is algal and cyanobacterial blooms, which are closely linked to excess nutrients (nitrogen and phosphorus compounds) and elevated temperatures. Such processes not only deteriorate the aesthetic quality of water but also lead to the production of toxins, posing risks to human health and the stability of aquatic ecosystems (Hense et al., 2013).

Scientific projections indicate that, under climate change conditions, the water temperature of the Baltic Sea will continue to rise, and during critical heat waves it may reach significant ecological thresholds (Copernicus Marine Service, 2023). Particular importance is attributed to the 20 °C threshold, at which the most intensive nutrient transformation processes and a higher risk of eutrophication are observed.

The aim of this study is to determine how changes in water temperature (15 °C, 20 °C, 23 °C, and 25 °C) affect the Baltic Sea water quality indicators – nitrogen and phosphorus compounds as well as biochemical oxygen demand (BOD_7) – and to identify the critical threshold at which the most intensive changes occur.

RESEARCH METHODS

A water sample from the Baltic Sea was collected in July 2023. The samples were kept in constant-temperature chambers at 15 °C, 20 °C, 23 °C, and 25 °C.

The dynamics of water quality were assessed by determining the following indicators: phosphate phosphorus (PO_4-P), total phosphorus (TP), ammonium nitrogen (NH_4-N), nitrite (NO_2^-), nitrate nitrogen (NO_3-N), total nitrogen (TN), and biochemical oxygen demand over 7 days (BOD_7). The research was carried out at the Environmental Research Laboratory of the Agriculture Academy, VMU, for one year with monthly measurements.

The research results were evaluated using mathematical statistical processing. The data were processed with Microsoft Excel, while the statistical analysis was performed using the program STATISTICA 10. The trends and determination coefficients were applied to assess the variation patterns of water quality indicator concentrations.

To assess the strength of the relationships between indicators under different temperature conditions, correlation coefficients were calculated ($p < 0.05$). Conclusions about the strength of the relationship were drawn based on the magnitude of the correlation coefficient. Correlation was considered statistically significant when $p < 0.05$.

Figure 1. Temperature-controlled chambers

A comparative analysis of the Baltic Sea water quality was performed by evaluating the mean concentrations of chemical indicators at different temperatures (15–25 °C). An independent t-test was applied to determine statistical significance. A difference was considered statistically significant when $p < 0.05$.

RESEARCH RESULTS AND DISCUSSION

At different temperatures in the Baltic Sea water, the following analyte concentrations were determined: biochemical oxygen demand (BOD_7), nitrites (NO_2^-), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), and total phosphorus (TP).

The variation of biochemical oxygen demand over 7 days at different temperatures during the period from 11 September 2023 to 1 August 2024 in the Baltic Sea water is presented in Figure 2.

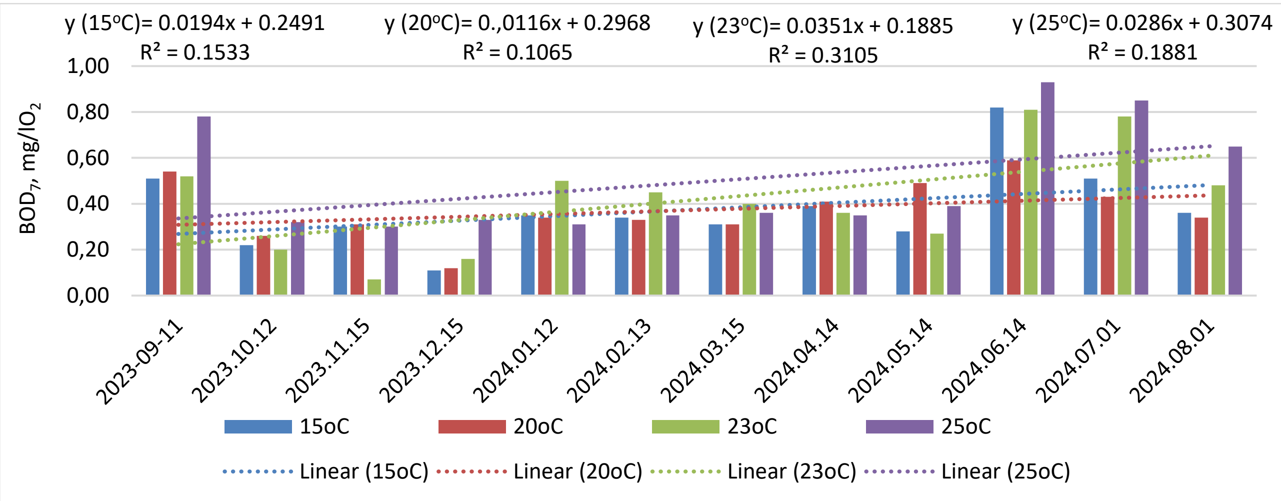


Figure 2. Biochemical oxygen demand (BOD_7) values in the Baltic Sea water

With increasing water temperature, BOD_7 values consistently increased, with the most pronounced rise observed at the 23 °C threshold. This indicates accelerated decomposition processes of organic matter and increased microbial activity. The variation of nitrite (NO_2^-) concentrations at different temperatures during the period from 11 September 2023 to 1 August 2024 in the Baltic Sea water is presented in Figure 3.

It was found that under most temperature conditions, nitrite concentrations decreased or remained low. The most significant reduction of NO_2^- over time was observed at 25 °C ($y = -0.0006x + 25.525$; $R^2 = 0.2143$), which may indicate faster nitrite degradation or their conversion into nitrates (NO_3^-) due to more intensive nitrification at higher temperatures. At 15 °C, a slight decreasing trend was also observed ($R^2 = 0.0593$), which may reflect the natural slowing of processes due to lower temperature. At 20 °C and 23 °C, the concentration changes were minimal ($R^2 = 0.0036$ and $R^2 = 0.0269$, respectively), suggesting that under these conditions nitrite dynamics were more stable and less affected by temperature.

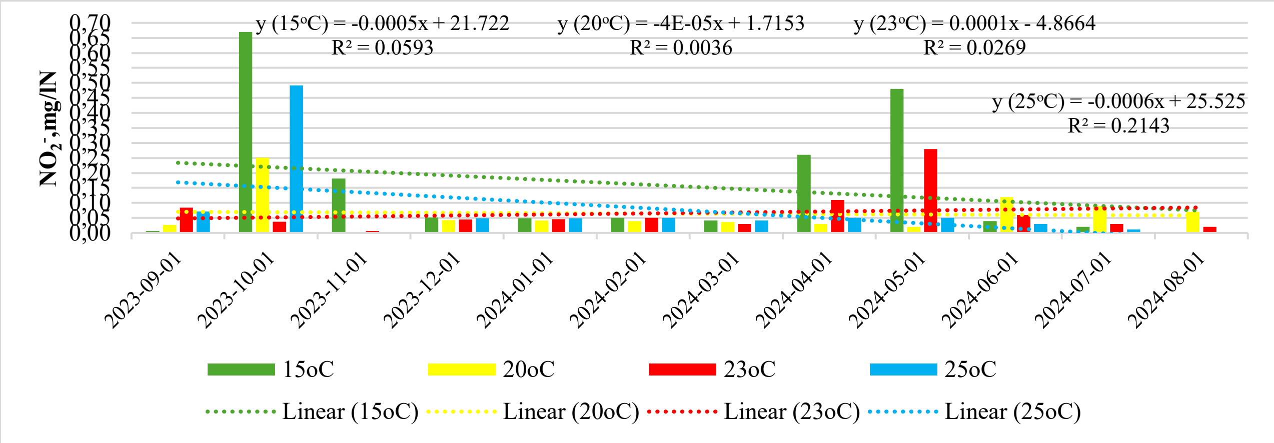


Figure 3. Nitrite (NO_2^-) values in the Baltic Sea water

The variation of ammonium nitrogen (NH_4-N) concentrations at different temperatures during the period from 11 September 2023 to 1 August 2024 in the Baltic Sea water is presented in Figure 4.

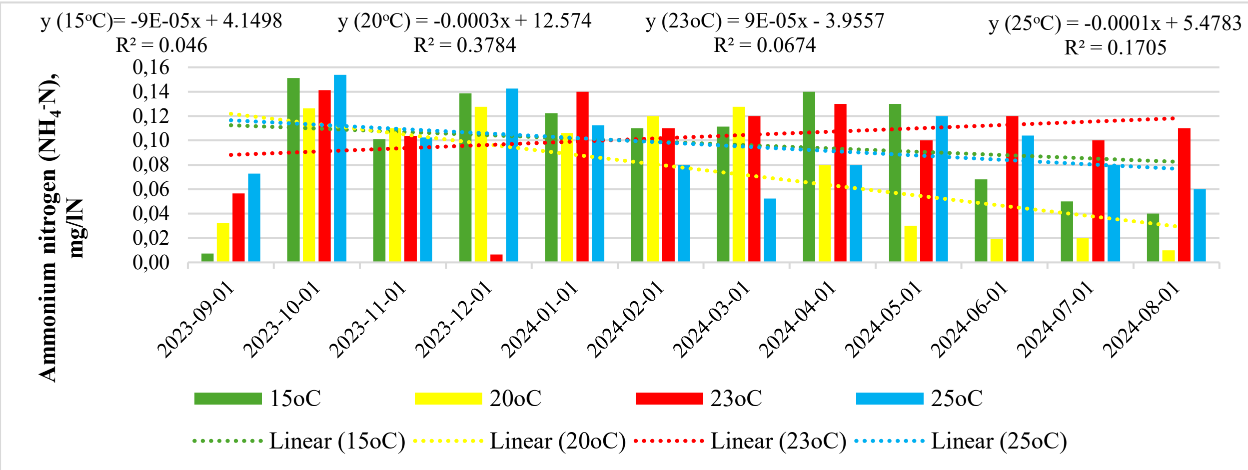


Figure 4. Ammonium nitrogen (NH_4-N) values in the Baltic Sea water

At the lowest temperature (15 °C), the variation in ammonium nitrogen levels was minimal, with a determination coefficient ($R^2 = 0.046$) indicating a very weak relationship between time and concentration changes. A similar result was obtained at 23 °C ($R^2 = 0.0674$), suggesting that at certain temperatures the amount of ammonium nitrogen remains relatively stable.

In contrast, at 20 °C and 25 °C, a more pronounced decrease in NH_4-N levels over time was recorded, supported by higher R^2 values – 0.3784 and 0.1705, respectively. This suggests that in warmer conditions, microbiological processes (such as nitrification, during which ammonium is converted into nitrites and nitrates) become more active, accelerating the transformation of this compound.

The variation of nitrate nitrogen (NO_3-N) concentrations at different temperatures during the period from 11 September 2023 to 1 August 2024 in the Baltic Sea water is presented in Figure 5.

Based on the obtained data, the trends of nitrate nitrogen concentration changes varied across different temperatures. At 20 °C, the most pronounced increase in concentration was observed. The linear relationship ($y = 0.1673x – 0.3455$; $R^2 = 0.6407$) indicates that at this temperature the nitrate content in the water increased most consistently, and the trend was statistically significant. At 23 °C, an increase was also recorded ($y = 0.0324x + 0.1204$), but the growth was much less intense, and the correlation coefficient ($R^2 = 0.4865$) indicates a moderate relationship. At 15 °C, only a very slight increase in concentration was observed ($y = 0.0042x + 0.0564$; $R^2 = 0.1057$), which is likely incidental, as the relationship was very weak. At 25 °C, virtually no change occurred ($y = –0.0016x + 0.0879$; $R^2 = 0.0117$), and the data scatter indicates that under this regime the nitrate nitrogen concentration remained stable or slightly decreased. The increase in nitrate nitrogen can be associated with ammonification and nitrification processes, which are more favorable at moderate temperatures. At 20 °C, these microbiological processes are most active, resulting in more efficient oxidation of ammonium nitrogen into nitrites and finally into nitrates. However, at higher temperatures (25 °C), these processes may slow down due to unfavorable conditions for microorganisms, such as oxygen deficiency or accelerated organic matter decomposition, which prevents nitrate concentration from increasing.

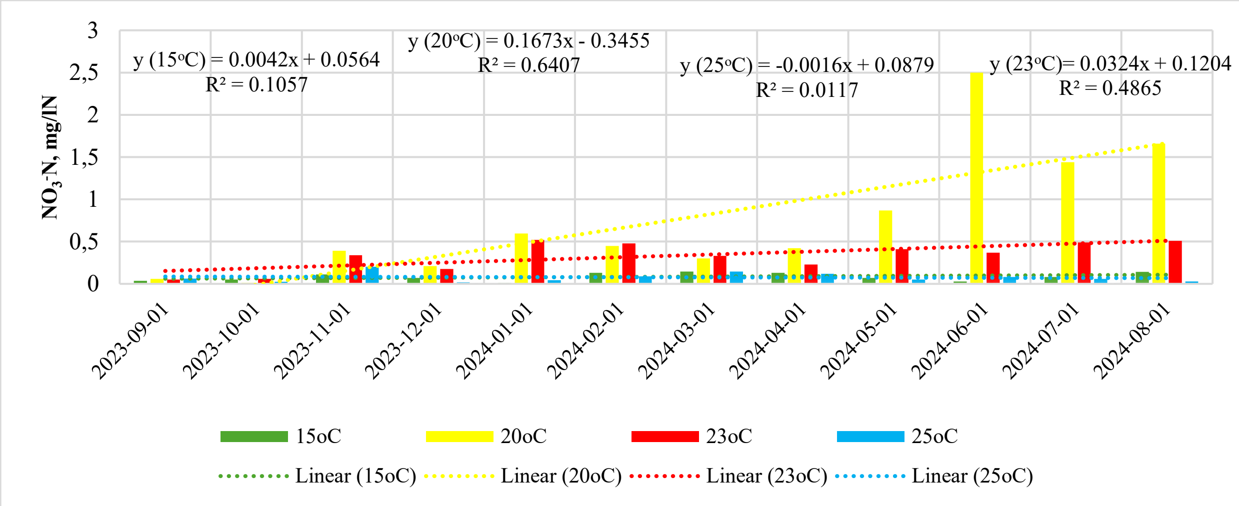


Figure 5. Nitrate nitrogen (NO_3-N) values in the Baltic Sea water

The variation of total nitrogen (TN) concentrations at different temperatures during the period from 11 September 2023 to 1 August 2024 in the Baltic Sea water is presented in Figure 6.

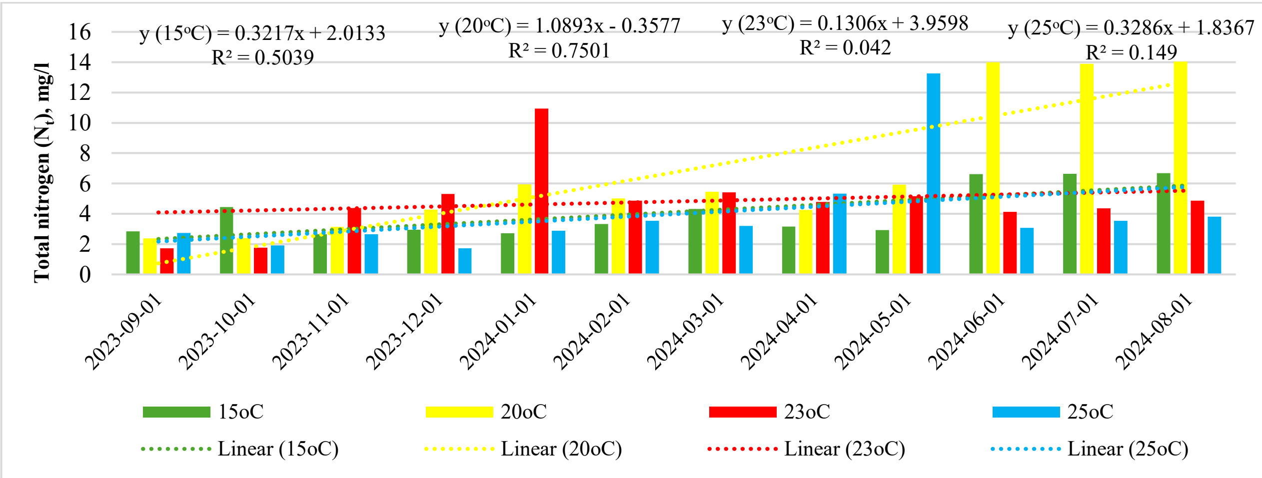


Figure 6. Total nitrogen (TN) values in the Baltic Sea water

Based on the presented data, the variation of total nitrogen concentrations over one year at different temperatures showed different trends. At 20 °C, the most pronounced increase in concentration was observed. The linear regression equation ($y = 1.0893x - 0.3577$) indicates a consistent growth, and the determination coefficient ($R^2 = 0.7501$) confirms a relatively strong relationship between time and concentration change. This suggests that this temperature is favorable for the accumulation of nitrogen compounds. At 15 °C ($y = 0.3217x + 2.0133$; $R^2 = 0.5039$), an increase was also observed, but the change was not as distinct as at 20 °C. Nevertheless, this indicates that nitrogen concentration growth may occur even at lower temperatures, although at a slower rate. At 25 °C ($y = 0.3286x + 1.8367$; $R^2 = 0.149$), a slight increase in concentration was recorded, but the relationship was weak. It can be assumed that at this temperature nitrogen loss processes, such as denitrification, may occur, limiting the growth of total concentration. At 23 °C ($y = 0.1306x + 3.9598$; $R^2 = 0.042$), the change was very slight and the relationship extremely weak. This may indicate that at this temperature nitrogen cycling processes are more stable or that competing mechanisms (e.g., nitrification and denitrification) are actively occurring.

The variation of total phosphorus (TP) concentrations at different temperatures during the period from 11 September 2023 to 1 August 2024 in the Baltic Sea water is presented in Figure 7.

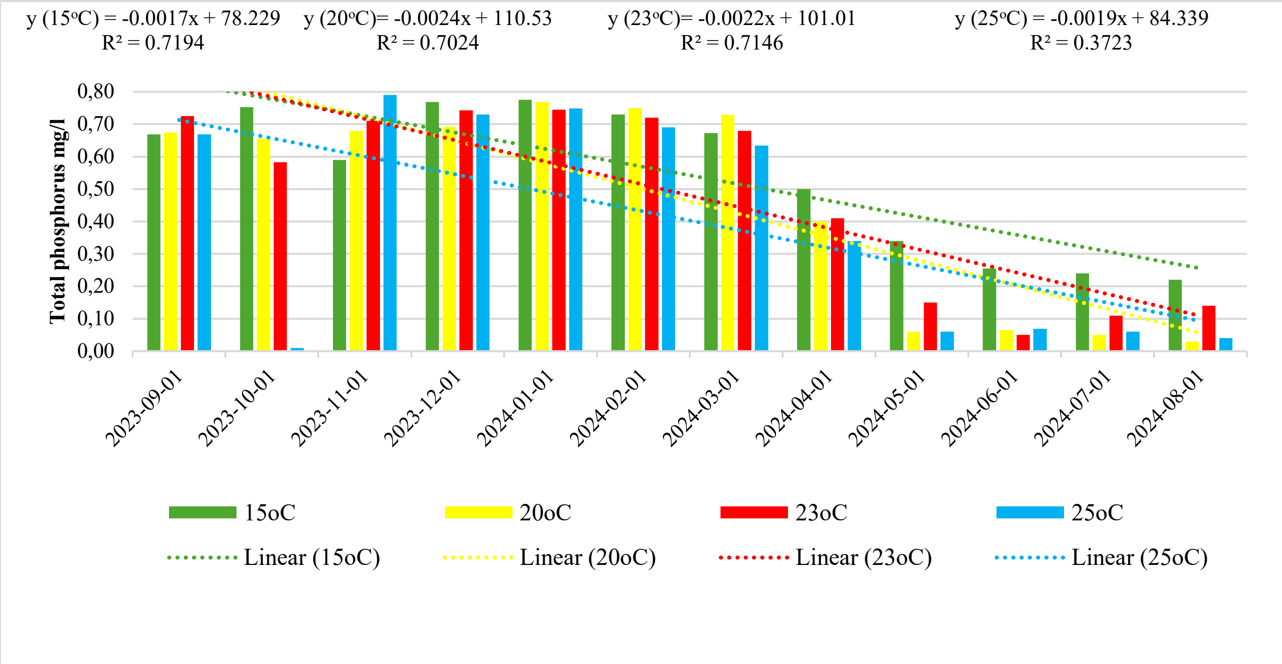


Figure 7. Total phosphorus (TP) values in the Baltic Sea water

The results show a decreasing trend in total phosphorus concentrations at all temperatures. This is also confirmed by the negative regression lines. These findings indicate that the most rapid decline in phosphorus levels over the year occurred at higher temperatures, particularly under 20 °C and 23 °C conditions. At 25 °C, the decrease was slower than at 20 °C and 23 °C, but more pronounced than at 15 °C, although the R^2 value was the lowest in this case.

The highest total phosphorus concentrations were recorded at the beginning of the study (September–December 2023), when the values often exceeded 0.70 mg/l regardless of temperature. Over time, the concentrations consistently decreased, with the lowest values observed at the end of the study (July–August 2024), when in most temperature regimes the concentration dropped below 0.10 mg/l.

In summary, it can be stated that higher temperature accelerated the decrease in total phosphorus concentration, which may be related to faster biogeochemical processes under warmer conditions – such as increased microbial activity or phosphorus sedimentation (a process in which phosphorus shifts from a dissolved state in water to a solid form and settles into the bottom sediments).

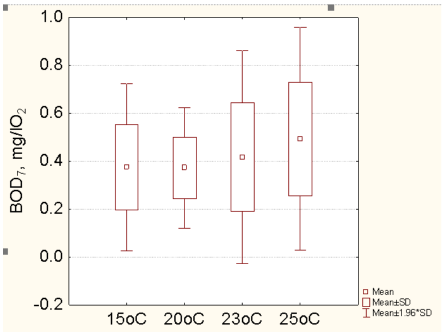
The research results revealed that changes in water temperature had a significant impact on the key water quality indicators of the Baltic Sea – nitrogen and phosphorus compounds as well as biochemical oxygen demand (BOD_7). The 20 °C threshold was particularly distinctive, with the most intensive chemical changes recorded at this temperature.

To evaluate at which temperature the concentrations of biochemical oxygen demand (BOD_7), nitrites (NO_2^-), nitrate nitrogen (NO_3-N), ammonium nitrogen (NH_4-N), total nitrogen (TN), and phosphate phosphorus (PO_4-P) were the highest, a statistical analysis was performed using the t-test. The concentrations of water quality indicators at different water temperatures are presented in Figure 8.

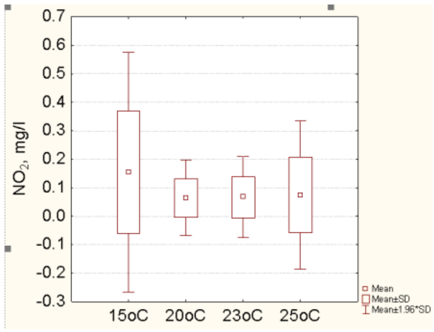
To assess at which temperature the total nitrogen concentrations were the highest, a statistical analysis was performed using the t-test. The results showed that the greatest changes were recorded at 20 °C, and the differences between 15 °C and 20 °C were statistically significant ($p < 0.05$). This confirms that this temperature is critical for nitrogen compound transformation. At temperatures up to 20 °C, nitrate nitrogen concentration increased significantly ($p < 0.05$) compared to 15 °C.

Further temperature increases (to 23–25 °C) also caused concentration fluctuations, but the most significant shift was observed at the 20 °C threshold.

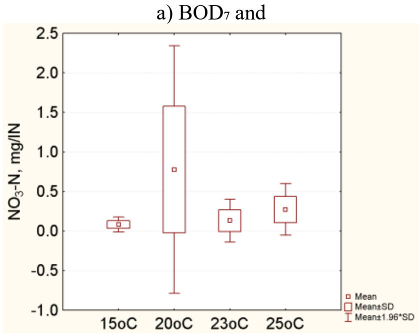
The obtained results are consistent with the findings of other authors. According to EPA (2024), a warming climate accelerates eutrophication, while Kaushal et al. (2023) emphasize that heat waves significantly deteriorate water quality. Copernicus Marine Service (2023) predicts that the surface water temperature of the Baltic Sea will continue to rise, further accelerating algal blooms and the expansion of “dead zones.” Thus, the future of the Baltic Sea ecosystem is closely dependent on the control of temperature changes and the reduction of nutrient loads.



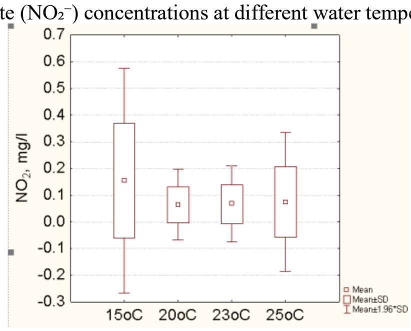
a) BOD_7 and



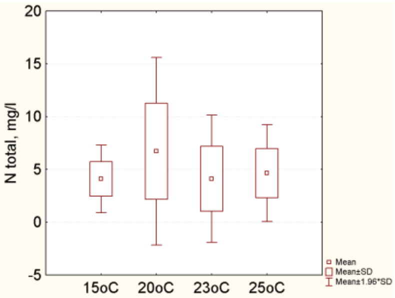
b) nitrite (NO_2^-) concentrations at different water temperatures



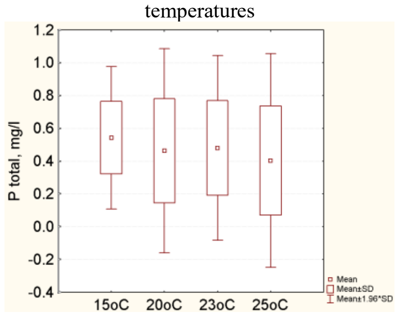
c) Nitrate nitrogen (NO_3-N)



d) ammonium nitrogen (NH_4-N) concentrations at different water temperatures



e) total nitrogen (TN)



f) total phosphorus (TP) concentrations at different water temperatures

Figure 8. Concentrations of water quality indicators at different water temperatures

CONCLUSIONS

1. It was established that changes in water temperature have a significant impact on the Baltic Sea quality indicators – nitrogen and phosphorus compounds as well as biochemical oxygen demand (BOD_7).
2. At a water temperature of 20 °C, the most pronounced changes in nitrogen and phosphorus concentrations and BOD_7 were recorded compared to lower temperatures.
3. Excess nutrients create favourable conditions for eutrophication and cyanobacterial blooms, which deteriorate the ecological status of the Baltic Sea.
4. Under climate change conditions, it is likely that water temperature will continue to rise; therefore, it is essential to reduce nutrient inputs into the Baltic Sea and strengthen international measures to manage this process.

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