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Diatom Responses to Palaeoenvironmental Changes in the South-Eastern Baltic Sea Region

DOCTORAL DISSERTATION

Natural Sciences,
Geology (N 005)

VILNIUS 2026

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VALSTYBINIS MOKSLINIŲ TYRIMŲ INSTITUTAS GAMTOS TYRIMŲ CENTRAS

Irina Sosnina

Titnagdumblių atsakas į paleoaplinkos pokyčius pietryčių Baltijos jūros regione

DAKTARO DISERTACIJA

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CONTENTS

LIST OF ABBREVIATIONS

^{14}C	–	radioactive isotope of carbon (carbon-14)
AD	–	Anno Domini (lat. in the year of the Lord), number years in the Julian and Gregorian calendars
AMS	–	accelerator mass spectrometry
BC	–	Before Christ, years before the estimated birth of Jesus Christ
b.s.l.	–	below sea level
BIL	–	Baltic Ice Lake
BP	–	years before present (counted from 1950)
cal yr BP	–	calibrated years before present (counted from 1950)
L1, L2, L3	–	first, second, and third transgressions of the Litorina Sea
LDAZ	–	local diatom assemblage zone
LOI	–	loss on ignition (method for determining sediment composition (%)
MS	–	magnetic susceptibility
OSL	–	optically stimulated luminescence
spp.	–	multiple species
sp.	–	a single unspecified species
var.	–	variety (taxonomic rank)
U1, U2, U3, U4	–	lithological units (distinguished by the author in the core sections)

INTRODUCTION

Research Problem

The Baltic Sea is one of the best-studied seas in Europe which is denoted by a complex evolutionary history during the Holocene, marked by several major developmental stages. Although the major stages of the Baltic Sea evolution have already been established, significant uncertainties remain regarding the nature and timing of transition between these stages, particularly across different parts of the basin.

One of the most debated issues concerns the timing and character of the Ancylus Lake – Litorina Sea transition. This transition was asynchronous across the Baltic Sea (Andrén et al., 2000; Kostecki et al., 2015), and its reconstruction is further complicated in some regions by intensified erosion, sediment redeposition, and glacio-isostatic land movements (Vaikutienė et al., 2025; Mojski, 2000). Additional unresolved questions include the pathways of saline water inflows into the Baltic Sea and the variability of salinity during the Litorina Sea stage (Björck, 1995; Rößler et al., 2011; Ning et al., 2017). Another important issue concerns the Holocene hydrological regime of the coastal lagoons. Recent studies in the south-eastern Baltic Sea suggest that the Curonian Lagoon has been isolated since the beginning of the Middle Holocene (8200 cal yr BP), with several episodic intrusions of Litorina Sea waters (Damušytė, 2011). However, uncertainties persist regarding how this affected water exchange, salinity gradients, and ecosystem functioning, as well as whether these changes occurred simultaneously in the southern and northern parts of the lagoon.

Addressing these problems requires a multidisciplinary approach, in which diatom analysis plays a crucial role. Diatoms are among the most informative palaeontological proxies which have been widely used in biostratigraphic and paleogeographic studies for decades (Denys & de Wolf, 2001). Because diatom assemblages respond sensitively to changes in salinity and water depth, their composition in sediment records can serve as a reliable indicator of relative water-level changes, seawater intrusions, and can distinguish between short- or long-term hydrological shifts during the Baltic Sea evolution.

Therefore, refining our understanding of the environmental evolution of the south-eastern Baltic coast, especially through high-resolution diatom-based reconstructions, remains essential for resolving questions on the Baltic Sea development and coastal dynamics.

Relevance of the Research

A new comprehensive reconstruction of three different types of coastal ecosystems contributes to a deeper understanding of the development of the south-eastern Baltic Sea region. Newly obtained data on the chronological framework and accumulation rates, combined with detailed analyses of diatom flora and sedimentological characteristics, enable a reliable reconstruction of past environmental conditions and shoreline fluctuations in the coastal paleobasins throughout the Holocene. Beyond their scientific relevance, these results have important practical applications and contribute to a better understanding of long-term coastal dynamics, which is essential for predicting further shoreline changes under the ongoing-sea-level rise and climate change. Such knowledge supports effective coastal management, informs nature conservation and restoration planning, and offers valuable data for estimating the anthropogenic and natural impacts on fragile lagoonal and wetland coastal ecosystems.

Main Objective and Tasks

The main objective of the present research project is to reconstruct the paleoenvironmental evolution of the SE Baltic during the Late Glacial-Holocene by integrating a multi-proxy approach with a focus on water-level fluctuations and climate-driven changes.

To achieve this objective, the following tasks have been undertaken:

- To analyse the sedimentary sequences of boreholes from different environments in order to clarify the peculiarities of deposition;
- To analyse diatom assemblages and infer shifts in the paleoenvironmental conditions;
- To integrate research findings into a regional paleoenvironmental framework;
- To correlate identified environmental settings with the Baltic Sea stages and global climate variations.

Statements to be Defended

1. Diatom assemblages can be indicators of the Baltic Ice Lake and Litorina Sea stages in the coastal waters' sediments of the SE Baltic

Sea, whereas the Yoldia Sea and Ancylus Lake stages are difficult to distinguish;

2. The diatom complex of the south-western part of the Curonian Lagoon developed in the isolated from the sea basin starting from the Middle Holocene;
3. The diatom flora in the Nemunas River delta was not affected by seawater intrusions due to the influence of the river's hydrological regime;
4. Diatom complexes in the SE Baltic Sea region demonstrate heterogeneity in different environmental conditions.

Novelty of the Research

In this thesis, the Holocene development of the south-eastern Baltic Sea region is interpreted with consideration of the local features of coastal facies, and it provides a new, complex diatom-based reconstruction of three ecosystems following the Last Deglaciation. In the south-western part of the Curonian Lagoon, diatom investigations were carried out for the first time. By combining diatom data with the stratigraphic context and absolute age, the research demonstrates the complex evolution of the coastal marine zone with minimal marine influence in both lagoon and deltaic ecosystem, even during the maximum Litorina Sea transgression, as well as the progressive isolation and eutrophication of the Curonian Lagoon throughout the Mid–Late Holocene. The results obtained complement the existing concept of south-eastern Baltic Sea region development following the Last Glacial Maximum.

Scientific Work Preparation

The research began in 2021 as a scientific project within the framework of my PhD study at the State Scientific Research Institute Nature Research Centre (hereafter – NRC) funded by the Republic of Lithuania. My understanding of the functioning of the Baltic Sea system was deepened during the INTIMATE-INQUA Summer School (Turku, Finland, September 2022). The methodology of diatom analysis was acquired under the supervision of Dr. Vaida Šeirienė, while the skills in taxonomic identification were improved through participation in international workshops: "*Staurosirella & Staurosira*" (Ohrid, North Macedonia, May 2024), the 7th Nordic Diatom Intercalibration (Norrtälje, Sweden, January 2024), and "*Revision of the European Brachysira Taxa*" (Meise Botanic Garden, Brussels, May 2023). During the study, the author examined diatom assemblages from the three sections, independently analysed 128 samples, and identified 424 taxa belonging to 95 genera.

Approbation of the Research

Since 2021, the results of the research have been presented with co-authors at five international and one national conferences. Two manuscripts with results of the research have also been published in peer-reviewed *ISI Web of Science* journals.

Structure and Content

The dissertation consists of an introduction, 6 chapters, conclusions, a list of references, 2 appendices, and a list of publications on the thesis subject. The thesis comprises 94 pages, 21 figures, and 7 tables.

1. BACKGROUND OF PALAEOGEOGRAPHICAL STUDIES IN THE SOUTH-EASTERN BALTIC

South-eastern Baltic paleoenvironmental research has been ongoing for over two centuries, initiated by German-Prussian scientists and geological surveys. Scholarly research begins with Gottlieb Berendt's monograph (1869), where he, as a pioneer, first summarised data on the geological structure of the Curonian Lagoon and its surrounding territory, while also providing the reconstruction of the main stages in the development of the territory. His work offers a classification of Quaternary deposits into alluvial and deluvial, as well as their ranking according to relative age. There are two important and needed to be mentioned, in my opinion, conclusions that Berendt suggested:

- a relatively young age of sandy dunes on the Curonian Spit and wetland deposits in the Nemunas River Delta;
- the aquatory (i.e., the water-covering territory) of the Curonian Lagoon is the eroded terrestrial territory that was later turned into the lagoon, and not the initial lagoon that was separated from the sea by alluvial sand.

In his monograph, he also presented his concept on the Curonian Lagoon development (Fig. 1).

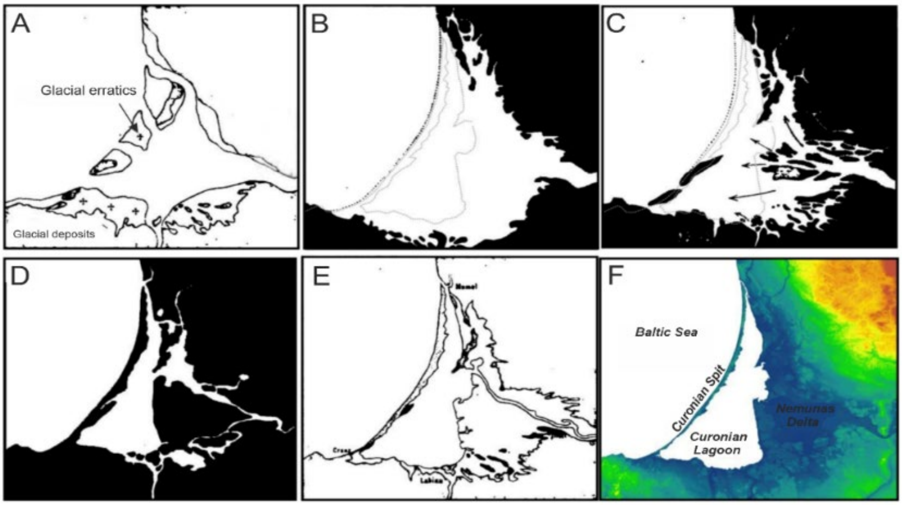


Fig. 1. G. Berendt's concept (1869) of the Curonian Lagoon and the Spit development, modified by A. Sergeev (2015).

1 pav. G. Berendto (1869) Kuršių marių ir Kuršių nerijos raidos koncepcija, modifikuota pagal A. Sergejevą (2015)

Later, Alexander Tornquist (1910) described in detail the geological structure of the Sambian Peninsula and first suggested the concept of along-coast sediment transport. He determined the direction of main sediment transport inflow from the Gdansk Deep, along the Sambian coast to the Curonian Spit and figured out the erosion and accumulation zones of the south-eastern coast. Geological investigations continued by Hans Hess von Wichdorf (1919), who suggested descriptions of the Sambian Peninsula, the Curonian Spit, the Curonian Lagoon, and the Nemunas River Delta, together with a geological map of the south-eastern Baltic coast. Most of the researchers concentrated on the study of the Curonian Spit genesis, morphology and evolution (von Wichdorf, 1919; Andrée, 1932; Beurlen, 1933; Pratje, 1935, 1948)

I would also like to pay attention to the earliest research that used a biostratigraphical approach. W. Benrath (1934) in his work attempted a geochronological classification using fossil plants from the biogenic post-glacial sediments to construct a scheme of the pollen flora on material taken from the Schwendlund bog (now known as Svinoe) and the south-western part of the Curonian Lagoon. Although W. Benrath's work does not include diatom diagrams, the main species found in the sediments of the Schwendlund bog were described, and a taxonomic list of species characterising the transgressions of the Litorina Sea in the southern part of the Curonian Lagoon was provided.

Systematic geological, geomorphological and palaeobotanical investigations of this area started only in the second half of the twentieth century. They are related to the names of Lithuanian scientists V. Gudelis (1959), R. Kunskas (1970), and M. Kabailienė (1967), who were the first to suggest the original concepts of the development of the southeastern coastal complex. This period in the research work is also important, as it is when researchers began to consider neotectonic changes and glacioisostatic uplift.

V. Gudelis (1959) was one of the earliest Lithuanian researchers who created a comprehensive model explaining the paleogeographical evolution of the southeastern Baltic coastal zone, including the area currently occupied by the lagoon and the spit. His hypothesis outlined three principal development stages: 1. Proglacial and glacial lakes; 2. Coastal freshwater lake; and 3. Development of the Curonian Lagoon. V. Gudelis (1959) suggested that, during the Litorina Sea stage (7500–6500 yr BC), a freshwater coastal lake existed in the southern part of the present-day lagoon. Later, around 5300 yr BC, a marine bay formed in its northern part as sea water intrusions breached the coastal zone. This bay was separated from the coastal lake by a moraine ridge, stretching along the central part to the cape of Ventė (Ventės Ragas, Fig. 2).

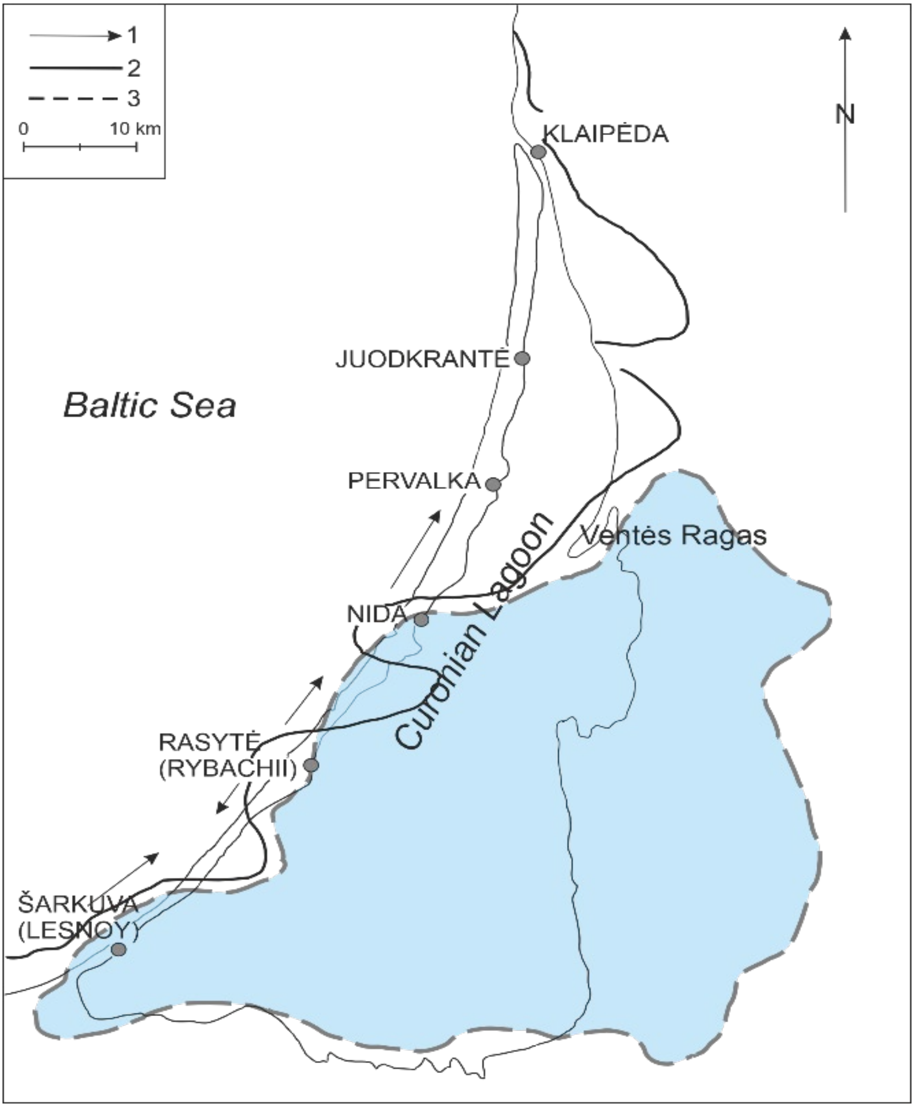


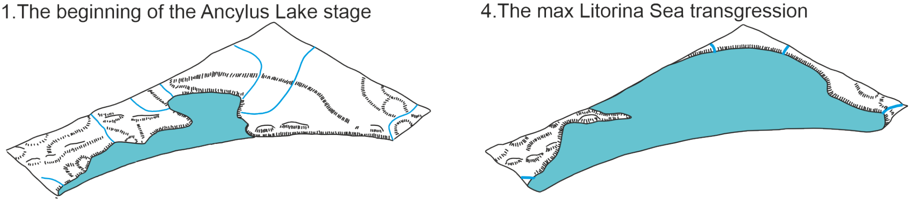
Fig. 2. Paleogeographic reconstruction of SE Baltic coast after V. Gudelis (1959), as modified by the author of this thesis. 1 – sediment transportation; 2 – coastline of the Litorina Sea; 3 – proposed site occupied by the coastal lake in the Boreal and Atlantic period.

2 pav. Pietryčių Baltijos pakrantės paleogeografinė rekonstrukcija pagal V. Gudelį (1959), modifikuota autorės. 1 – nuogulų pernaša; 2 – Litorinos jūros kranto linija; 3 – pakrantės ežero užimta teritorija borealinio ir atlantinio laikotarpio metu

In the second half of the Litorina Sea stage, the combined effects of glacioisostatic uplift and neotectonic activity caused a sea regression and a northward shift of the paleo-Nemunas River mouth. Around 4500–4000 yr BC, this process facilitated the degradation of the morainic ridge and the merging of the previously separated lake and bay into one basin. According to V. Gudelis (1959), the newly formed lagoon was gradually separated from the sea by the Curonian Spit formation, which extended along the entire length of the lagoon. In terms of genesis, he conceptualised the spit as a three-part geomorphological structure: the southern segment, interpreted as the eroded prolongation of the Sambian Peninsula; the central segment, described as a marine-accumulative sandbar; and the northern segment, considered as an aeolian-accumulative body (Gudelis, 1959).

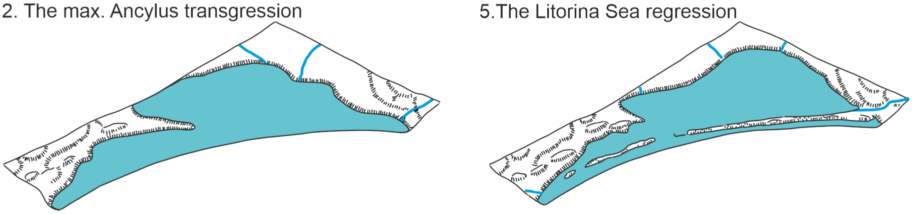
Beyond coastal morphology, the research by Gudelis addressed issues of neotectonics, as well as the shifting location of ancient coastlines. V. Gudelis published one of the detailed sedimentological schemes of the Curonian Lagoon bottom. These results challenged earlier assumptions of uniform coastal development and emphasised the role of localised tectonic activity and sediment supply in shaping the region. Moreover, these findings laid the groundwork for later studies focused on sediment dynamics and paleoenvironmental changes.

In her study on the development of the Curonian Lagoon and Spit, M. Kabailienė (1967) applied diatom analysis to Baltic coastal-lagoon sediments for the first time. Her work yielded extensive data on diatom assemblages from multiple locations, including the northern part of the lagoon, boreholes along the Curonian Spit, and the southern shore of the lagoon. Importantly, she was the first scientist to describe specific diatom complexes related to the Baltic Sea stages. To establish the relative chronology of depositional sequences, M. Kabailienė (1967) also employed spore-pollen analysis, which provided insights into the age of sediments and the vegetation landscape during different stages of south-eastern Baltic development.



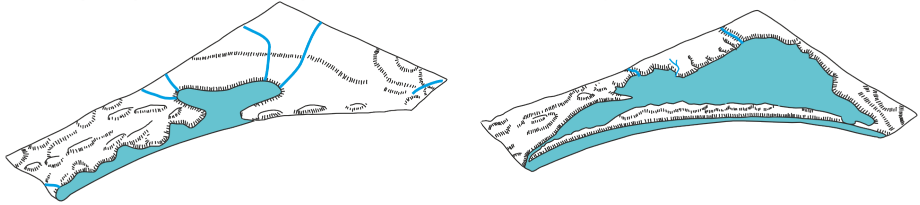
1.The beginning of the Ancylus Lake stage

4.The max Litorina Sea transgression



2. The max. Ancylus transgression

5.The Litorina Sea regression



3.The beginning of the Litorina stage

6. Present stage of the Curonian Lagoon

Fig. 3. Scheme of the Curonian Spit and the Curonian Lagoon development according to M. Kabailienė, 1967.

3 pav. Kuršių nerijos ir Kuršių marių raidos schema pagal M. Kabailienę (1967)

M. Kabailienė (1967) placed the initiation of the Curonian Spit's formation after the second transgression of the Litorina Sea (second half of the Atlantic period). She emphasised that the northern and southern segments of the spit developed under different conditions (Fig. 4). While, in the southern segment, a sandy ridge had already formed, resulting from the infilling of depressions in the moraine topography with sediments derived from ancient water bodies, in the northern segment, a chain of islands with palaeochannels still existed. According to M. Kabailienė (1967), the final formation of both the Curonian Spit and the semi-closed lagoon was completed in the second half of the Subatlantic period, when these geomorphic elements achieved a configuration close to that of the present day.

R. Kunskas (1970) made a significant contribution to the understanding of the Holocene evolution of the Nemunas River delta. On the grounds of drawing data from approximately 100 boreholes, as well as geological drilling records and palynological data, R. Kunskas reconstructed the main stages of delta development (Fig. 3). He identified the environmental factors influencing the formation of the coastal wetland complex in the estuary. In his research, R. Kunskas emphasised that the formation of the Curonian Spit during the first half of the Middle Holocene was not only the result of moraine abrasion and coastal sediment transport, but also an additional role was played by sediment inflow from the Nemunas River delta. Throughout the Middle Holocene, the delta was characterised by a chain of islands and delta front bars, which acted as a morphological basis for the later development of the Curonian Spit. These features provided natural barriers and sediment traps, facilitating the progressive isolation of the lagoon. By the Late Holocene, the consolidation of these geomorphic elements, together with continued marine and aeolian processes, led to the formation of the Curonian Spit in a configuration similar to its current form, but still featuring several straits that allowed exchange between the lagoon and the Baltic Sea (Kunskas, 1970).

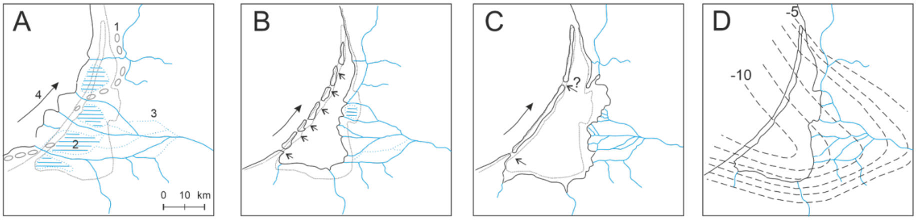


Fig. 4. A – the Nemunas River delta in the period between L1 and L2 transgressions (6000–5000 yr BC); B – delta after the Limnea transgression (1500 yr BC); C – delta in the period of the second Baltic transgression (1000 yr AD); D – tectonic lowering of the delta.
1 – morainic ridge; 2 – coastal lagoons; 3 – channels; 4 – nearshore current. After R. Kunskas (1970), modified by the author of this thesis.
4 pav. A – Nemuno delta laikotarpiu tarp L1 ir L2 transgresijų (6000–5000 m. pr. Kr.); B – delta po Limnėjos transgresijos (1500 m. pr. Kr.); C – delta antrosios Baltijos transgresijos laikotarpiu (1000 m. po Kr.); D – deltos tektoninis nusėdimas.
1 – moreninis gūbrys; 2 – pakrantės lagūnos; 3 – protakos; 4 – priekrantinė srovė. Pagal R. Kunską (1970), modifikuota autorės.

Research investigations into the development of the coastal area were conducted not only in the Curonian Lagoon, but also in the offshore zone. The materials from marine expeditions formed the basis of A. Blazhchishin's (1998) concept of the palaeogeographical development of the south-eastern Baltic coastal area.

In his monograph, A. Blazhchishin devoted substantial attention to the lithostratigraphical facies and palaeogeographical development of the Baltic Sea, and particularly such issues as seismostratigraphy, lithostratigraphy and geochemistry of the Late Pleistocene and Holocene Baltic sediments. Through detailed sedimentological and geomorphological analyses of sediment cores obtained from the coastal zone of the Sambian Peninsula, he reconstructed the depositional environments and shoreline displacements over the Holocene (Blazhchishin, 1998). A. Blazhchishin (1998) proposed that, during the transgression of the early Ancylus Lake stage, there existed two sandbars, connected to abrasion terraces (Sambian Peninsula and Rybachy Plateau). These features likely played an important role in modifying the local hydrodynamics, influencing the transport and depositional patterns in the coastal zone. His work also provided one of the earliest maps of the coastline associated with successive stages of the Baltic Sea, including three Litorina Sea transgressions.

In addition to stratigraphic observations, A. Blazhchishin incorporated radiocarbon dates and results of micropaleontological analysis into his reconstructions. Two uncalibrated radiocarbon ages obtained from coastal terraces were used to establish a preliminary period of shoreline development. Furthermore, diatom analysis carried out by N. Davydova (1974), on sediments from the Yoldia Sea stage, revealed the dominance of a freshwater diatom assemblage, indicative of a shallow, macrophyte-rich basin. This finding provided important palaeoecological evidence for the nature of the Yoldia Sea aquatic environments in the SE Baltic Sea region. A more detailed description of the diatom flora for this area was presented in the early publications (Blazhchishin et al., 1974; Davydova et al., 1967; Davydova et al., 1970; Davydova, 1974). Blazhchishin's integration of geomorphological mapping, sedimentological profiles and microfossil evidence offered a multi-proxy approach to the reconstruction of the Holocene landscapes of the southeastern Baltic, significantly advancing the understanding of coastal evolution.

J. Lavrushin (1993) proposed a version about the possible glaciotectonic nature of the formation of the Curonian Spit. According to his concept, the base of the spit could have been pushed out under the influence of the glacier at the very end of the Last Glacial. This happens at the junction between the melting ice mass located in the area now occupied by the Curonian Lagoon and the still-active moving ice sheet in the modern Baltic Sea depression.

At the same time, diatom analysis became one of the major tools to detect local shifts from freshwater to brackish conditions (Ancylus Lake – Litorina Sea transition) and reconstruct Holocene palaeoenvironments along the Lithuanian coast and in lagoonal basins.

J. Kasperovičienė (1990) made an important contribution to the study of diatoms in Lithuanian aquatic systems, particularly through her investigations of the Curonian Lagoon and inner lakes. Her research concentrated on the analysis of planktonic and surface-sediment diatom assemblages, which provided important insights into the ecological status and spatial variability of the basins. By documenting the dominant diatom taxa and their relation to salinity gradients, nutrient enrichment, and seasonal variability, she established indicator species that are now widely applied in environmental monitoring and water-quality assessment (Snoeijs & Kasperovičienė, 1996). J. Kasperovičienė's work also revealed how eutrophication and anthropogenic pressure are reflected in the composition of diatom assemblages, thereby offering a valuable baseline for detecting long-term ecological trends.

At the modern stage of research work into the south-eastern Baltic coast evolution, a considerable contribution has been made by researchers from the Lithuanian Geological Survey, Vilnius University, Institute of Geology and Geography of the Nature Research Centre, and Klaipeda University. In its development starting with the 19th century, the research approach gradually changed, and, along with multi-proxy studies, high-resolution analysis of the material was used.

D. Ūsaitytė (2001) contributed to the biostratigraphy of the Late Quaternary sediments from the SE Baltic offshore area based on radiocarbon dates, diatom analyses, and pollen results. In her work, she combined palaeobotanical investigations with numerical analyses and enabled to make biostratigraphical correlations that can be used across the region. She also concluded that sediment lithology and composition of pollen spectra can be different but still follow the general trends and main features of postglacial history.

Changes in paleogeographical conditions of the Baltic Sea during the Late Glacial-Holocene have been extensively studied through diatom analysis, with contributions being made by G. Vaikutienė (Vaikutienė, 2003; Trimonis et al., 2008; Kabailienė et al., 2009; Emelyanov & Vaikutienė, 2013; Kaminskas et al., 2019; Vaikutienė et al., 2025). Her research focused on correlation diatom assemblages from the central and south-eastern Baltic, marking clear differences in species composition that correspond to major stages of the Baltic Sea's development. In particular, she described characteristic diatom taxa for Baltic Ice Lake, Ancylus Lake, Yoldia Sea, and Litorina Sea, thereby establishing biostratigraphic complexes for identifying these stages in sediment records. G. Vaikutienė (2003) concluded that the Yoldia Sea stage in the western part of the basin was dominated by, mostly, a freshwater diatom complex, reflecting limited marine influence at that time.

Beyond deep water-sediments reconstructions, her work on surface-sediment diatom assemblages in the Curonian Lagoon has been especially valuable in establishing the drivers of diatom composition dynamic. These studies revealed that, in addition to sea fluctuations, factors such as the hydrological regime, nutrient load, and local geomorphological settings strongly influence diatoms (Vaikutienė, 2003; Kasperovičienė & Vaikutienė, 2007; Trimonis et al., 2010). Together, these findings underscore the importance of fossil and modern diatom studies.

The significant research work was conducted by a group of scientists under the large-scale mapping project of the Lithuanian Coast region (Bitinas et al., 1997; 2000; 2004). In the course of the project, different geological aspects were investigated that turned into some vulnerable discoveries but also revealed some limitations of the palaeogeographical investigations in the Lithuanian coast zone.

With application of various dating techniques and experimental ^{14}C dating of modern live molluscs' water biocarbonates, the uncertainty of the reservoir effect in the Curonian Lagoon was discovered (influx of 'old' carbonates into the Curonian Lagoon), which added an error margin to the dating results. The study figured that even the dating of mollusc shells might have resulted in younger ages than expected (by a few thousand years). These findings reveal the necessity of applying the local reservoir correction for the Curonian Lagoon and the Nemunas River delta area (Bitinas et al., 2001). However, it also shows that, for the *Baltic Ice Lake* (BIL) sediments, the OSL age overestimation could be an indicator of the deposit genesis.

A few challengeable conclusions were made during the reinvestigation of the Nemunas River delta by using a multi-proxy approach (Bitinas et al., 2002). Following the regression of Ancylus Lake, the northern part of the delta was occupied by isolated basins and peat-forming bogs. After the Litorina Sea regression at around 6000 BC, the Minija River changed its course, which was interpreted as evidence of glacioisostatic rebound. The timing of the Post-Litorina Sea transgression was estimated at approximately 4000 BC. The authors also suggested that the formation of the northern part of the Nemunas River delta began at around AD 1000. These conclusions proved some early findings and, at the time, raised new scientific questions.

Further investigations allow for correcting the Lithuanian coast development data during the Litorina Sea stage. Complex analysis revealed 3 transgressions and regressions during the Litorina Sea stage and two Post-Litorina transgressions, with more accurate time and relative sea levels. It also revealed that the neotectonic movements significantly complicate the eustatic curves for the Lithuanian coast. The position of the Litorina Sea coastline was found at varying altitudes in different parts of the coast (Bitinas & Damušytė, 2004).

In addition to onshore research, the offshore landscapes were mapped, and their geomorphology was studied. Through the integration of coastal morphology, geophysical profiles and absolute dating, L. Ž. Gelumbauskaitė (2009) developed a spatial model of relative sea-level changes along the Lithuanian coast and made a great contribution to the study of geomorphology and submerged ancient shore formations of the south-eastern Baltic Sea. Her data reveal a pronounced diachrony in the timing of stage boundaries and fluctuations across the region. It is particularly marked in the discrepancies between the shorelines of the Litorina Sea transgressions, which is a key reference for explaining the Baltic Sea evolution. Analysis of shoreline hypsometry displayed that considerable tilting of ancient shorelines, attributable to glacioisostatic rebound, persisted until the Ancylus Lake stage. Subsequent deformation patterns affecting the Ancylus-Litorina shoreline levels were interpreted as a combined effect of tectonics and eustatic factors, suggesting that postglacial uplift interacted with the global sea-level fluctuations, leading to the observed morphometric variability (Gelumbauskaitė & Šečkus, 2005).

Later, she investigated the Palaeo-Nemunas River Delta using hydroacoustic survey instruments supplemented with grain size compositions of the bottom sediments that allow tracking the change of environment from lagoon-deltaic to marine. She concluded that the palaeo-Nemunas River delta formation began in the Preboreal time and finished during the Boreal period. Importantly, the grain size composition of the deposits on the subsurface top showed no modern marine accumulation at the delta region (Gelumbauskaitė, 2010).

The PhD research of J. Šečkus (2009) focuses on Lithuanian coastal and offshore areas by using a four-dimensional (4D) geological model that integrates spatial and temporal data to reconstruct postglacial coastal changes and predict future developments. By modelling the sickness of marine and lacustrine sediments and analysing isostatic and tectonic processes, J. Šečkus provided a clearer picture of how the Baltic Sea evolved during the Yoldia Sea, Ancylus Lake, Litorina Sea, and Post-Litorina Sea stages. His research outlines the stepwise formation of the Curonian Spit and highlights the asynchronous nature of sea-level changes along the Lithuanian coast, with the southern and northern sections experiencing different transgression-regression dynamics from the Litorina Sea stage onward.

A major work focused on the palaeogeographical evolution of the Lithuanian coast and the formation of a barrier-spit system in response to the Holocene sea-level fluctuations was carried out by A. Damušytė (2011) and outlined in her doctoral thesis. Her research incorporated new absolute dating results and detailed analysis of subfossil mollusc assemblages, which provided a valuable palaeoenvironment indicator. Importantly, her reconstructions accounted for both glacioisostatic uplift affecting different segments of the Lithuanian coast during the Late Glacial and Holocene and neotectonic movements of crystalline basement blocks. This enabled her to present a spatially differentiated model of water-level fluctuations, with separate reconstructions for the northern, central and southern parts of the Lithuanian coastal region. In her work, A. Damušytė identified and differentiated eight distinct sedimentary palaeoenvironments, each associated with transgressive or regressive phases of the Baltic Sea evolution. These units reflect changes in depositional settings that can be traced in the Litorina Sea sequences, allowing a more nuanced understanding of the transgression-regression pattern across the region. On the results of her robust analysis, she proposed three clear Litorina Sea transgressions: L1: 8300–8000 cal yr BP, L2: 7500–7000 cal yr BP, and L3: 4700–4100 cal yr BP, which were supported by radiocarbon chronologies as well as stratigraphic sequences from coastal and lagoon archives.

In contrast, she highlighted inconsistencies in data concerning the Ancylus Lake shoreline, thereby suggesting that the interpretations of this stage remain problematic for the Lithuanian coast.

According to her conclusions, the initial spit development began no later than 8500–8300 cal yr BP, during the Ancylus Lake transgression or the onset of the first Litorina Sea transgression. The key geological and geomorphological characteristics of the modern spit (i.e., its current orientation and internal structure) formed later, at around 6900–6300 cal yr BP, after the second and maximal Litorina Sea transgression.

Meanwhile, A. Sergeev’s (2015) thesis proposes a comprehensive geological spatio-temporal model for the evolution of the southeastern Baltic coast, including the southern part of the Curonian Spit, lagoon, and the adjacent sea. His reconstruction spans multiple stages of the palaeowater body’s development and includes a detailed analysis of the paleorelief dynamic.

A key focus of his research is the Litorina Sea stage with its crucial role in shaping the modern Baltic coastline. He postulates the existence of a broad bay between the original coastline of the Sambian Peninsula and the Rybachy

Plateau and the seawater intrusions into the paleovalley of the Nemunas River, influencing the regional lithodynamic regime and the nature of the deposited material. At the beginning of the Middle Holocene, marine transgression facilitated the accumulation of the lagoonal deposits on the southern and eastern coasts of the Curonian Lagoon.

At around 7500 BC, A. Sergeev identified the beginning of paleosandbar formation northwest of the present-day Curonian Spit and gradually prograded eastward, marking the initial stage of spit development. Aeolian processes and an inflow of abrasive material played a major role in the further progradation and inland migration of the sandy barrier system. A. Sergeev also described the genesis and diapiric deformation of relict lagoonal deposits.

A significant transgressive phase of 4500 BC led to the flooding of an elevated terrain within the lagoon area, triggering renewed peat formation on the submerged hills. This event underscores the importance of sea-level oscillations in driving local palaeoecological shifts and the complex type of interactions between the rising sea level and the local hydrography.

A. Sergeev notes that, in the Late Holocene, the coastal evolution was being increasingly shaped by the eustatic sea-level rise of the World Ocean. This long-term sea-level increase intensified abrasion processes along the southeastern Baltic coast, contributing to the active coast erosion and sand reworking into the modern Curonian Spit. A. Sergeev's thesis provides detailed palaeogeographic and geomorphological studies, which still remains a critical reference for understanding the evolution of the southern Curonian Spit-lagoon system.

Similar studies on palaeoenvironmental changes along the south-eastern Baltic coast have been carried out in neighbouring countries around the Baltic Sea. Investigations conducted in Poland, Latvia, and Estonia provide valuable comparative material, as they address the same questions of shoreline displacement, salinity fluctuations and lagoonal development during the Late Glacial and Holocene periods.

Among the Polish researchers, S. Uścinowicz (2006) extensively investigated Holocene-sea-level changes and the development of the Polish coast of the Baltic Sea, by using a combination of lithostratigraphy and geochronology with the objective to identify successive marine and brackish phases (Uścinowicz, 2006). A. Witkowski (2000), who is widely renowned for his taxonomic expertise, advanced diatom biostratigraphy of the Baltic Sea coastal area, by providing detailed species-level identification that strengthened reconstructions of salinity and hydrological fluctuations

(Witkowski, 2000). Collectively, Polish studies emphasise the use of diatoms as precise indicators of sea-level changes, sedimentation dynamics, and anthropogenic impacts.

Whereas, in Latvia, palaeogeographical studies have been central to understanding the Holocene history of the Gulf of Riga and the Latvian Baltic Sea coast. I. Grudzinska (2015) has contributed significantly through her research on diatom assemblages in lagoonal sediments, by linking shifts in diatom flora to sea-level fluctuations and changes in the water exchange between the Baltic Sea and the local basins (Grudzinska, 2015; Rosentau et al., 2023).

Estonian researchers have also made important advances. A. Rosentau with his colleagues combined geological, geodetic and archaeological shore displacement evidence to create a temporal and spatial water-level change model for the SW Estonian coast of the Baltic Sea since the Early Holocene (Rosentau et al., 2011). By applying diatom analysis to Estonian coastal lakes and lagoonal deposits, A. Heinsalu has helped clarify the environmental impact and timing of the Baltic Sea transgressions during the Holocene (Heinsalu, 2000).

2. DIATOMS AS A RELIABLE PROXY FOR PALEOENVIRONMENTAL RECONSTRUCTIONS

Diatoms are microscopic organisms classified as algae (Division Bacillariophyta, Class Bacillariophyceae) which are characterised by siliceous cell walls and the unique microstructure of their frustules (Fig. 5). In general, there are two valves: the upper valve is named the *epivalve*, and the lower valve is the *hypovalve*. These are attached to each other by *girdle bands* and form a *frustule*. Most diatoms are solitary, but some taxa form colonies.

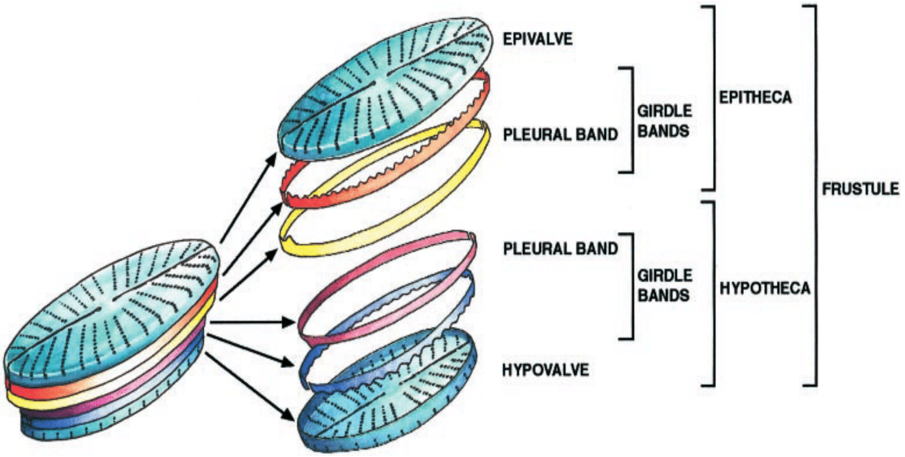


Fig. 5. Schematic overview of the siliceous components of diatom structure. Drawing by Ian Nettleton from Zurzolo & Bowler, 2001

5 pav. Titnaginių dumblių šarvelio struktūtros schema. Ian Nettleton piešinys (Zurzolo & Bowler, 2001)

The first diatom genus was described in 1771 (*Bacillaria* Gmelin). Thereafter, taxonomic studies progressed rapidly with more sophisticated equipment (Round et al., 1990). Taxonomic identification of diatoms is based on the shape, fine structure, and size of the valves, which are investigated under a light microscope by using different magnifications and phase contrast. It requires an understanding of the basic morphology of the cells, that has been described in detail in several publications (Battarbee et al., 2001; Lange-Bertalot et al., 2017). Under the microscope, the diatoms can be observed from two perspectives: *valve view* or *girdle view*. Diatoms lying in valve view are easier to identify, as all taxonomic features are visible, whereas, in girdle view, only the general shape and girdle bands are usually observable.

Later, at the turn of the nineteenth and twentieth centuries, it was observed that each taxon has a specifically defined ecological optima and responds differently to environmental shifts (Smol & Stoermer, 2010). This naturally placed diatoms as indicators of water quality (de Wolf, 1982; van Dam et al., 1994). Furthermore, as diatom siliceous valves are practically unaffected by diagenetic processes and are well preserved as fossils in bottom sediments, their potential as a proxy in palaeoenvironmental studies was recognised (Denys, 1991; Vos & de Wolf, 1993).

Diatoms inhabit almost all aquatic environments worldwide, while occurring in both planktonic and benthic zones. Most species are characteristic of one habitat or the other, although some can occur in both. Planktonic taxa spend the entire life cycle in the water column, although some spend part of their life cycle on the sediments (meroplankton). Tychoplankton (e.g., pseudoplankton) live in the benthos but can occasionally be found in the water column.

A benthic lifestyle is related to the substrate, and the abundance of benthic diatoms is limited by both the ability of suitable substrates and the depth to which light can penetrate. Depending on the substrate, benthic habitats include epilithon (stones), epiphyton (aquatic plants), epipsammon (sand grains), and epipelon (muddy sediments). Fixed stones allow the development of long-term, complex diatom communities, while aquatic plants provide a substrate only during the warm season and die in winter, thereby restricting the life period and diversity of diatom assemblages. Epipsammon usually consists of small taxa that can survive dark, anoxic and, on the other hand, dynamic environments. Epipelon includes taxa adapted to low light conditions.

From a palaeoecological perspective, the key feature of diatoms is their ability to identify important chemical and physical parameters governing diatom assemblages in past aquatic environments through the analysis of fossil assemblages from the sediment record. These parameters include temperature, pH value, salinity, light, turbulence, nutrients, water-level fluctuations, and oxygenation.

Temperature influences the diatom life cycle and population growth and can shift the dominant taxa seasonally (e.g., during spring blooms). Although temperature is not straightforward to reconstruct from diatom assemblages alone, long-term trends, such as the Holocene Thermal Maximum, may be identified when combined with other proxies and regional climate records. Studies from the Baltic region have linked temperature variability to community shifts over timescales ranging from millennia to centuries (Virta & Soininen, 2017; Bolius et al., 2025).

Past *pH* values can be reconstructed by using diatoms because many taxa exhibit well-defined pH optima. Diatom-inferred pH models are well established and can complement other proxies ($CaCO_3$, LOI) in palaeoreconstructions. In coastal and lagoonal systems, pH is less variable than salinity but still influences the species composition indirectly through carbonate precipitation and nutrient cycling (Birks et al., 1990).

Salinity is a major environmental factor structuring diatom communities, particularly in brackish and coastal waters (Ulanova & Snoeijs, 2006). Many diatom taxa have distinct salinity preferences; therefore, changes in salinity lead to predictable shifts in diatom assemblages. In coastal lagoons, the salinity signal may be muted by natural barriers (spits, extensive estuarine systems), and diatom assemblages therefore often show gradual shifts rather than abrupt marine invasions (Vaikutienė, 2002).

Light availability controls photosynthesis and therefore influences diatom productivity and community composition, while also determining the depth distribution of benthic diatom communities. Increased turbidity reduces the euphotic depth, creating favourable conditions for the growth of low-light tolerant taxa (e.g., benthic epipsammic diatoms) on the sediment surface. In basins, episodic sediment inflow or enhanced autochthonous productivity can rapidly reduce water transparency and alter the benthic-planktonic balance. Nevertheless, light can only be reconstructed indirectly from sediment records (Saulnier-Talbot et al., 2003).

The hydrodynamic regime (mixing, turbulence, water depth) determines whether a site is occupied by benthic/epiphytic or planktonic taxa. Well-mixed, turbulent conditions or deep waters are suitable for the heavier tychoplanktonic *Aulacoseira*, while long-term stable, stratified waters (i.e., reduced water-column mixing) favour planktonic, small-celled *Cyclotella* (Rühland et al., 2015). Low-energy, vegetated margins are suitable for epiphytic *Pseudostaurosira* and *Staurosira* species. In particular, in semi-closed Baltic lagoons, variations in wind forcing, barrier formation, marine intrusions, and freshwater river discharge can influence the hydrodynamic regime. This is reflected in shifts between benthic-dominated and planktonic-dominated assemblages, producing local 'transgressive' signals in the sediment record.

Habitat. The species composition of benthic (including epiphytic) diatoms depends on different types of the substrate: epipsammic taxa colonise sand, epilithic taxa colonise stones, etc. Changes in substrate availability, driven by hydrological or climatic factors, can cause shifts in diatom communities. For example, an increase in epipsammic *Staurosirella martyi* is a classic signal of silty-sandy littoral habitats, whereas the expansion of submerged macrophytes promotes the growth of epiphytic diatoms from the genera *Fragilaria* and *Staurosira*. In coastal zones and lagoons, substrate heterogeneity is a key control on benthic diversity. Several Baltic studies explicitly demonstrate habitat preferences and show predictable shifts when substrate conditions change (Hetko et al., 2022).

Redox/oxygenation. Bottom-water oxygenation and sediment redox conditions influence benthic complexes and the preservation of frustules. Anoxic or sulfidic conditions can cause the selective dissolution of some diatom frustules while promoting the preservation of more heavily silicified taxa. Diatom assemblages in anoxic bottom waters often show a trend towards taxa that tolerate low oxygen levels or exhibit low absolute valve concentrations.

Nutrients. Nutrient availability controls the primary productivity of diatoms. Increases in phosphorus, together with nitrogen, tend to boost taxa such as *Aulacoseira* or *Stephanodiscus* and can change the balance between benthic and planktonic communities by promoting planktonic blooms. In coastal Baltic areas, nutrient enrichment from rivers, land use, or eutrophication is a major driver of diatom community change, and it often explains planktonic peaks in the Late Holocene records. HELCOM and multiple Baltic studies document eutrophication impacts and link them to taxonomic shifts in diatom assemblages (HELCOM, 2009; Norbäck Ivarsson et al., 2019).

Data on diatom assemblage composition and taxon abundance allow the reconstruction of specific environmental conditions. However, not all diatom species are preserved equally. Valve thickness (silicification), pH values, and post-depositional transport influence which taxa are recorded in sediments. Therefore, low diatom concentrations or selective losses may reflect taphonomic processes rather than the true ecological absence. Comparative studies emphasise that any interpretation of low-count horizons requires caution and cross-checking with LOI, sediment composition, and valve preservation metrics.

Diatoms were chosen as the main indicators of paleoenvironment in this dissertation due to their ecological specificity, excellent frustule preservation, and ability to complement sedimentological and geochemical data. In the context of the south-eastern Baltic Sea region, diatom analysis provides an opportunity to identify both regional Holocene events and local ecosystem transformations.

3. MATERIALS AND METHODS

3.1. Study Area and Key Sites

The study investigates the coastal complex of the south-eastern Baltic Sea, by focusing on three key sites selected to clarify the unresolved questions concerning the environmental and sedimentological evolution of the Baltic Sea during the stages of its development. The selected locations encompass different geomorphological and hydrological settings: the marine coast adjacent to the Curonian Spit, the Curonian Lagoon, and the mouth of the Nemunas River (Fig. 6).

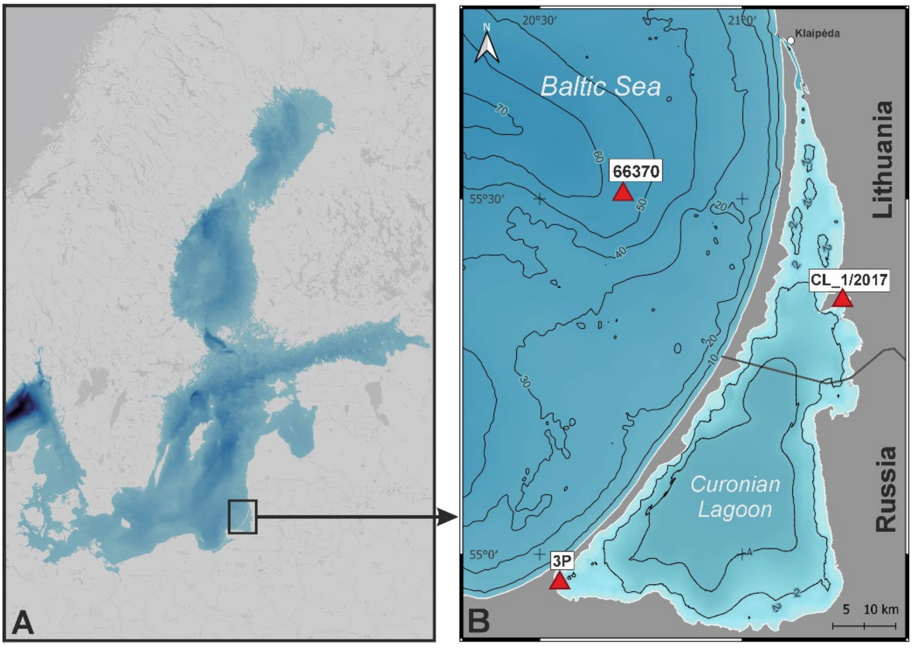


Fig. 6. Location of the study area and boreholes (marked as red triangles).
6 pav. Tyrimų plotas ir gręžinių vietos (raudoni trikampiai)

The **first study site**, where core **66370** was retrieved, is situated in the southernmost part of the Lithuanian economic zone and territorial waters (Fig. 6). The seafloor topography of the region exhibits a complex morphology with water depths varying from -16 m in the nearshore to -65 m in the offshore area. The northern part encompasses the elongated Pra-Nemunas Valley (Blazhchishin, 1998), also known as the Palaeo-Nemunas Delta (Gelumbauskaitė, 2010), along with the eastern slope of the Gdansk

Depression, while the Curonian-Sambian Plateau extends across the eastern and southern parts of the study area (Gelumbauskaitė, 1986) (Fig. 7).

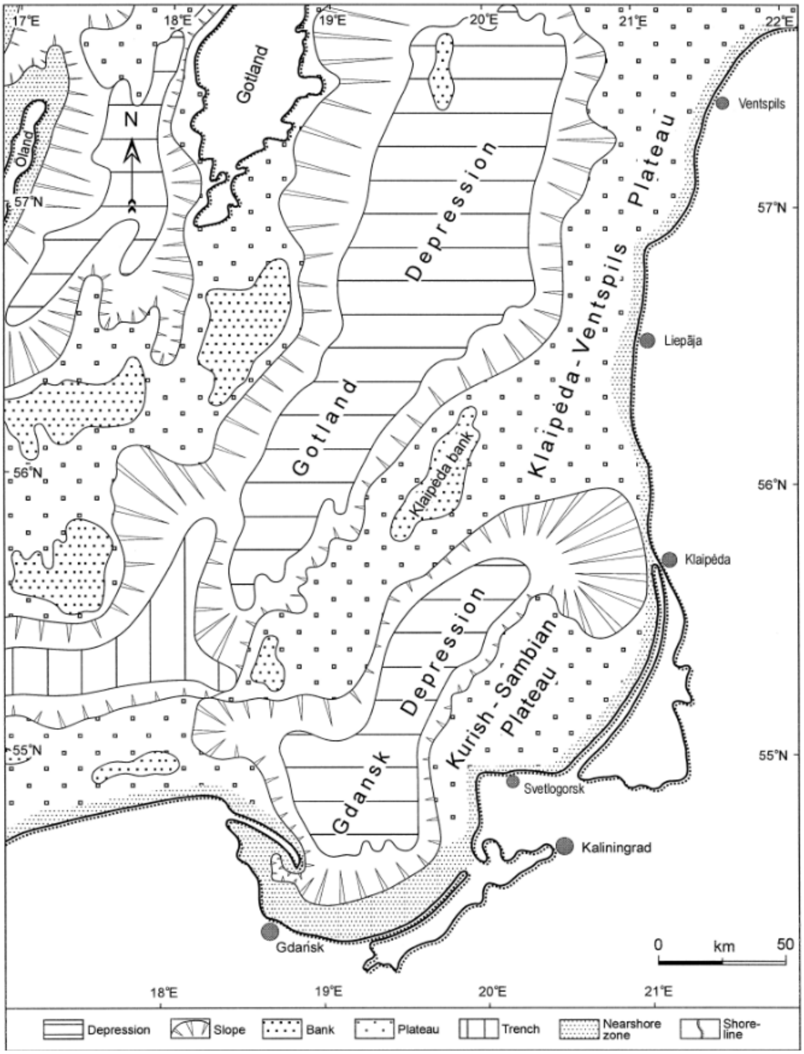


Fig. 7. Geomorphological structure of the SE Baltic Sea, after L. Ž. Gelumbauskaitė (1991), modified by D. Ūsaitytė (2001).
7 pav. Pietryčių Baltijos jūros geomorfologinė sandara pagal L. Ž. Gelumbauskaitę (1991), modifikuota D. Ūsaitytės (2001)

Present-day hydrodynamic conditions vary across the area. The nearshore zone is strongly influenced by the Nemunas River flow, wave activity, and the East Baltic nearshore current, contributing to high sedimentation mobility and active redeposition. However, at depths greater than 20 m, bottom currents generally exert minimal influence, and water circulation is relatively stable, thus promoting the steady accumulation of fine-grained material at a rate ranging from 1.0 to 1.3 mm/year (Weisse et al., 2021; Mažeika et al., 2004). The seafloor surface is covered with a complex of Holocene marine sediments, presented by fine-grained sands, mixed medium or coarse sands, and, locally, gravel and coarse silt (aleurite) (Emelyanov, 2001).

Core 66370 is located deeper than the littoral zone, i.e., in the case of the Baltic Sea, deeper than the underwater shore slope – a strip of nearshore bottom from the shoreline to the depth at which the storm waves still influence it (Gudelis, 1993). Thus, for the sediment accumulation in specific environmental conditions in the nearshore zone of the SE Baltic Sea, the specific term 'coastal waters', or 'coastal water zone', has been introduced (Vaikutienė et al., 2025). In this study, the coastal waters are defined as the area of the sea bottom from the shoreline to a depth of the minimum sea level during the Yoldia Sea stage, i.e., up to approximately 60–65 m below the current sea level.

The second study site (3P) is situated in the south-western part of the Curonian Lagoon (Fig. 6). The Curonian Lagoon is a coastal waterbody in the south-eastern part of the Baltic Sea connected to the open sea via the narrow Klaipeda Strait, which is 0.4–1.1 km in width. Its total shoreline length is 611.82 km. The water surface of the lagoon is 12 cm on average above the mean sea level (Žaromskis, 1996). The state border between the Republic of Lithuania and the Russian Federation runs through its central part. The mean depth of the lagoon is 3.8 m, although this varies spatially: the western part is generally deeper, and it reaches up to 4 m, while the depth in the eastern part is shallower, typically 1–2 m deep. The deepest sector is situated within the Klaipėda Strait, where artificial dredging deepened it down to a depth of 14 m (Gasiūnaitė et al., 2008).

The primary factors influencing the hydrodynamics of the Curonian Lagoon are the wind regime and the river runoff (Gasiūnaitė et al., 2008). The largest river flowing into the Curonian Lagoon is the Nemunas; whereas, smaller rivers delivering their waters are the Severnaya, Atmata, Matrosovka, Giliya, and Deima. Approximately 23 km^3 of fresh water is supplied by the river runoff annually (Gailiušis et al., 2001). Episodically, the brackish water of the Baltic Sea invades the lagoon, which causes irregular, rapid (hours-to-days) salinity fluctuations in the range of 0–7‰. The area of seawater intrusions is limited by the northern part of the lagoon, to about 40 km (Daunys, 2001; Gasiūnaitė et al., 2008). Seasonal dynamics of the water temperature for shallow lagoons with an annual amplitude of up to 25–29 °C are observed. Temperature stratification of the water column is weak and unstable. The temperature of the bottom water is 1–2 °C lower than the temperature in the upper layer (Pustelnikovas, 1998). The mean annual water temperature ranges from +8 to +10 °C. The ice cover in the lagoon persists for approximately 110 days annually. The dissolved oxygen content in the waters fluctuates both seasonally and during the day and is 11.8 mg/l on average. Local anoxia can occur in summer at night and is most likely to happen in the southern part of the lagoon (Gudelis, 1959). The highest concentrations of nutrients are observed in winter and early spring (Razinkovas & Pilkaitytė, 2002). What concerns the current sedimentological conditions, the prevailing bottom deposits are fine sand and silty sediments. The northern part of the lagoon functions as a transit zone for sediment transport and is covered with fine and medium sand, while the central and southern parts are predominantly heterogeneous in terms of sediment type. In these parts of the lagoon, fine sand, mixed with shells, medium sand, peat and gravels predominates. Muddy bottoms are characteristic of localised depressions in the western part of the lagoon along the Curonian Spit (Olenin & Daunys, 2004; Trimonis et al., 2003). A peculiarity of the Curonian Lagoon sediments is the presence of shells. In general terms, the lagoon presents itself as an accumulated basin with weak water exchange, where, annually, 6.9 million tonnes of dissolved substances are accumulated, mostly in the southern part. These features allow the Curonian Lagoon to be classified as a closed freshwater estuary (Alimov, 2004).

The third study site (CL_1/2017) is in the mouth of the Nemunas River (Fig. 6). This is the greatest river in Lithuania, with a total length of 937 km. It originates in the Republic of Belarus, flows northward through Lithuania, and then turns westwards to discharge into the Curonian Lagoon.

The Nemunas River basin spans across the territory of five countries: Lithuania (46,700 km^2), Belarus (45,390 km^2), Poland (2,520 km^2), Russia (317 km^2), and in Latvia (88 km^2) (Gailiušis et al., 2001). In its downstream part, the river forms the physical and state border between Lithuania and the Russian Federation's Kaliningrad exclave (Fig. 8).

The mean annual water temperature ranges between 5.5 and 6.5 °C, with the coldest temperature being observed in January and the warmest in July (Poluckaja, 2000). Annual precipitation varies from 520 to 800 mm, with higher values observed close to the Baltic Sea coast than in the south-eastern upland area. The river discharge regime is dominated by meltwater (40%), groundwater inputs (35%), and precipitation (25%).

Fig. 8. The Nemunas River catchment area (after Čerkasova, 2019).
8 pav. Nemuno upės baseinas (pagal Čerkasovą, 2019)

The Nemunas River catchment landscape was formed by Quaternary glaciation and ancient marine transgressions, resulting in a 100–200 m thick sedimentary cover of sandy-gravel moraine. The deposited coarse rock debris formed hills with fine debris (sand, clay, sand, fine gravel), blanketing over large areas. Therefore, the Nemunas River basin is formed as a large featureless plain, with some highlands rising above it. The central part of the basin is intersected by the Vilkiškės Marginal Ridge, while the lower deltaic part is characterised by a broad, slightly undulating plain. The river current slows down as the relief reduces (Bitinas et al., 2017).

3.2. Fieldwork, Drilling and Sampling

Three sediment cores, representing three different geological-geomorphological environments (coastal water zone, lagoon, delta) of the south-eastern Baltic coastal zone (Fig. 6), were selected for detailed palaeobotanical and paleoenvironmental investigation.

Between 2017 and 2021, a series of offshore drillings were conducted within the southern part of Lithuania's Exclusive Economic Zone in the Baltic

Sea. This project, carried out by specialists from the Lithuanian Geological Survey aboard the marine research vessel *Mintis* (operated by Klaipėda University), resulted in the extraction of 11 boreholes. The drilling was performed by using a VKG 3/6 vibro-drill rig, with a working length of 5 m, enabling full core recovery.

Among the 11 cores, **core 66370** was selected for further detailed investigation based on its location and lithological sequence, which clearly represents the major stages of the Baltic Sea development. The core was retrieved from the northern slope of the Gdansk Deep (55°30.86'N, 20°43.94'E) at a depth of 57.7 m. Five consecutive 1-m sections were described, photographed and transported to the Quaternary Laboratory at the NRC for further subsampling at 15 cm intervals and laboratory analyses.

In January 2021, **core 3P** was collected during research fieldwork by specialists from the Atlantic Branch of the Shirshov Institute of Oceanology and the author of this thesis. The drilling took place in the south-western part of the Curonian Lagoon (54°57'55.60" N, 20°32'54" E) on a frozen lagoon surface by using a TBG-1 Russian peat corer with a 1-meter working length. A total of six 1-m sections were extracted, of which, five were successfully combined into a continuous core (3P) with a total length of 4.14 m. The sections were subsampled at 2 cm intervals.

Between 2017 and 2019, eight sediment cores were collected from the Nemunas River delta during fieldwork conducted by researchers from the Laboratory of Nuclear Geophysics and Radioecology of the NRC. For the purpose of this study, **core CL_1/2017**, which was 1.9 m in length, was retrieved from Kniaupas Bay (55°21'36.2"N, 21°14'47.2"E) was selected for further analyses. The core was subsampled at 5 cm intervals. For all cores, lithological description was performed, which was further supported by sedimentological analyses allowing the author of this thesis to subdivide lithological units (U1, U2, etc.) for each core.

Additionally, a field expedition of Quaternary Laboratory researchers and the author was organised to the Nemunas River delta with the aim of collecting material representing the eastern part of the Curonian Lagoon development. By using a Russian peat corer (1-m working length), a total of seven boreholes were drilled, resulting in the recovery of three cores suitable for paleoenvironmental analysis. However, during the sample preparation stage, it was realised that two cores of the three did not contain diatom frustules, whereas, in the third core, only the upper 50 cm section was rich with diatoms and most likely represented the modern complex. This material was considered invalid for the purposes of the study.

Due to stratigraphical non-heterogeneity of the palaeocoastal environments, the multi-proxy analysis was chosen as a reliable approach to provide a reliable correlation of the obtained data.

3.3. Radiocarbon Dating

To correlate the paleoenvironmental records with regional climatic phases and broader palaeogeographical developments, a robust chronological framework is essential. Given the relatively young age of the studied sediment sequences, radiocarbon dating was chosen as a suitable method for establishing chronology. Radiocarbon dating (^{14}C) can be applied to most types of organic material and can reliably span dates from several hundred years to approximately 50,000 years. Nevertheless, despite its widespread use in paleoenvironmental and palaeogeographical studies, radiocarbon dating is highly dependent on the source and quantity of the deposited organic carbon, and it can be affected by several limitations. These include the marine reservoir effect, reworking or redeposition of older organic matter, incorporation of allochthonous material, and low concentrations of organic carbon – all of which can lead to inaccurate or misleading results (Hedenström & Possnert, 2001; Björck & Wohlfarth, 2002).

To minimise the impact of such issues, accelerator mass spectrometry (AMS) has been proposed as a partial solution, enabling the dating of samples with extremely low carbon content. Nevertheless, uncertainties in age-depth correlation remain, especially when dating bulk sediments or samples with unclear deposition environments. Therefore, botanical and sedimentological analyses were applied to support the chronological interpretation and correlate the lithological and biostratigraphic units with the defined stages of Baltic Sea development and Holocene boundaries (Fig. 9).

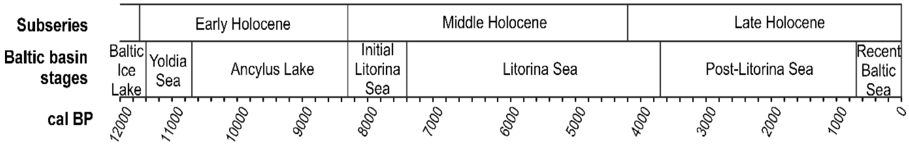


Fig. 9. Correlation between Baltic Sea stages as recorded in Gotland Basin (Andren, 1999) and Holocene subseries (Hang et al., 2020).
9 pav. Baltijos jūros raidos stadijų, užfiksuotų Gotlando baseine (Andrén, 1999), ir holoceno subserijų koreliacija (Hang et al., 2020)

Ten bulk sediment samples were submitted for AMS radiocarbon dating at the Mass Spectrometry Laboratory (Vilnius Radiocarbon) of the Nuclear

Research Department at the State Research Institute Center for Physical Sciences and Technology. The dates were calibrated by using *OxCal* version 4.4 (Bronk Ramsey et al., 2009), applying the *IntCal20* atmospheric calibration curve (Reimer et al., 2020) for lacustrine and marine sediments, following the practice of the Baltic Sea sediments research (Lougheed et al., 2017; Ryabchuk et al., 2021; Van Wirdum et al., 2019).

3.4. Age-Depth Modelling

To interpolate the ages of undated layers and establish sedimentation rates between dated horizons, age-depth models were constructed by the author of this thesis by using the 'rbacon' package, launched in the *R* environment (Blaauw et al., 2025; R Core Team, 2022).

The 'rbacon' package implements the Bayesian ACcumulatiON (Bacon) algorithm (Blaauw & Christen, 2011), which combines chronological data with prior assumptions about the sedimentation process. It generates millions of possible depositional scenarios by using an adaptive *Markov Chain Monte Carlo* (MCMC) algorithm, estimating the deposition time (i.e., the inverse of the sedimentation rate, expressed in yr/cm) for an array of segments with a user-defined thickness (default = 5). Sediment accumulation within each segment is assumed to be uniform and is modelled as an autoregressive gamma process, where both the amount of autocorrelation and the shape of the gamma distribution are given prior estimates. The zones of convergence across the MCMC iterations in the resulting age-depth model indicate the most probable ages for each depth level (Trachsel & Telford, 2016).

Taking into account the deposits composition and its prior accumulation rates, for the 3P core, the age-depth model was constructed by using the following parameter settings: acc.mean = 10, 13, 20; acc.shape = 1.5; mem.mean = 0.54; and mem.strength = 6. For the CL_1/2017 core, slightly different parameters were applied: acc.mean = 20, 40, 22; acc.shape = 2; mem.mean = 0.6; and mem.strength = 6. A detailed explanation of what these functions stand for and how they should be used can be found on the *R Help* page (R Core Team, 2022).

To reflect the lithostratigraphic heterogeneity, the 'boundary' argument was used to define distinct prior accumulation rates for different stratigraphic sections. To test the convergence and mixing quality of the MCMC runs with the chosen settings, the 'Baconvergence' function was applied. This function runs the age-depth model several times (n = 5) and compares the different runs by using the Gelman and Rubin Reduction factor. Robust MCMC mixing is indicated by a Gelman and Rubin Reduction factor below the 1.05 safety threshold (Brooks & Gelman, 1998).

All radiocarbon ages are reported in calibrated years before present (cal yr BP, reference year = 1950). In the text, the mean values of the calibrated intervals are given.

3.5. Loss-on-Ignition

Loss on ignition (LOI) was employed on samples from two cores as a proxy for sediment composition and source material (organic vs. minerogenic), thus providing a basis for describing lithological units and correlating sediment cores. The analysis followed standard procedures provided by Heiri et al. (2001). Sediment samples were first weighed, and 5 g of wet material was placed in pre-weighed crucibles. At the beginning, the crucibles were heated at 105 °C for 12–24 hours to determine the water content. Next, the dried samples were combusted at 550 °C for 4 hours in a muffle furnace to remove organic matter. Finally, the samples were heated at 900 °C for 2 hours to eliminate carbonates. After each heating phase, the samples were cooled in a desiccator and reweighed. Weight loss at each step was calculated and expressed as a percentage of the weight, representing the proportion of organic matter, carbonates, and minerogenic material in the sediments. The determination of the carbonate content followed the method of B. Gedda (2001).

3.6. Magnetic Susceptibility

Mass magnetic susceptibility (MS) measurements of 145 samples from borehole 66370 were carried out at the Paleomagnetic Laboratory of the Nature Research Centre (Vilnius, Lithuania) while using the MFK1-B kappa bridge (AGICO) equipment, and employing the static specimen method with a manual holder. The standard for the instrument calibration was used, and an empty holder correction was applied. All air-dried samples were weighed, and MS was recalculated considering their weight. Data analysis was performed by using the *SAFYR* software. MS values are expressed in $\times 10^{-8} m^3/kg$.

3.7. Diatom Analysis

For diatom analysis, samples were prepared by using the conventional technique described by Battaerbee (1986). Wet samples were air-dried at room temperature. Then, a small amount (2–5 g) of dry material, depending on the sediment type, was placed into heat-resistant glass beakers.

All subsequent chemical treatments were performed under a fume hood for safety. To remove organic matter, 10 ml of 30% hydrogen peroxide (H_2O_2) was added to each beaker. The reaction was monitored until foaming subsided. The samples were left to react for approximately 12 hours, after which, an additional portion of H_2O_2 was added. The beakers were then heated gently on a hot plate to accelerate the oxidation of organic material. To enhance the reaction, potassium dichromate ($K_2Cr_2O_7$) was added as a catalyst at this stage. For some sediment samples, such as peat, removing organic matter was the only step, but, for sediments rich in carbonates or salts, an additional pretreatment step was necessary. Before organic matter removal, the samples were treated with 30% hydrochloric acid (HCL) to dissolve carbonates. The reaction with HCl was managed similarly to that with H_2O_2. Following chemical digestion, the samples were rinsed with distilled water multiple times (at least three) to remove residual chemicals. The rinse intervals were 4 hours, 12 hours, and 6 hours, respectively. Washing continued until the samples had reached neutral pH, as confirmed by using the litmus test paper.

For slide preparation, 2–4 drops of cleaned diatom suspension were pipetted onto clean coverslips and left to dry at room temperature. Once fully dried, the coverslips were mounted using *Naphrax*, a synthetic resin with a high refractive index (n = 1.74). Such a high index helps delineate the fine details of frustule structures under a light microscope.

Diatoms were counted by using a *Nikon Eclipse E100* light microscope equipped with phase-contrast optics and an oil-immersion objective at ×1000 magnification. Taxonomic identification was based primarily on Snoeijs (1993), Snoeijs and Vilbaste (1994), Snoeijs and Potapova (1995), Snoeijs and Kasperovičienė (1996), Snoeijs and Balashova (1998), supplemented by Krammer and Lange-Bertalot (1986–1991), Lange-Bertalot et al. (2017), and Witkowski et al. (2000) works. Additional identification and nomenclature updates were supported by using online resources such as *AlgaeBase* (https://www.algaebase.org/), *Diatom Flora of Britain and Ireland* (https://naturalhistory.museumwales.ac.uk/diatoms/Home.php), and taxonomic workshops materials.

Wherever possible, taxa were identified to the species level. A minimum of 400 valves per sample was counted. The complete list of the identified taxa is provided in Appendix A. Representative micrographs of the identified taxa are provided in Appendix B.

Diatom relative abundance is presented as percentages of the total valve sum. Ecological affinities of the identified species concerning the pH value, salinity, and nutrient preferences were interpreted based on the classification by Barinova et al. (2006) and Mertens et al. (2025). Diatom taxa were grouped according to their salinity preferences (i.e., marine, marine-brackish brackish-marine, brackish, brackish-freshwater, fresh-brackish, freshwater), as well as their habitat form, such as benthic (including tychoplanktonic and epiphytic) and planktonic.

To establish distinct diatom assemblage zones within each core, a constrained hierarchical clustering algorithm (CONISS) was applied with the help of *Tilia* software (Grimm, 1987). *CONISS* uses the incremental sum of squares method, which is an agglomerative algorithm, placing clusters in a hierarchy and considering only stratigraphically adjacent layers for clustering. To increase the influence of the less abundant taxa, a square root transformation was applied to the relative abundance data (Grimm, 1987). The resulting *Local Diatom Assemblage Zones* (LDAZ) were determined considering the dendrogram produced by CONISS and the observed changes in the species composition. While CONISS offers a quantitative approach for stratigraphic zonation, it is of importance to keep in mind its limitations: clusters can be separated into several zones by cutting the dendrogram into different height units (the total sum of squares), which means that different interpretations can arise from the same dataset (Bennett, 1996). Therefore, CONISS was used as an auxiliary tool, and final zonation was based on ecological shifts in diatom assemblages. Diatom relative abundance and the proportion of benthic and planktonic taxa with their salinity preferences were plotted as percentage diagrams by using *Tilia* and *TiliaGraph* software (Grimm, 1992).

The basic counting unit was one valve, with each frustule counted as two valves. For *Gyrosigma* species, valve fragments were included in the count only if the central part of the valve was observed. In the case of *Ulnaria*, *Synedra* and large *Fragilaria* species, valve ends were counted, and their total amount was divided by two to estimate the number of valves.

During the analysis of the samples from the 3P core, two taxa were initially identified as *Staurosira venter* and *S. construens* var. *binodis*. However, after participation in a taxonomic workshop where the classification of some species from *Staurosira* genera were rewatched, the author of this thesis revised the previous identification of *S. construens* var. *venter* to *S. construens* var. *pumila*. The name of *S. binodis* was retained, but, in the context of the 3P core, this species comprises two related taxa: *S. venter* and

S. binodis. Despite the morphological differentiation, early mentioned *Staurosira* taxa are indicative of similar ecological conditions, primarily associated with epiphytic habitats in freshwater to slightly brackish environments, and thus the taxonomic revision does not affect the overall interpretation of the palaeoenvironmental reconstruction.

3.8. Molluscs

In the core Cl_1/2017, malacofauna was investigated to get information on the paleoecological environment in the horizons, where the sample quantity was insufficient for diatom analysis. Fossil molluscs and their ecological preferences were identified with the naked eye and binocular microscope by Aldona Damušytė following the identification books with molluscs characterised for the Baltic Sea and Lithuania (Šivickis, 1960).

4. RESULTS

4.1. Core 66370

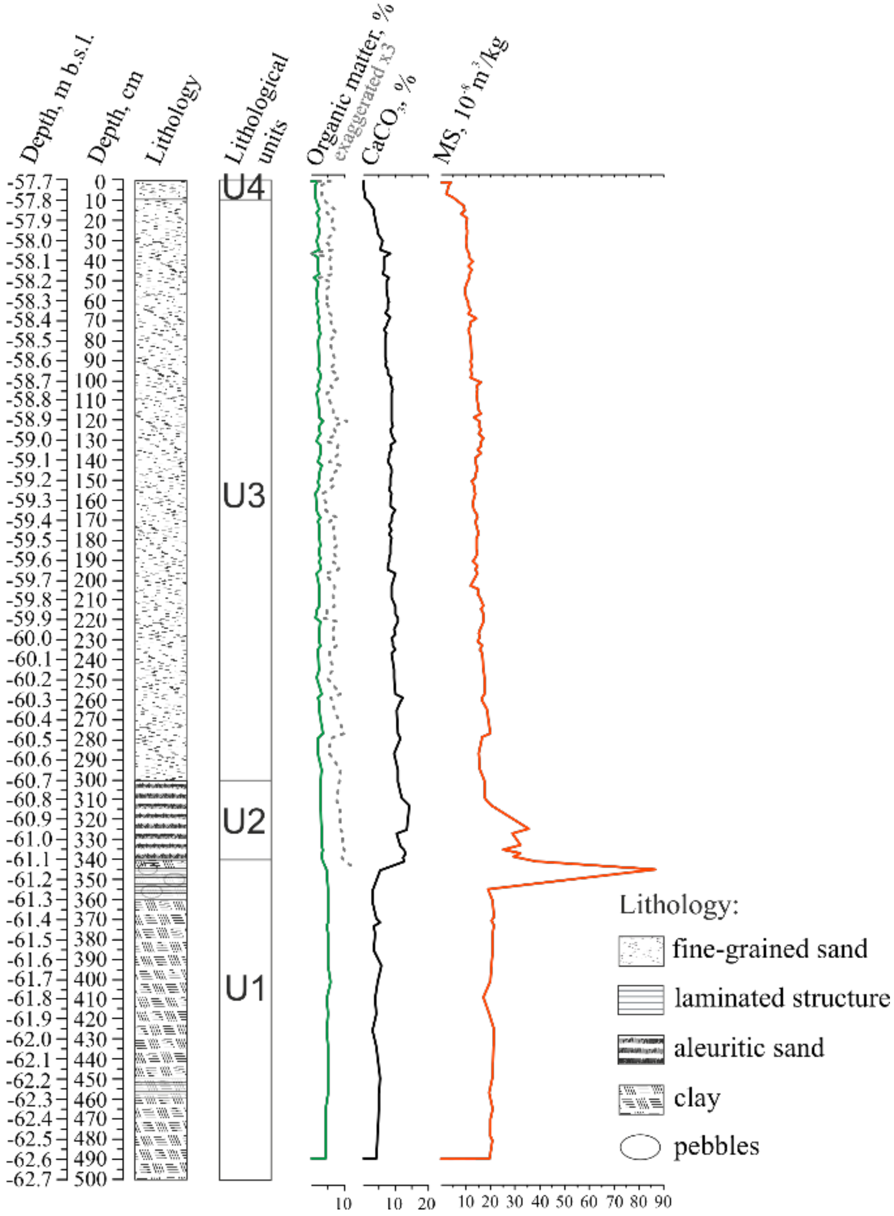


Fig. 10. Lithological composition, LOI and MS results of core 66370.
10 pav. Gręžinio 66370 litologinė sudėtis, LOI ir MS rezultatai

4.1.1. Sediment characteristics

Unit U1 (500–340 cm depth, Fig. 10) is characterised by grey-brown clay with black clay inclusions and fine sandy interlayers containing pebbles and dispersed organic matter (360–344 cm), as well as an interval with only fine sandy interlayers (460–450 cm). Its organic matter content is low throughout the unit, ranging from 3.4% to 6%. Calcium carbonate ($CaCO_3$) content is also low (~3%), but it increases sharply to 12% towards the top of the unit. MS values remain relatively stable with a mean of 25.2, until reaching a peak of 86.5 at 345 cm. These characteristics indicate a low-energy depositional environment with a minimal carbonate input and relatively stable hydrological conditions. However, the occurrence of pebbles and sandy interlayers towards the top of the unit suggests episodic higher-energy events followed by changes in the depositional material.

Unit U2 (340–300 cm) consists of grey silty sediments with sand interlayers. Within this unit, the organic matter content decreases upward from 3.4% to 2.6%, while the carbonate content increases markedly, by reaching a peak value of 14.1%. MS values fluctuate between 20.4 to 35.7, followed by a general decrease beginning at 310 cm and continuing toward the top of the core. This transitional unit reflects a shift in the sedimentological regime and hydrological conditions, with an elevated MS indicating an increased detrital input associated with enhanced erosion.

Unit U3 (300–10 cm) is marked by a sediment shift to very fine sand with dispersed organic matter and iron sulfide (FeS) patches. The organic matter content decreases gradually; the highest value was recorded as 3.6% at 120 cm, and the lowest value was 0% at 36 cm. The carbonate content of the layer followed the same trend as the organic content, with an average value of 8.1%. The MS values decrease progressively and end up reaching a value of 7.2 at the top of the unit.

The lowest percentage of organic matter was observed in Unit U4, which consists of a very fine sand layer (10–0 cm). Its mean organic content was found to equal 1.2%, while the mean carbonate content was 0.22%, and the mean magnetic susceptibility was 3.2.

The analysis results obtained along the entire core reveal a general tendency for all three parameters to decline up-section. However, an exception to this trend was noted in the 360–320 cm interval, with a marked upward trend in carbonates and a maximum in MS values. This may be attributed to a shift in sedimentation conditions and the composition of the deposited material caused by the intensification of erosion processes.

4.1.2. Chronology

The radiocarbon dates obtained for the core are significantly older than expected, most likely due to the presence of redeposited older organic matter in the dated samples, which is a phenomenon commonly observed in the Baltic Sea region (Uścinowicz et al., 2000; Häusler et al., 2017; Lougheed et al., 2013; Ponomarenko et al., 2024; Rößler et al., 2011; Suteerasak et al., 2017). As the obtained ages increase upward in the sediment core rather than becoming younger towards the surface, and because the dates are unrealistically old for the sediments deposited after the Last Glacial period, a reliable age-depth model cannot be constructed (Table 1).

Table 1. Radiocarbon ages of the dated material from core 66370.
1 lentelė. Gręžinio 66370 mėginių radioanglies datos

Lab. code	**Dated material**	**Depth, cm**	**^{14}C age, cal yr BP**	**Calibrated age, cal yr BP (probability 95.4%)**
FTMC-MO60-1	Very fine sand with dispersed organic matter	44–46	29424±139	34354–33670
FTMC-MO60-2	Very fine sand with dispersed organic matter	142–144	26720±107	31137–30828
FTMC-MO60-3	Very fine sand with dispersed organic matter	196–198	34670±203	40385–39377
FTMC-MO60-4	Very fine sand with dispersed organic matter	276–278	31886±159	36632–35859
FTMC-MO60-5	Clay with dispersed organic matter	344–346	28506±130	33199–32096
FTMC-MO60-6	Clay with dispersed organic matter	432–434	15944±58	19446–19082

4.1.3. Diatoms

The diatom composition of the studied core revealed three *Local Diatom Assemblage Zones* (LDAZ), identified through cluster analysis and visual inspection (Fig. 11). In this core, several diatom-poor layers were observed.

LDAZ I (500–300 cm) is dominated by fresh-brackish taxa. The epipsammic *Staurosirella martyi* comprises on average 39.3% of the total assemblage, while the epiphytic *Pseudostaurosira brevistriata* exceeds 20%. At the bottom of the zone, benthic *Amphora pediculus* peaks at ~14%, and *Staurosirella neopinnata* reaches 16.8%. Planktonic taxa, such as *Aulacoseira islandica*, occur at low levels (3% on average), and decline upward. A minor presence of *Epithemia adnata* (mean 4.2%) was also recorded. Toward the top of the zone, brackish-marine *Cocconeis scutellum* increases to 9.4% of the total assemblage, accompanied by a small proportion of marine *Paralia sulcata*. Overall, planktonic taxa account for 0.2–21.7%, while benthic taxa comprise 76%–99.8%. Approximately 80% of the taxa prefer fresh-brackish salinity conditions, although brackish-freshwater taxa gradually increase upward (Fig. 12).

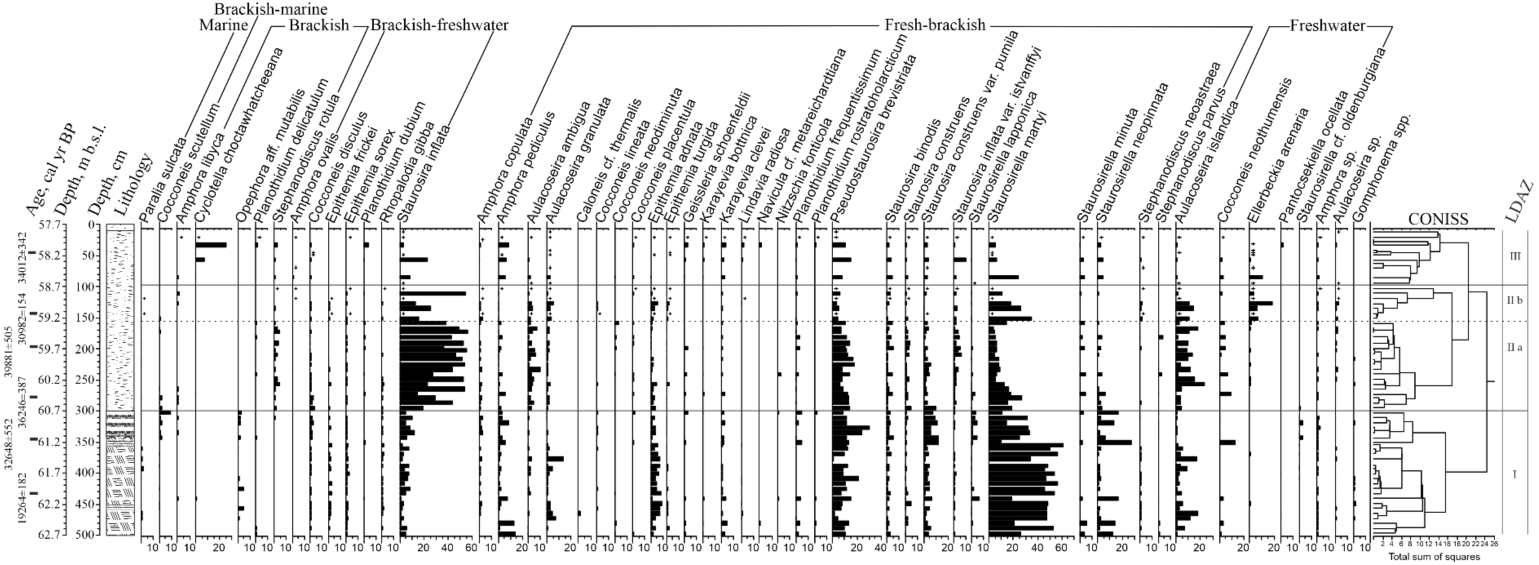


Fig. 11. Percentage diatom diagram of selected taxa from core 66370 with the CONISS dendrogram and local diatom assemblage zones. *Note*. The sign '+' marks diatom-poor samples.

11 pav. Procentinė titnagdumblių diagrama, rodanti būdingiausių taksonų pokyčius gręžinyje 66370; "+" žymi titnagdumblių stokojančius mėginius; pateikta CONISS dendrograma ir vietinės titnagdumblių zonos

LDAZ II (300–100 cm) is subdivided into two subzones, IIa and IIb, based on taxonomic shifts. Throughout the zone, *Staurosirella martyi* and *Pseudostaurosira brevistriata* remain ecologically significant. The growing presence of planktonic *Aulacoseira ambigua* (1.2–9.7%) and *A. islandica* (1.4–23.2%) was observed. LDAZ IIa (300–155 cm) is distinguished by a sharp transition from the fresh-brackish *S. martyi* to the brackish-freshwater *Staurosira inflata* (Fig. 11). The abundance of *S. martyi* decreases to 3.4%, while epiphytic *S. inflata* rises to 55%. Planktonic taxa account for 0.4–32% of the assemblage (mean 12.4%), whereas benthic taxa dominate with 70.3–99.4% (mean 86.5%). LDAZ IIb (155–100 cm) is marked by the appearance of the freshwater benthic *Ellerbeckia arenaria* and the disappearance of *Staurosirella neopinnata*, thus reflecting changes in environmental conditions. This subzone also includes several diatom-poor levels (Fig. 11), where the total valve counts are reduced. Planktonic taxa range from 2.8% to 19.6%, with a slightly increased mean of 13%, and benthic taxa remain dominant at 79–97% (with a mean of 85.5%, Fig. 12).

The uppermost zone, LDAZ III (100–0 cm), is characterised by a notable decrease in diatom abundance. Diatoms are poorly represented or nearly absent, which suggests periods of unfavourable preservation conditions or ecological stress. Only three samples yielded statistically reliable results. Within this zone, the diatom assemblage shows variability in the dominant taxa, including *Pseudostaurosira brevistriata*, *Staurosira inflata*, and *Staurosirella martyi*. Notably, two distinct peaks of the brackish *Cyclotella choctawhatcheeana* (7.5% and 25%) are observed (Fig. 11).

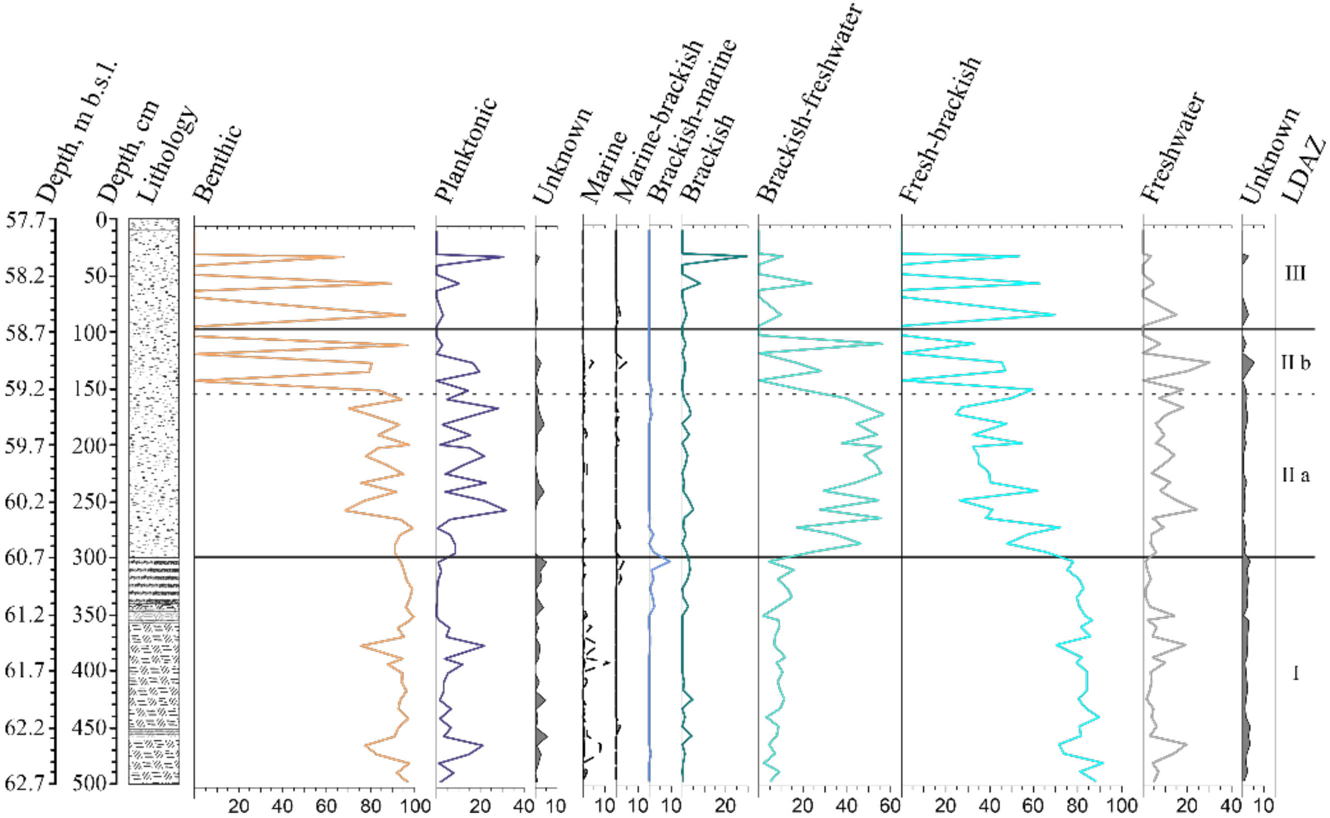


Fig. 12. Ecological groups of diatoms according to habitat and salinity in core 66370; the dotted line marks exaggeration ×10.

12 pav. Titnagdumblių ekologinės grupės pagal buveinę ir druskingumą gręžinio 66370 nuosėdų; punktyrinė linija žymi padidinimą ×10

4.2. 3P Core

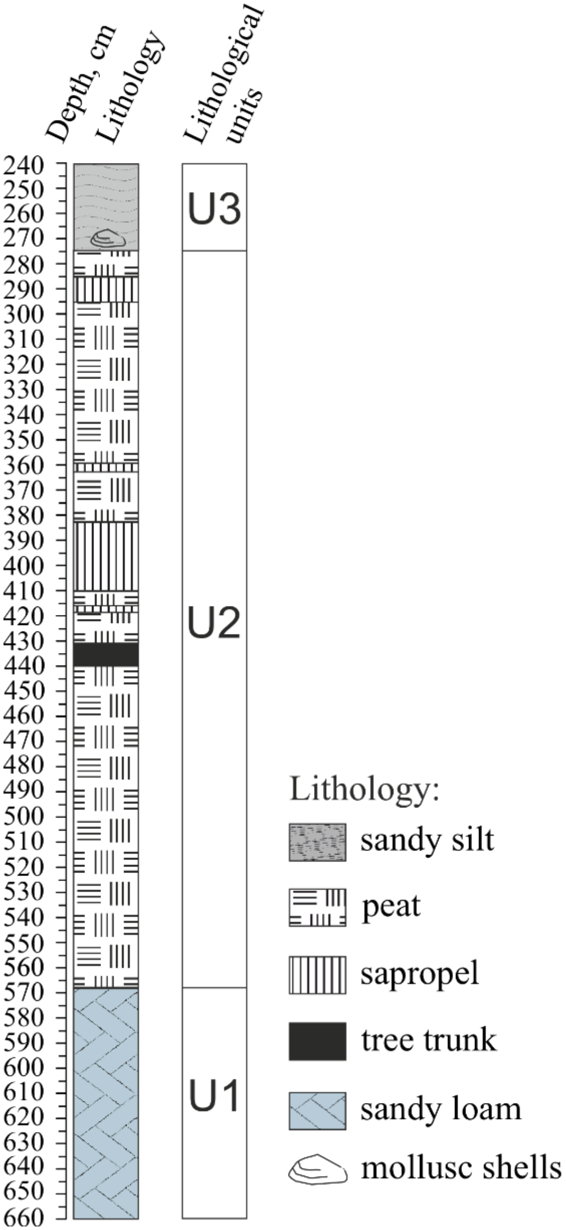


Fig. 13. Lithological composition of core 3P.
13 pav. Gręžinio 3P litologinė sudėtis

4.2.1. Sediment characteristics

Unit U1 (654–568 cm depth, Fig. 13) of the core is composed of homogeneous sandy loam. Unit U2 records the accumulation of alternating peat and thin sapropel layers. At a depth of 420–415 cm, undecomposed remains of a tree trunk were observed. Unit U3 (275–245 cm) marks a return to minerogenic sedimentation, with coarse sandy silt and mollusc shells concentrated in the lower part.

4.2.2. Chronology

The age-depth model was constructed by using three chronological markers: two radiocarbon dates and a known age of the surface layer (2021 AD), converted into calibrated years before present (Table 2). The model spans approximately 10 000 years, covering the entire Holocene (Fig. 14). The sandy loam is interpreted as deposits from the Ancylus Lake stage of the Baltic Sea basin, corresponding to the Early Holocene. Organic-rich sediments accumulated between ~8860 and 2990 cal yr BP, while the overlying sandy silt corresponds to the Late Holocene.

Table 2. Radiocarbon ages of the dated material from 3P core.
2 lentelė. Gręžinio 3P datuotų mėginių radioanglies datos

Lab. code	**Dated material**	**Depth, cm**	**^{14}C age, BP**	**Calibrated age, cal yr BP (probability 95.4%)**
FTMC-EH59-3	Peat	408–409	5927±31	6489–6890
FTMC-EH59-4	Peat	567–568	7945±347	8643–9030

The mean sedimentation rate for the sequence below 408 cm is 0.075 cm/yr (a reverse of 13 yr/cm), suggesting relatively stable peat-forming conditions in a low-energy environment. At around 3000 cal yr BP, the sedimentological environment was shifted with an input of silty material. For this layer, a lower accumulation rate of 0.05 cm/yr (or 20 yr/cm) was calculated, reflecting the slower deposition (Mėžinė et al., 2019).

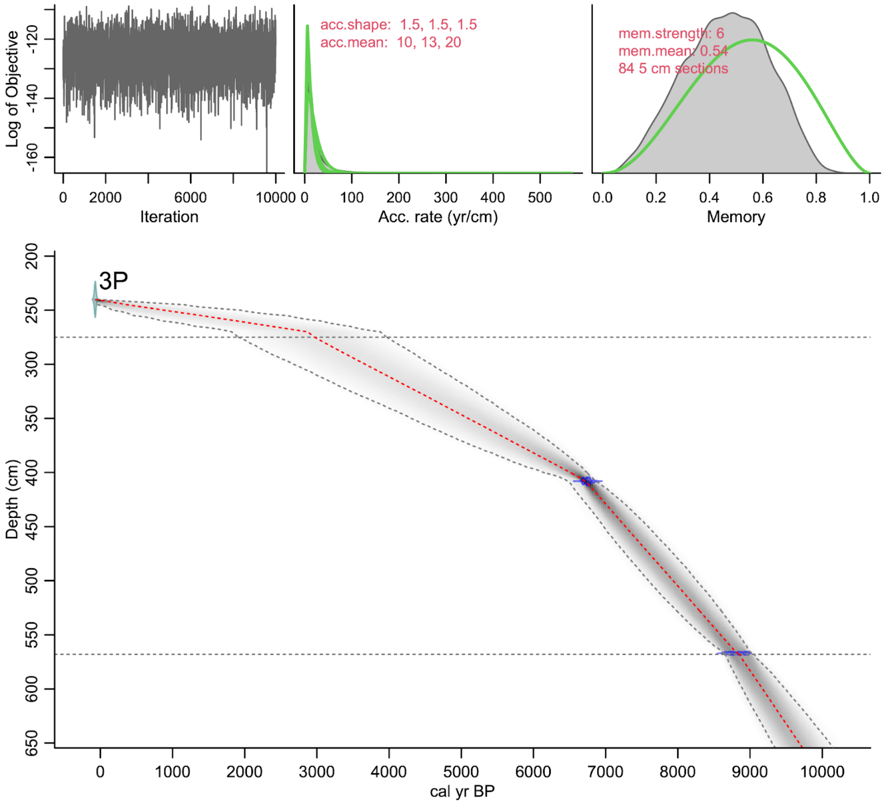


Fig. 14. Age-depth model of 3P sediment core, where the horizontal dotted lines mark lithological boundaries.

14 pav. Gręžinio 3P nuogulų amžiaus-gylio modelis; horizontalios punktyrinės linijos žymi litologines ribas

4.2.3. Diatoms

In the 3P core, three local diatom assemblage zones were identified and subdivided based on statistical analysis and visual inspection. Some layers contained insufficient numbers of diatoms, as indicated in the diagram (Fig. 15).

LDAZ I (660–565 cm) is characterised by high diversity and abundance of benthic fresh-brackish diatoms. The most abundant taxa include *Pseudostaurosira brevistriata*, comprising up to ~30% of the total assemblage in several layers, followed by *Staurosira construens* var. *pumila* (~19% on average) and *Staurosirella neopinnata* (16%). Other notable fresh-brackish species include *Staurosirella martyi* (up to 13.4%) and *Staurosira binodis* (to 11.7%). Taxa with brackish-freshwater affinity are also present, including *Staurosira inflata* (0–7%), *Amphora ovalis* (<3%), and *Rhopalodia gibba*

(<2%). Brackish and brackish-marine taxa are rare but noteworthy, such as *Opephora* aff. *mutabilis* (up to 3%). Benthic taxa of the genera *Epithemia, Gomphonema*, and *Ulnaria* occur more frequently in some layers of this zone.

In terms of the habitat and salinity preferences, the complex is overwhelmingly dominated by fresh-brackish taxa, accounting for over 80% of the total sum. Diatoms with brackish-freshwater affinity contribute less than 10%, thus supporting an interpretation of low salinity levels between 1‰ and 2‰ (Mertens et al., 2025). The proportion of planktonic taxa is low, ranging from 1.2% to 13.3% (Fig. 16), which is typical for a shallow aquatic environment dominated by epiphytic and benthic diatoms.

LDAZ II (565–320 cm) is characterised by alternating diatom-rich and diatom-poor layers, which suggests fluctuating environmental conditions that affected both diatom productivity and preservation (Fig. 15). Despite these gaps, *Pseudostaurosira brevistriata* remains dominant, exceeding 50% of the total sum in several layers. Other well-represented benthic taxa include *Staurosira binodis*, with a mean relative abundance of 17.6%, and *S. inflata*, whose abundance fluctuates between 6.8 and 25.2%. In contrast, the relative abundances of *S. construens* var. *pumila* (~8% on average), *Staurosirella neopinnata* (<3%), and *S. martyi* (<1%) decline considerably compared to the previous zone. A slight but consistent increase is observed in planktonic fresh-brackish taxa, including *Aulacoseira ambigua* (1–7%), *A. granulata* (1–5.5%), and *A. italica* (up to 5.7%). Additionally, the brackish-freshwater *Actinocyclus normanii* reaches up to ~7%. In contrast, taxa of the genus *Amphora*, which were more abundant in the previous zone, decline to nearly zero.

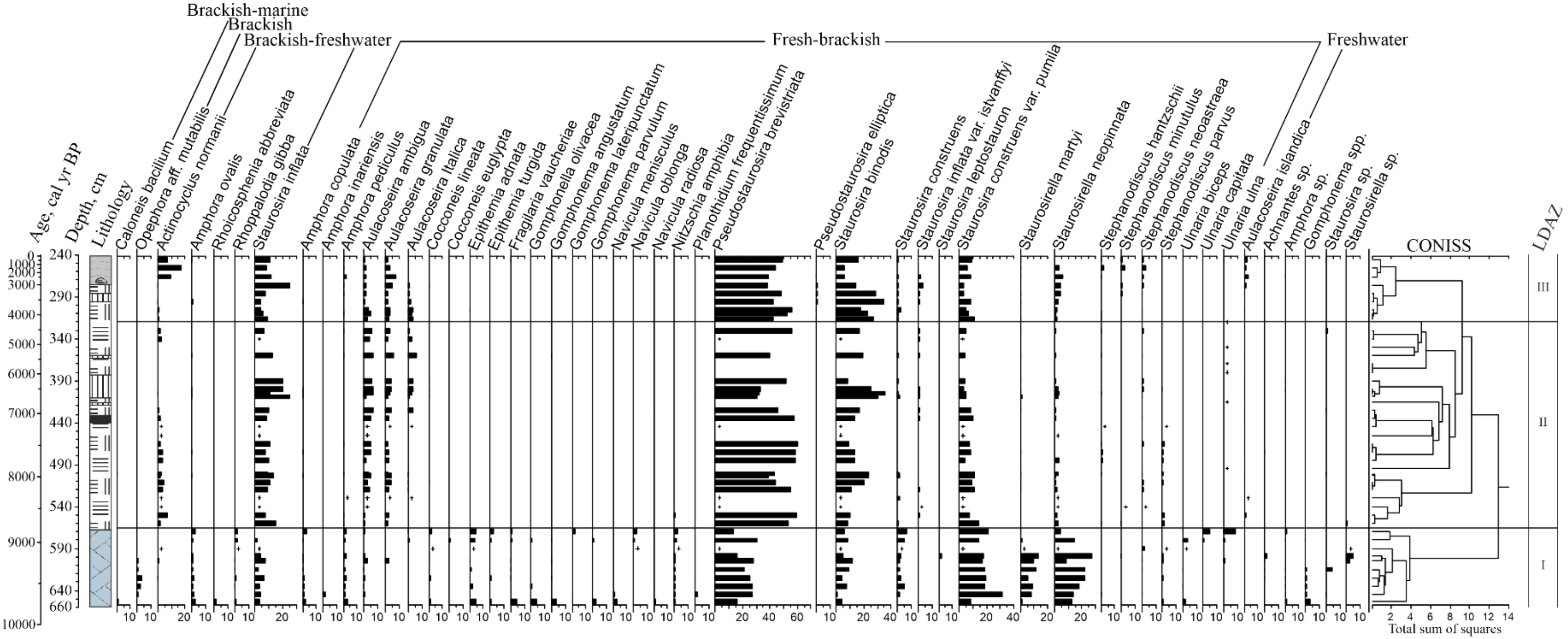


Fig. 15. Percentage diatom diagram of selected taxa from the 3P core with the CONISS dendrogram and local diatom assemblage zones. *Note.* The sign ‘+’ marks diatom-poor samples.

15 pav. Procentinė titnagdumblių diagrama, rodanti pasirinktų taksonų pokyčius gręžinyje 3P; "+" žymi titnagdumblių stokojančius mėginius; pateikta CONISS dendrograma ir vietinės titnagdumblių zonos

The proportion of planktonic taxa shows a fluctuating increase, ranging from 17.4 to 33.7%, while benthic species continue to dominate (Fig. 16). This trend correlates with changes in salinity groups, as brackish-freshwater taxa gain relative importance (8.8–25.3%), although fresh-brackish taxa remain dominant, nevertheless.

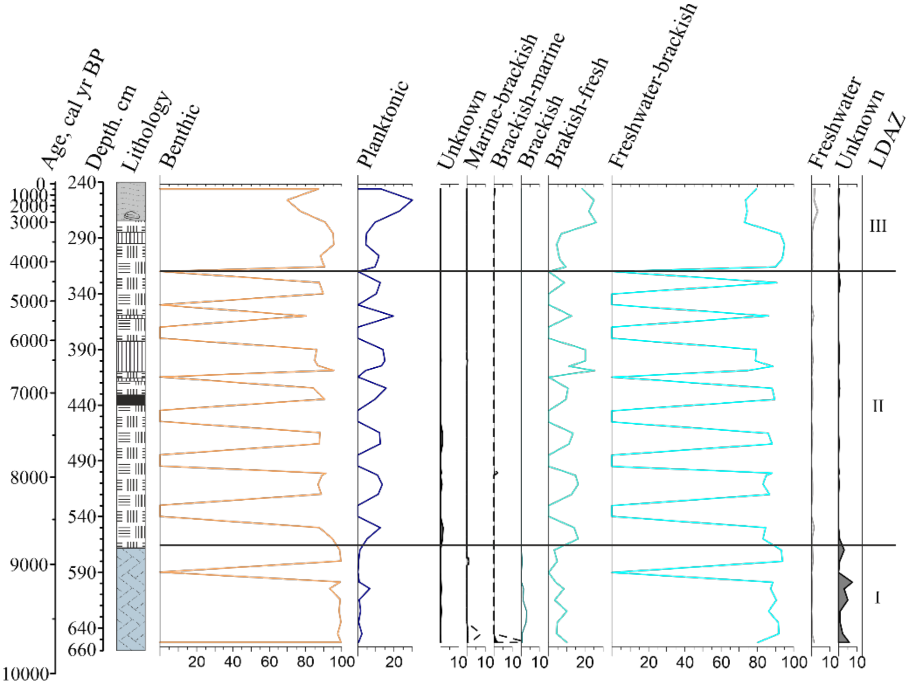


Fig. 16. Ecological groups of diatoms according to habitat and salinity in the 3P core, where the dotted line marks exaggeration ×10

16 pav. Titnagdumblių ekologinės grupės pagal buveinę ir druskingumą gręžinio 3P nuosedų; punktyrinė linija žymi padidinimą ×10

LDAZ III (320–240 cm) marks a continued transformation of the diatom assemblage (Fig. 15). While taxa of the genera *Aulacoseira, Pseudostaurosira,* and *Staurosira* remain dominant, several important shifts in composition and ecological groups are evident. The proportion of *Staurosirella neopinnata* shows a modest but stable increase (0.1–5.8%). In the upper part of the zone, planktonic diatoms become increasingly significant. This surge is driven by rising abundances of several taxa, including brackish-freshwater *Actinocyclus normanii* (0–17%), freshwater *Aulacoseira islandica* (up to 3%), fresh-brackish *Stephanodiscuss hantzschii* (up to 2.2%), *S. minutulus* (up to 2.4%), and *S. neoastraea* (up to 3%). These compositional changes are clearly reflected in both habitat and salinity group curves, where peaks in planktonic taxa, brackish-freshwater, and freshwater taxa correspond closely to the increasing abundances of the species listed above (Fig. 16).

4.3. CL_1/2017 Core

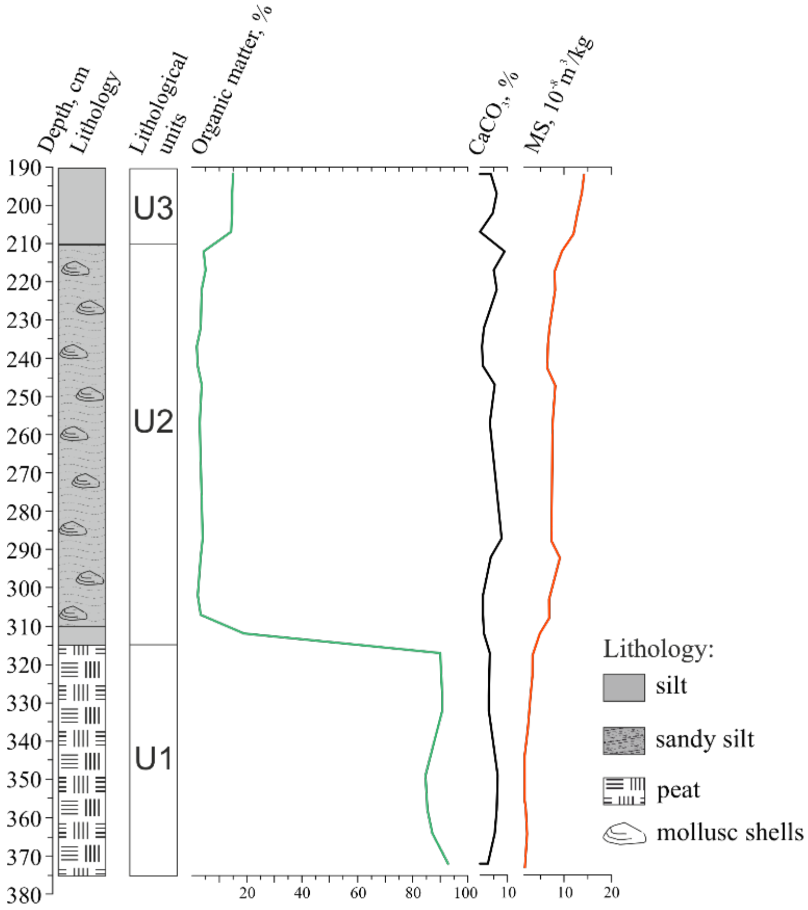


Figure 17. Lithological composition, LOI and MS results of core CL_1/2017.
17 pav. Gręžinio CL_1/2017 litologinė sudėtis, LOI ir MS rezultatai

4.3.1. Sediment characteristics

The CL_1/2017 sediment core comprises three distinct lithological units (Fig. 17). The U1 unit (375–315 cm depth) consists of peat with a very high organic matter content, exceeding 84%. Calcium carbonate percentages are low (3–6%), and magnetic susceptibility values are minimal.

A sharp lithological transition occurs at 315 cm, where the U1 unit is followed by the silty U2 unit (315–210 cm). This change is clearly reflected in the organic content and MS curves. The organic matter content drops to 19% in the 310–315 cm layer, whereas the $CaCO_3$ content decreases to approximately 1%, and MS shows a slight upward trend. Above 310 cm, a sandy silt layer (310–210 cm) appears, enriched with mollusc shells and characterised by very low organic matter values (2–5%). Meanwhile, the carbonates trend is variable, ranging from 1 to 6% with a peak of 9% at 210 cm. The MS curve increases moderately but consistently.

The uppermost U3 unit (210–190 cm) consists of homogeneous silt with a relatively high organic content (~14%). The $CaCO_3$ curve shows a positive trend from nearly 0 to 6%, and magnetic susceptibility exhibits a steady increase.

4.3.2 Chronology

The age-depth model was established based on two radiocarbon dates (Table 3) and the known age of the core surface sample (2017 AD). According to this model, the studied interval covers sediment accumulation from the Middle Holocene and continues up to the present day (Fig. 18).

Table 3. Radiocarbon ages of the dated material from core CL_1/2017.
3 lentelė. Gręžinio CL_1/2017 datuotų mėginių radioanglies datos

Lab. code	Dated material	Depth, cm	^{14}C age, BP	Calibrated age, cal yr BP (probability 95.4%)
VS-2826	Silt	310–315	5180±70	5599–6155
VS-2825	Peat	368–375	6175±80	6817–7385

The peat interval displays a relatively consistent accumulation rate of approximately 0.05 cm/year (or 20 yr/cm), indicating stable depositional conditions within the wetland environment. At around 6000 cal yr BP, the lithology shows a shift in the sedimentation regime, associated with a higher sedimentation rate.

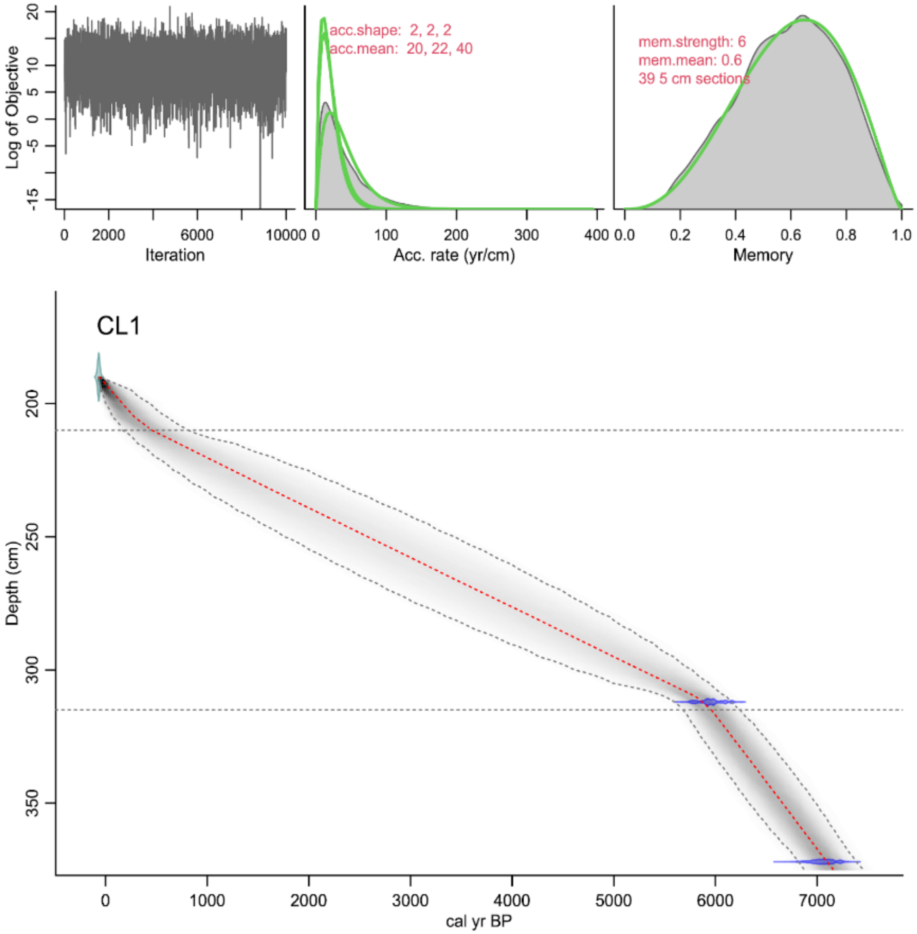


Fig. 18. Age-depth model of the sediment core CL_1/2017. The horizontal dotted lines mark lithological boundaries.
18 pav. Gręžinio CL_1/2017 nuogulų amžiaus-gylio modelis; horizontalios punktyrinės linijos žymi litologines ribas

4.3.3. Molluscs

The molluscan assemblage documented in the sandy silt unit between 310 and 210 cm of depth comprises both bivalves and gastropods (Table 4). The taxonomic composition indicates moderate richness of species, including naturalised alien taxa such as *Lithoglyphus naticoides* and *Dreissena polymorpha*. Most molluscs are typical of freshwater environments, as they tend to occur in habitats ranging from ponds and lakes to slow-flowing rivers and lagoons.

Table 4. List of mollusc species identified in core CL_1/2017.
4 lentelė. Moliuskų rūšių, apibūdintų CL_1/2017 gręžinyje, sąrašas

Depth, cm	**Mollusc name**	**Size of remains, mm**
215–220	*Dreissena polymorpha* (Pallas, 1771)	2 halves, 26x11 mm
	Bithynia tentaculata (Linnaeus, 1758)	3 shells, 8–9 mm and 1 fragment
	Valvata piscinalis (Müller, 1774)	1 shell, 4 mm
220–225	*Dreissena polymorpha* (Pallas, 1771)	1 half 16x9 and 2 fragments
230–235	*Viviparus fluviatilis* (Schlesch, 1939)	1 shell, 25 mm
	Unio tumidus (Philipsson, 1788)	1 fragment
235–240	*Viviparus fluviatilis* (Schlesch, 1939)	1 shell, 24 mm
240–245	*Valvata piscinalis* (Müller, 1774)	1 shell, 5 mm
285–290	*Bithynia tentaculata* (Linnaeus, 1758)	1 shell, 7 mm
	Lithoglyphus naticoides (C. Pfeiffer, 1828)	1 fragment

The composition of the lower part suggests a low-energy, calcium-rich aquatic environment with abundant vegetation. The presence of the alien *Lithoglyphus naticoides* may indicate its early distribution in the area. Molluscs from the 245–230 cm interval point to prolonged freshwater conditions with sufficient oxygenation. Th shell size and good preservation of *Viviparus fluviatilis* indicate favourable ecological conditions and a slow rate of sedimentation. The upper part of the interval (225–215 cm) is marked by the presence of the alien *Dreissena polymorpha*, a mollusc tolerant of brackish and eutrophic water, which could signal episodes of brackish water intrusions.

4.3.4. Diatoms

Diatom analysis was performed only within the units corresponding to the last Litorina and Post-Litorina Sea transgressions, where shifts in salinity and hydrological connectivity are most pronounced and therefore most informative for reconstructing the evolution of the delta ecosystem. The diatom record allows the delimitation of two local diatom assemblages zones (Fig. 19).

LDAZ I (310–220 cm): the fresh-brackish *Pseudostaurosira brevistriata* is the dominant species, with an abundance ranging from 17 to 39%. This zone is also characterised by a higher abundance of *Staurosirella martyi* in the upper part (14–36%). Other secondary taxa include fresh-brackish *Staurosira construens*, *S. construens* var. *pumila*, and *S. venter*, whose combined percentages do not exceed 40% of the total assemblage. Moreover, there are two distinct peaks in the abundance of brackish-freshwater taxa: *Staurosira inflata* (17.7%) and *Navicula cari* (2.6%). The total abundance of benthic taxa is close to 100% (Fig. 20), and species with low salinity preferences prevail (<1‰); however, there is a peak of brackish-freshwater taxa at 17.8%

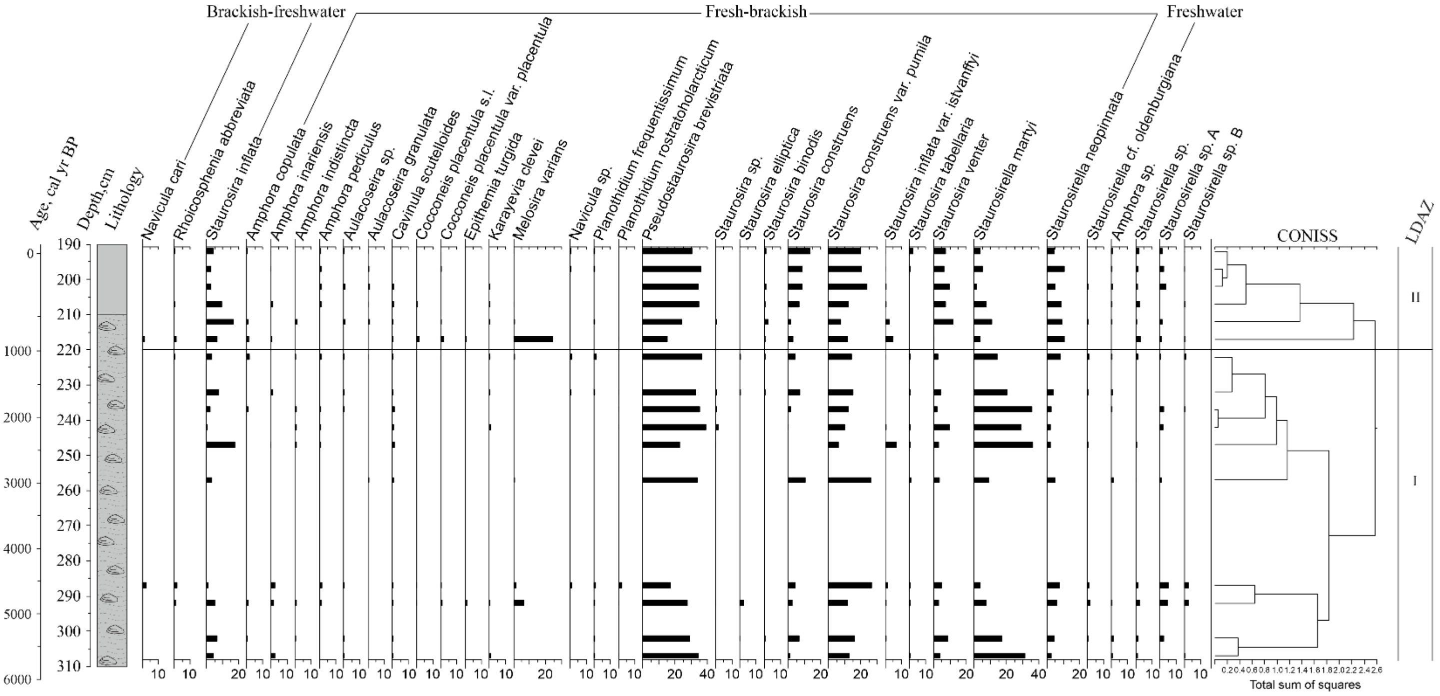


Fig. 19. Percentage diagram of selected taxa from core CL-1/2017 with the CONISS dendrogram and local diatom assemblage zones.
19 pav. Procentinė titnagdumblių diagrama, rodanti pasirinktų titnagdumblių taksonų pokyčius gręžinyje CL_1/2017; pateikta CONISS dendrograma ir vietinės titnagdumblių zonos

LDAZ II (220–190 cm) which reveals a high peak of fresh-brackish *Melosira varians* (24.2%), an increasing percentage of *Staurosirella neopinnata* (to 10%), and a low percentage of *S.martyi* (less than 10%). This zone also records fluctuation in the abundance of the brackish-freshwater *Staurosira inflata*, rising to 16.6% before dropping to 3–4% (Fig. 19). The total percentage of benthic taxa remains consistently high (Fig. 20). The salinity preference diagram indicates a peak in brackish-freshwater taxa, strongly associated with *S. inflata*.

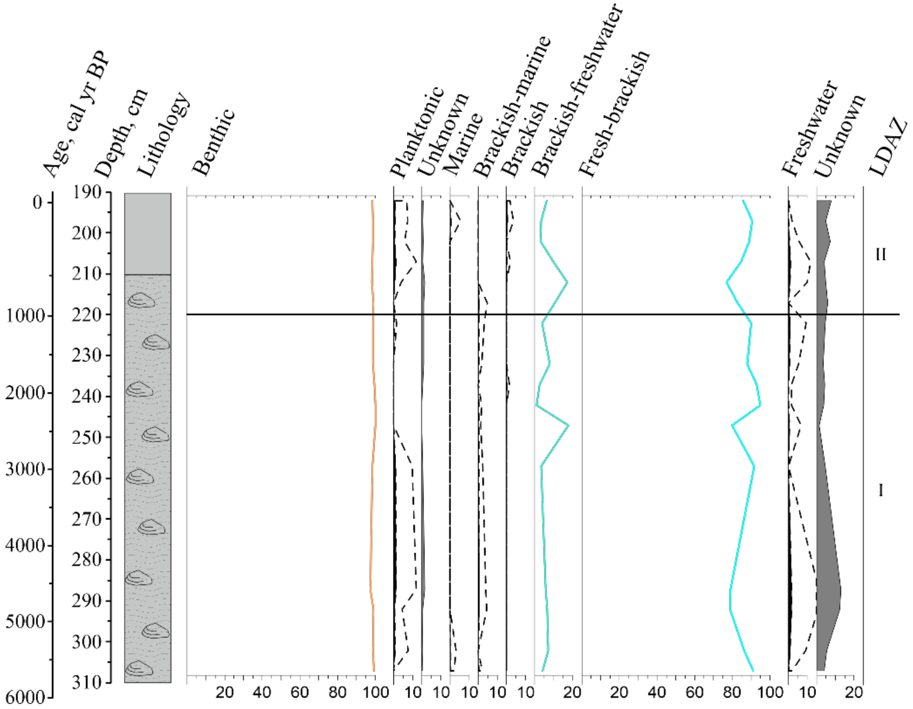


Fig. 20. Ecological groups of diatoms according to habitat and salinity in core CL_1/2017. The dotted line marks exaggeration ×10.

20 pav. Titnagdumblių ekologinės grupės pagal buveinę ir druskingumą gręžinio CL_1/2017 nuosėdų; punktyrinė linija žymi padidinimą ×10

5. PALEOENVIRONMENTS IN THE SOUTH-EASTERN BALTIC

5.1. Coastal Waters Paleoenvironment

The radiocarbon dates obtained from the various intervals and sediment types within core 66370 are consistently older than their expected age according to the stratigraphic position. This discrepancy likely arises from the intrusions of re-deposited organic matter. The phenomenon of reworked organic material yielding anomalously old dates has been previously described in other studies, such as the research on the Mecklenburg Bay, where it served as an indicator of the Litorina Sea stage (Häusler et al., 2017). A similar case from the Bornholm Basin was explained by resuspension of older deposits reaching the wave base at greater water depths (Andrén, 2000). Rößler et al. (2011) highlighted that this pattern is mostly related to bulk sediment dating, in which, the small carbon content (less than 1%) may include a significant proportion of reworked material. In studies of the Arcona Basin and the Mecklenburg Bay, it was revealed that the observed age offsets resulted from the mixing of reworked older Ancylus Lake sediments with the Litorina Sea material, whereas samples consisting solely of Ancylus Lake deposits yielded reliable age values (Rößler et al., 2011).

In the sediments of the south-eastern Baltic coast, age differences exceeding 1000 years are observed and are not limited to the lithological unit associated with the Litorina Sea stage; therefore, they cannot be interpreted solely as indicators of a brackish basin stage. It should also be noted that, in the studied section, the age offsets, mainly in bulk samples, exceed 20 000 yr, whereas the oldest uncorrected ages for the Baltic Sea sediments were obtained from charcoal material (AMS dating: Andrén, 1999; Ringberg, 1980) and sand (OSL dating: Gelumbauskaitė, 2009). Such an age trend most likely reflects active erosional processes and dynamic hydrological conditions that persisted throughout the Holocene in the coastal zone.

In the absence of reliable radiocarbon dates, the stratigraphy of the sediment section was aligned with the stages of the Baltic Sea evolution. In contrast to deep-water areas, correlation of coastal-zone sediments is complicated by the heterogeneity of depositional facies; therefore, the interpretation follows A. Blazhchishin (1989) and L. Ž. Gelumbauskaitė (2009, 2010) with minor modifications based on the author's observations.

Homogenous glaciolacustrine clay (U1; 500–340 cm) was deposited in a low-energy environment. The minimal carbonate input and relatively stable conditions suggest an environment which is consistent with a coastal zone of the lake. The unit was likely formed after a significant BIL regression, as indicated by the predominance of benthic diatom assemblages. The dominant diatom taxon is a fresh-brackish benthic *Staurosirella martyi*. Its massive abundance (over 28%) is a characteristic feature of Baltic Ice Lake sediments, as detailed by A. Cleve-Euler (1951) and further supported by M. Kabailienė (1995). A possible scenario for the post-Last Deglaciation development of the studied area, which could explain the anomalously old age of the sediments, involves BIL water-level fluctuations that, together with waves and currents, transported terrestrial material offshore (Fig. 21).

While the short Yoldia Sea stage can be difficult to discern, the upper part of the U1 unit (400–350 cm) shows evidence of a minor marine influence. This is suggested by the presence of marine *Paralia sulcata* and peaks of planktonic *Aulacoseira granulata* and *A. islandica*. These observations may indicate the initial phase of a transgression. When compared to the diatom complex associated with the Yoldia Sea deposits from the deep part of the Gdansk Depression or from the south-eastern littoral submarine zone (Kabailienė, 1995), there are too few common species to definitively mark a new development stage. Moreover, the palaeosalinity record demonstrates that the Yoldia Sea in the Gdańsk Depression was characterised by very weakly brackish waters, with salinity of about 2‰ (Grigoriev et al., 2011). The interval between 360–340 cm contains pebbles and sandy interlayers, which likely represent an episodic input of erosion-reworked material. This input most likely occurred during a period of rising water levels, further supporting the idea of a dynamic and unstable environment. Many researchers have concluded that several freshwater lagoons once occupied this area, and that their coastlines were later eroded during the Ancylus Lake transgression (Blazhchishin et al., 1974; Gelumbauskaitė, 2010; Kabailienė, 1995; Žulkus et al., 2020).

The next lithological unit (U2, 340–300 cm) marks a distinct lithological transition, characterised by a clear shift to silt with higher $CaCO_3$ percentages. This change suggests an increased inflow of carbonate, likely from a nearby source, and indicates a dynamic depositional event. The concurrent increase in magnetic susceptibility points to a greater input of ferromagnetic minerals, which is a classic indicator of active erosion processes (Sandgren & Snowball, 2002).

In the diatom record, this unit shows a significant decrease in the dominant fresh-brackish *Staurosirella martyi* and a very low abundance of planktonic taxa (*Aulacoseira* sp.). This decline in freshwater indicators, together with the appearance of the brackish-marine *Cocconeis scutellum* (which peaks at the top of the zone), provides compelling evidence of a transgressive onset. Despite this marine influence, the prevailing freshwater benthic diatom assemblage indicates that the environment remained a low-salinity, nearshore setting.

These paleoenvironmental indicators, including the lithological shift, increased erosion proxies, and changes in the diatom flora, align with the geological evidence of the two transgressions. The combination of the proxies effectively illustrates the dynamic interplay between rising water levels, changing sediment sources, and the biological response of the aquatic ecosystem during this period. However, the Ancylus Lake sediments cannot be reliably distinguished on the basis of the obtained results.

The distinct contact zone between U2 and U3 units, at 300 cm, most likely represents a transgressive surface with overlying very fine sand. This shift clearly corresponds to the initial Litorina Sea stage (Rößler, 2006; Uścinowicz, 2014). The occurrence of FeS patches in two depth intervals (300–172 cm and 166–138 cm) provides strong evidence for reduced (anoxic) depositional conditions beneath a deeper, less-ventilated water column (Boman et al., 2010). Such iron monosulfide deposition is an indicator of the onset of brackish conditions and may therefore reflect two Litorina Sea highstands (Hardisty et al., 2021).

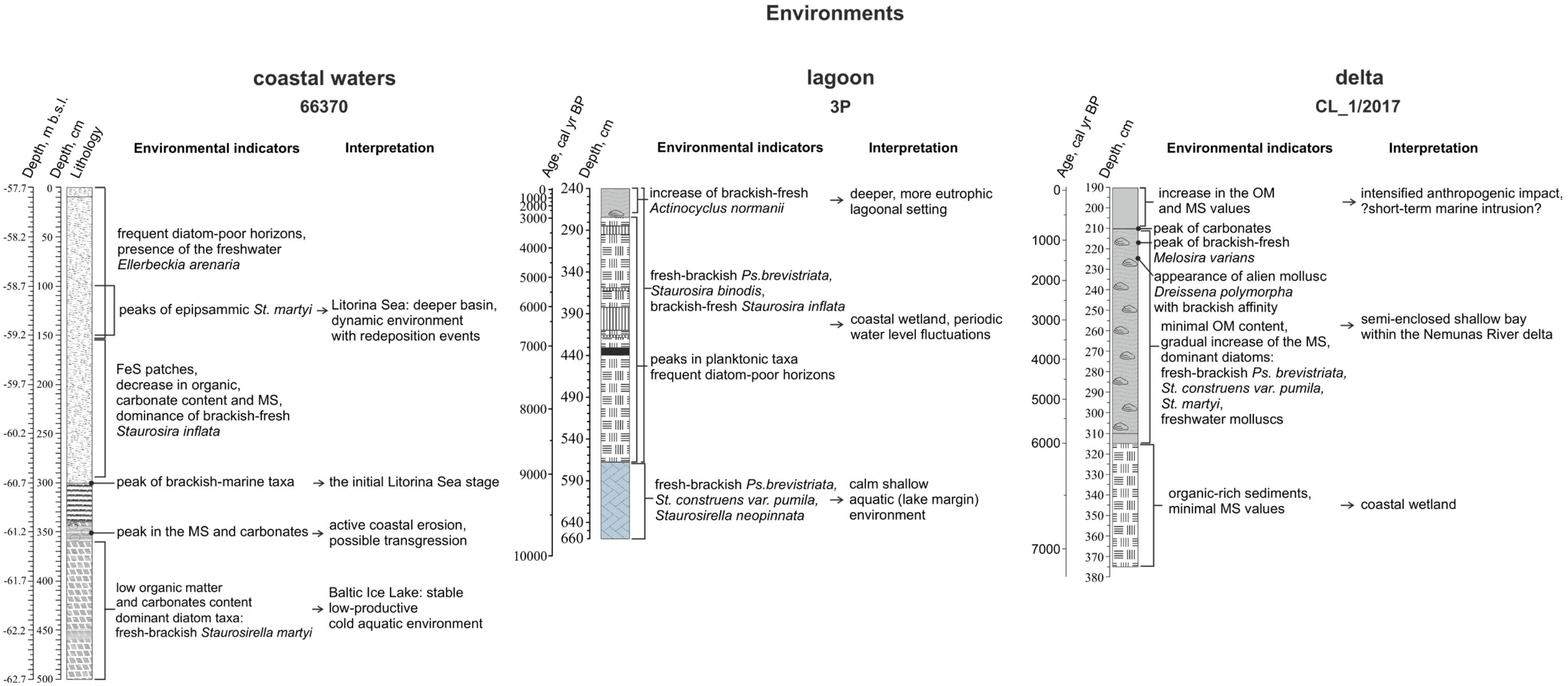


Fig. 21. Interpretation of environmental indicators of different ecosystems in relation to the lithological composition and chronology of sediments.

21 pav. Įvairių ekosistemų aplinkos rodiklių interpretavimas atsižvelgiant į nuodsėdų litologinę sudėtį ir chronologiją

The dominant diatom species in the fine sand (U3) is *Staurosira inflata*, a brackish-freshwater taxon that typically occupies coastal lagoons and which is widespread in the Curonian Lagoon. The marked increase in planktonic taxa, along with the co-occurrence of epiphytic diatoms from the *Fragilaria* genus, suggests a sub-littoral coastal environment with both well-developed macrophytes and pelagic zones. Higher up the core, the deposited material remains largely stable, but the diatom assemblage records a clear reduction in the marine influence. This is evidenced by the appearance of freshwater *Ellerbeckia arenaria* and the loss of dominance by *Staurosira inflata* to renewed *Staurosirella martyi*. Frequent layers with low diatom frustule counts suggest that ecological conditions became less favourable for diatom development or preservation. The diatom complex likely provides evidence of an intensified erosion. With the gradual rise in the sea level, benthic diatoms would have lost access to sufficient light, which should be reflected in their decreasing relative abundance. Moreover, the appearance of freshwater diatoms within a brackish setting could be explained by the input of terrigenous material transported with combined action of waves and coastal currents. Otherwise, as documented along the Polish coast in the Gulf of Gdańsk, large flood events can lead to the redeposition of alluvial sediments far offshore. In such cases, the diatom assemblage typically exhibits a similar pattern: a predominance of benthic species with affinity for low salinity (Szcześniak et al., 2023). These changes collectively point to a period of an increased turbidity.

The distinction of a clear Post-Litorina Sea unit is challenging due to the lack of significant lithological and geochemical changes until the U4 unit (10–0 cm), which shows limonite sand intrusions and a decrease in all geochemical parameters (Fig. 10). The key feature is the increasing percentage of the brackish *Cyclotella choctawhatcheeana* at a depth of 57 cm that could mark the onset of the stage. This taxon is often considered a key component of diatom assemblages that developed in response to the contemporary eutrophication of the Gdansk Depression, which began in the 19th century (Leśniewska & Witak, 2008; 2011). Its presence at this depth could therefore indicate an earlier start to the Post-Litorina Sea stage. Another reason to question the presence of the Post-Litorina Sea sediments in the core is influence of underwater current activity. Present-day hydrodynamic conditions in the area are complex. The nearshore zone is influenced by the water discharge from the Curonian Lagoon, wave activity, currents, and bottom topography, all of which contribute to high sediment mobility. In contrast, in the littoral zone, bottom currents generally have a minimal effect. Water circulation in these deeper areas is relatively stable, which promotes the steady accumulation of fine-grained material. However, it is of importance to note that some researchers have provided evidence for the erosion of Holocene sediments caused by deep-water current activity (Harin & Zukovskaya, 2013; Gelumbauskaitė, 2009).

5.2. Lagoonal Paleoenvironment

While sediment accumulation in the coastal water zone was influenced by hydrological conditions, the lagoon paleoenvironment likely developed under an internal hydrological regime and climatic fluctuations (Fig. 21). Sandy loam sediments found at depths of 654–568 cm were deposited prior to 8850 cal yr BP, most likely in a calm, shallow aquatic environment corresponding to the Ancylus Lake stage of the Baltic Sea (Gudelis, 1979).

The high abundance of *Pseudostaurosira brevistriata*, *Staurosira venter* and *Staurosirella neopinnata* suggests a salinity of approximately 1‰. The presence of a small number of benthic *Amphora* and *Epithemia* species indicates that this part of the palaeobasin was not excessively deep, and that the epiphyte population was not dense enough to significantly limit light for the benthic community. Furthermore, the high percentage of *Staurosirella neopinnata* and *S. martyi* points to a high level of oxygen saturation, thereby suggesting cold, oligotrophic conditions (Mertens et al., 2025). This interpretation is supported by the benthic-planktonic ratio, where benthic species constitute over 80% of the total assemblage, which is indicative of a low water level.

Pollen data from nearby sites, such as the Nemunas River delta and the central part of the Curonian Spit, suggest the dominance of a mixed pine-birch forest during this stage (Napreenko-Dorokhova, 2015; Kaminskas et al., 2019; Damušytė et al., 2021). The climate at that time exhibited a trend toward warmer and drier conditions (Kabailienė, 2006; Kaminskas et al., 2019). Collectively, these data suggest that, during the Early Holocene, the site was likely a lake margin or a riverine estuary containing fresh water.

Starting from 8850 cal yr BP, the sedimentological conditions in the basin rapidly shifted. The accumulation of lowland peat with wood remains began on top of the lacustrine sediments, indicating the terrestrial environment. This transition aligns chronologically with the late phase of the Ancylus Lake stage and the beginning of the Boreal climate period. Before the onset of the Litorina Sea stage, the sea level was approximately 43 meters lower than it is today (Sergeev, 2015). From a vegetation perspective, this period represents a transition during which deciduous forests with the dominance of hazel and alder gradually occupied the coast (Damušytė, 2011; Gelumbauskaitė, 2009). At that time, the climate became warmer than before, and precipitation levels were relatively low (Kabailienė, 2006).

These dramatic changes in sedimentation directly influence the diatom community. During this phase, the fresh-brackish epiphytic taxon *Pseudostaurosira brevistriata* doubled its relative abundance, largely due to favourable substrate conditions provided by reeds and sedges. Moreover, peaks in planktonic taxa (*Aulacoseira* spp., *Actinocyclus normanii*) and brackish-freshwater taxa (*Staurosira inflata*) were observed, alternating with diatom-poor horizons. *Aulacoseira* species are characterised by heavily silicified frustules, which result in a high sinking rate (Lotter et al., 2010). Consequently, these species are known to thrive in turbulent and nutrient-rich environments (Wang et al., 2008). While the diatom-poor horizons could mark stressful ecological conditions attributed to an arid environment favouring peat accumulation, the peaks in planktonic taxa are interpreted as water fluctuations with a gradual level rise.

It could be assumed that the rise in the water level in the basin was caused by the Litorina Sea intrusions. During the first Litorina Sea transgression (8300–8000 cal yr BP; as based on Damušytė, 2011), the water level rose to approximately 25 m b.s.l., which means that the studied basin was located far inland, and that it could not have been affected by brackish waters from the Litorina Sea. This interpretation is supported by the presence of a mostly freshwater diatom complex. In contrast, the peaks at around 7600 cal yr BP and 6900 cal yr BP closely align with the second Litorina Sea transgression (7500–7000 cal yr BP, as based on Damušytė, 2011). Data provided by A. Sergeev (2015) indicate that the sea-level highstand reached only 10 m b.s.l. in the southern part of the coast, thereby suggesting the progradation of an isolated wetland environment. Previous geological investigations have confirmed the presence of a thick peat interval filling a depression beneath the southernmost part of the Curonian Spit (Kunskas, 1970). The depth of the lower peat boundary decreases from the Curonian Lagoon towards the sea (from -6 to -8 m), which suggests water runoff and sediment transport in that direction. These sediments were apparently plant debris (reeds and sedges) that grew in the Curonian Lagoon and its coastal areas (Badyukova et al., 2010). Given this, the direct influence of seawater on this site is rather improbable. Similarly, the peak in planktonic species around

4500 cal yr BP corresponds to the third Litorina Sea transgression (4700–4100 cal yr BP, as based on Damušytė, 2011), but there is no clear evidence for significant storm activity or seawater intrusions, such as thick sand layers or marine and brackish diatoms frustules. Instead, fluctuations in the diatom assemblage were most likely driven by climate change and paleoriver discharge. To sum up, during the Middle Holocene, the basin developed as a coastal wetland environment with shallow and calm conditions.

A similar pattern of lagoon coast evolution was observed in the Nemunas River delta, where, from the Middle Holocene (at around 7000 cal yr BP), the area developed into a wet, periodically inundated boggy environment influenced by inflows and streams (Damušytė et al., 2021). In the southern part of the Nemunas Delta, the mire formation started at 7000 cal yr BP on the Bol'shoye Mokhovoye Raised Bog and at 9750 cal yr BP on the Kozye Raised Bog (Napreenko-Dorokhova, 2015). In the southern part of the Curonian Spit, the Svinoe Raised Bog began to develop at 7000 cal yr BP on the substrate of a previously existing shallow water body (Napreenko et al., 2019).

In the Late Holocene, the hydrological and ecological conditions became more stable. Beginning at 3000 cal yr BP, a lagoonal inundation occurred, accompanied by the accumulation of sandy silt. This development stage correlates with the Post-Litorina Sea transgression (3700–2400 cal yr BP, after Damušytė, 2011). The lower part of sandy silt contains mollusc shells, which can be interpreted as *Dreissena polymorpha* and *Valvata piscinalis*, as based on data from W. Benrath (1934) from the same area. Their presence indicates freshwater to slightly brackish conditions in a shallow-water environment (Damušytė, 2009).

According to the diatom assemblage, the basin became deeper and more eutrophic. The presence of *Actinocyclus normanii*, a warm stenothermic species, could serve as an indicator of an increased eutrophication (Kiss et al., 2012). The frequent occurrence of *Stephanodiscuss minutulus*, a species typical of meso- to eutrophic lakes, which is most abundant in productive nearshore zones, river mouths of large rivers and coastal embayments, further supports this interpretation (Stoermer & Yang 1969). In paleolimnological records, an increased abundance of *S. minutulus* is considered a strong indicator of cultural eutrophication (Reavie et al., 2000).

5.3. Delta Paleoenvironment

The paleobasin during the Middle Holocene, 7164–6015 cal yr BP, is interpreted as a relatively stable, organic-rich phase of wetland development. The low carbonate content and magnetic susceptibility values suggest sustained waterlogged conditions with limited fluvial activity and minimal catchment erosion. These characteristics are consistent with a terrestrial swamp or wetland environment with peat accumulation.

At around 6015 cal yr BP, the simultaneous decline in both carbonate and organic content points to a new depositional regime dominated by silt. This transitional layer reflects an early stage of lagoon water expansion, during which, minerogenic input began to overrun the previously organic-rich unit. The diatom assemblage at that time is characterised by a high abundance of fresh-brackish species, thereby indicating an aquatic environment with low salinity. The dominance of *Pseudostaurosira brevistriata* throughout this zone, together with *Staurosira construens*, *S. construens* var. *pumila*, *S. venter*, which are known to live attached to substrates including aquatic plants (macrophytes), indicates predominantly benthic and epiphytic ecological conditions. The overall diatom complex is overwhelmingly benthic, with benthic taxa comprising nearly 100% of the total, and thus suggesting a persistently shallow environment with extensive aquatic vegetation. The most notable features are the increase in *Staurosirella martyi* in the upper layers (14–36%) and two distinct peaks in brackish-freshwater taxa, specifically, *Staurosira inflata* (reaching 17.7%) and *Navicula cari* (2.6%). Although the overall salinity level remains low (less than 1‰), these peaks may provide evidence of periodic water-level fluctuations. Such intrusions, although not sustained, were sufficient to temporarily alter the diatom assemblage. These findings align with the previously discussed evidence of a transitional lagoon environment, subject to both freshwater input and episodic water level fluctuations, likely related to the Litorina Sea transgressions.

The presence of molluscs supports the interpretation of a shallow lagoonal or fluvio-lacustrine basin. The dominance of freshwater molluscs in the lower part of the silt unit, at around 4820 cal yr BP, suggests a stable, low-energy environment. This habitat likely had abundant vegetation and minimal sediment influx, providing favourable conditions for these organisms. The later appearance of the mollusc species *Unio* and *Viviparus* indicates prolonged, ecologically stable freshwater conditions. The size and preservation of their shells suggest favourable living conditions and a slow rate of sedimentation. These characteristics support a stable phase in a slowly transgressing water body.

The appearance of the alien species *Dreissena polymorpha* marks a significant shift at 1456 cal yr BP (494 AD). These data are in good agreement with the findings of Buynevich et al. (2011), who dated shells of *D. polymorpha* from the same area of the Curonian Lagoon and linked their presence to Viking voyages around 820–941 AD. This species is tolerant of both brackish and eutrophic waters, and its presence may indicate either seawater influence or environmental stress, possibly associated with anthropogenic activity.

This interpretation is supported by the magnetic susceptibility signals, which indicate a gradual increase in the alluvial input from the catchment area. The rise in organic matter could reflect decreased sedimentation rates and, possibly, slightly eutrophic conditions. In the diatom community, the Late Holocene is marked by a high peak in *Melosira varians* relative abundance, which is species commonly found in eutrophic, shallow freshwater environments. This is accompanied by an increasing percentage of *Staurosirella neopinnata* and a low-level occurrence of *S. martyi*. The low occurrence of *S. martyi* may indicate environmental conditions that were less favourable for this species. The most dynamic feature of this zone is the fluctuations of the brackish-freshwater *Staurosira inflata*. Its abundance rises significantly at about 800 cal yr BP before dropping afterwards. This peak could be an indicator of periodic increases in salinity, likely due to episodic brackish water intrusions. The consistently high percentage of benthic taxa throughout the zone confirms that the water body remained shallow.

The transition from a terrestrial peat-forming environment to a shallow lacustrine or lagoonal setting, marked by a shift in the deposited material, is consistent with the geochemical and biological markers. It is most probable that the environmental evolution of the study site was driven by multiple factors, including the eustatic sea-level rise, along with the ongoing subsidence of the Earth's surface contributing to the inundation of coastal areas, and regional hydrological fluctuations.

The combined effect of these factors provides a robust explanation for the gradual water-level rise that resulted in the sedimentary and environmental changes observed in the core. The sandy silt interval therefore represents a stable phase in which the rates of water-level rise and sedimentation input were in balance, allowing the development of a shallow lacustrine or lagoonal environment which is consistent with regional paleogeographic reconstructions for the Late Holocene (Damušytė, 2011).

6. DIATOM COMPLEXES AS INDICATORS OF SUCCESSIVE BALTIC SEA STAGES: A COMPARATIVE VIEW

The post-glacial history of the Baltic Sea is subdivided into several characteristic stages, each defined by a relative or quantitative range of salinity (Table 5). These stages are associated with distinctive diatom assemblages, which can be applied to reconstruct salinity, hydrological changes, and shoreline displacement in the study area (Snoeijs, 2001). In this study, the listed taxa indicators of the Baltic Sea developmental stages were compared with diatom complexes from the studied sediment cores.

Table 5. Characteristics of water salinity during different stages of the Baltic Sea development.
5 lentelė. Vandens druskingumo charakteristikos įvairių Baltijos jūros raidos stadijų metu

Developmental stage	Characteristic
Baltic Ice Lake	cold, fresh melting water
Yoldia Sea	cold, mixture of marine water and fresh melting water
Ancylus Lake	freshwater
Mastogloia Sea (initial Litorina Sea)	brackish, 0.5–5‰
Litorina Sea	brackish, 5–25‰
Post-Litorina (Limnaea) Sea	more-or-less the present conditions, brackish

The comparison between the diatom assemblages of core 66370 and classic indicator taxa for the Baltic Sea developmental stages shows both correspondences and important deviations (Table 6). For the Baltic Ice Lake stage, only a partial signal is present. *Aulacoseira islandica* was recorded, although not at the subspecies level (*Aulacoseira islandica* spp. *helvetica*), as listed among the indicator taxa. Other cold freshwater planktonic taxa, such as *Aulacoseira alpigena* and *Stephanodiscus rotula* are absent. This may suggest either limitations in taxonomic identification or local environmental conditions that were unfavourable for the development of these taxa. Most of the recognised Yoldia Sea indicator taxa are absent from the diatom assemblages of core 66370, including *Diploneis* spp., *Thalassiosira baltica*, and *Grammatophora oceanica*. The identified assemblages are dominated by freshwater and fresh-brackish taxa with sporadic occurrences of *Actynocyclus normanii* instead of *A. octonarius*. This pattern reveals that at site 66370, marine influence during the Yoldia Sea stage was greatly weakened, most likely due to its semi-isolated coastal or lagoonal setting with limited water exchange.

The Ancylus Lake diatom assemblage also does not correspond well to the listed indicator taxa. Many littoral epiphytes (*Epithemia*, *Encyonema*, *Cymatopleura*) are absent, which may be explained by habitat limitations in a deltaic-lagoonal site and poor preservation of the fragile frustules. This hypothesis is further supported by the fact that the same dominant taxa are present but only in low relative abundance. The minor presence of *Aulacoseira islandica* in the record may reflect low-salinity conditions. One of the indicator taxa, the freshwater species *Ellerbeckia arenaria*, was identified above the presumed unit of the Ancylus Lake stage. Overall, diatom assemblage did not match with indicator taxa, nevertheless, the diatom composition points on rather freshwater conditions.

The Mastogloia Sea (or the initial Litorina Sea) signal is more clearly visible. The presence of diagnostic *Mastogloia* spp. and *Epithemia turgida,* together with *Stephanodiscus neoastraea*, may indicate a genuine signal of the initial Litorina Sea. This suggests that, during the early Litorina Sea transgression, brackish-freshwater communities developed at this site. However, it is difficult to define this interval as a classic Mastogloia Sea stage because of the very low occurrence level of *Mastogloia* frustules.

Finally, during the Litorina Sea stage, the assemblage again deviates from the classical diatom community, which typically includes diverse marine planktonic species. Marine planktonic indicators, such as *Chaetoceros*, *Thalassionema*, *Diploneis*, *Rhabdonema* and *Coscinodiscus*, are absent. Here, *Cocconeis scutellum* occurs in significant amounts at the base of the lithological unit associated with the Litorina Sea, providing a clear but restricted signal. In the upper part of the unit, the occurrence of *Actynocyclus octonarius* and *Pseudosolenia calcar-avis*, together with *Cyclotella choctawhatcheeana* – a small planktonic taxon often associated with brackish and eutrophic conditions – suggests an increasing brackish influence. This complex reflects the dynamic, mixed environment of the Litorina Sea stage at this location.

The core 66370 record reflects a lagoon-delta margin with limited marine connectivity, where freshwater and fresh-brackish taxa dominate, whereas classical marine indicators are scarce. This comparison also suggests that the study site experienced the initial Littorina Sea transgression, which is reflected in the diatom record in a non-classical manner, probably due to the influx of eroded material from the coastal zone.

Table 6. Comparison of diatom complexes identified in core 66370 with those recognised as characteristic of the Baltic Sea stages.
6 lentelė. Titnagdumblių kompleksų, nustatytų gręžinio Nr. 66370 nuosėdose, palyginimas su kompleksais pripažintais būdingais Baltijos jūros raidos stadijoms

Stage	Indicator species (Snoejs, 2001)	Core 66370	Match	Notes
Baltic Ice Lake	*Aulacoseira islandica* ssp. *helvetica,* *Aulacoseira alpigena,* *Stephanodiscus rotula,* *Tabellaria fenestrata*	*Staurosirella martyi,* *Pseudostaurosira brevistriata,* *Aulacoseira islandica,* *Epithemia adnata,* *Staurosira construens var. pumila*	partially yes	Assemblage fits BIL shallow littoral type in SE Baltic, where *S.martyi* recognised as a key indicator
Yoldia Sea	*Aulacoseira islandica* ssp. *helvetica* *Actinocyclus octonarius* *Diplones didyma., D. interrupta,* *D. smithii,* *Nitzschia obtusa,* *Thalassiosira baltica,* *Tryblionella navicularis, Tr. punctata,* *Grammatophora oceanica,* *Rhabdonema arcuatum,* *Rhopalodia musculus*		no	Yoldia Sea stage poorly expressed, fresh settings maintained nearshore, likely no open marine connection

Stage	**Indicator species (Snoejs, 2001)**	**Core 66370**	**Match**	**Notes**
Ancylus Lake	*Aulacoseira islandica* ssp. *helvetica,* *Caloneis latiuscula,* *Campylodiscus noricus,* *Cocconeis disculus,* *Cymatopleura elliptica,* *Diploneis domblittensis,* *D. mauleri,* *Ellerbeckia arenaria,* *Encyonema prostratum,* *Epithemia hyndmannii,* *Eunotia clevei,* *Gomphocymbella ancyli,* *Gyrosigma attenuatum,* *Navicula jentzschii*	*Aulacoseira islandica,* *Caloneis* sp., *Staurosira inflata,* *Staurosirella martyi,* *Pseudostaurosira brevistriata,* *Cocconeis scutellum,* *Epithemia frickei, sorex*	no	Low percentage of *A. islandica*, low salinity settings Freshwater benthic marker *Ellerbeckia arenaria* is noted above the presumed sedimentary unit of the Ancylus Lake stage
Mastogloia Sea (initial Litorina Sea)	*Stephanodiscus astraea, St. neoastraea,* *Campylodiscus clypeus, C. echeneis,* *Ctenophora pulchella,* *Diploneis smithii,* *Epithemia turgida,* *E. turguda var. Westermannii,* *Mastogloia sp.,* *Navicula peregrina,* *Rhoicosphenia curvata*	*Stephanodiscus neoastraea,* *Staurosira inflata, Aulacoseira ambigua, islandica* *Staurosirella martyi,* *Pseudostaurosira brevistriata,* *Epithemia turgida* *Rhoicosphenia abbreviata,* *Mastogloia sp.*	partially yes	Rare valves of *Mastogloia* spp., only minor *Stephanodiscus* spp.

Stage	Indicator species (Snoejs, 2001)	Core 66370	Match	Notes
Litorina Sea	*Actinocyclus octonarius,* *Campylodiscus clypeus,* *Cocconeis scutellum,* *Coscinodiscus asteromphalus,* *Diploneis didyma, D. interrupta,* *Chaetoceros diadema, Ch. mitra,* *Petroneis latissima,* *Rhabdonema arcuatum, Rh. minutum,* *Thalassionema nitzschioides,* *Ardissonea crystalina,* *Hyalodiscus scoticus,* *Pseudosolenia calcar-avis*	*Actinocyclus octonarius,* *Cocconeis scutellum,* *Pseudosolenia calcar-avis,* *Ellerbeckia arenaria,* *Cyclotella choctawhatcheeana*	partially yes	Peak of *Cocconeis scutellum* low numbers of *Pseudosolenia calcar-avis* and *Actinocyclus octonarius* valves

Meanwhile, the lagoonal and deltaic complexes, which most likely reflects semi-isolated parts of the basin, were compared specifically with refence lists describing the Curonian Lagoon environment (Table 7). The diatom record from the Curonian Lagoon (3P) and the Nemunas River delta (CL_1/2017) correspond only partially to assemblages typical of the Baltic Sea stages, as they are strongly influenced by the local lagoonal and deltaic environmental conditions. This suggests a pronounced local facies control.

The lower part of the 3P core matches well with Ancylus Lake indicators, including *Staurosirella martyi*, *Amphora pediculus*, and *Pseudostaurosira brevistrtiata*, thus confirming shallow freshwater conditions with littoral vegetation. The transition to the Litorina Sea stage is expressed by an increasing number of *Aulacoseira* taxa together with abundant benthic species (*Pseudostaurosira brevistriata*, *Staurosira construens* var. *pumila*), which replace the classic Litorina Sea brackish complex, including *Grammatophora marina*, *Diploneis* spp., and *Chaetoceros* spores, in this shallow, vegetated setting. Instead of the classical key indicators, the lagoonal core contains brackish-freshwater taxa, such as *Actynocyclus normanii* and *Staurosira inflata*, reflecting limited exchange with the open sea. Evidence for the Litorina Sea transgression is weaker than in the offshore record. The diatom assemblage of the CL_1/2017 core differs markedly from the indicators described by Kabailienė et al. (2009), reflecting the strongly deltaic conditions of the eastern Curonian Lagoon. The assemblage is dominated by small benthic and epiphytic diatoms from *Staurosira*, *Staurosirella*, and *Pseudostaurosira* genera. This composition indicates that the eastern part of the lagoon remained isolated freshwater to slightly brackish environment during the mid-Holocene Litorina Sea transgression. The dominant diatoms indicate a macrophyte-rich environment, shallower than the southern Curonian Lagoon, with its hydrology being strongly influenced by the inflow from the Nemunas River delta rather than the sea.

The uppermost complex of the 3P core deviates even more from the general scheme of the Post-Litorina Sea diatom complex, which is expected to include a brackish ‘modern-like’ community, such as *Navicula digitoradiata*, and the rare brackish taxa *Pinnularia borealis* var. *minor* and *P. microstauron* var. *brebissonii.* Instead, the record shows a continued dominance of fresh-brackish taxa, thus indicating that the lagoon underwent progressive isolation with its hydrology being dominated by riverine inflows and eutrophic conditions. In the Post-Litorina stage interval of the CL_1/2017 core, fresh-brackish taxa again predominate (Table 7), suggesting river-dominated lagoonal conditions with minimal seawater intrusion.

Table 7. Comparison of diatom complexes identified in cores No. 3P and CL_1/2017 with those recognised as characteristic of the Baltic Sea stages.

7 lentelė. Titnagdumblių kompleksų, nustatytų gręžinių Nr. 3 ir CL_1/2017 nuosėdose, palyginimas su kompleksais būdingais Baltijos jūros raidos stadijoms

Stage	Indicator species (Kabailienė et al., 2009)	3P core	CL_1/2017 core	Match	Notes
Baltic Ice Lake	*Aulacoseira granulata, A. islandica,* *A. ambigua, Stephanodiscus rotula,* *Opephora martyi*	-	-	-	Sedimentation began later than the BIL stage
Ancylus Lake	*Aulacoseira granulata,* *A. islandica,* *A. ambigua, Stephanodiscus rotula, Opephora martyi (syn.), Amphora pediculus, Navicula scutelloides (syn.), Fragilaria brevistriata (syn.)*	*Amphora copulata, A. pediculus, St. inflata, Act. normanii, Epithemia adnata, E. turgida, Nitzschia amphibia, Pseudostaurosira brevistriata, Staurosira binodis, St. construens, St. construens var. pumila, Staurosirella martyi, St. neopinnata, Ulnaria sp.*	Sedimentation began later	yes	Assemblages consistent with the Ancylus Lake stage, though lagoon setting modifies benthic flora.
Litorina Sea	*Grammatophora marina, Diploneis didyma,* *D. smithii var. rhombica*, marine resting spores of *Chaetoceros* sp.	*Pseudostaurosira brevistriata, Staurosira binodis,* *St. construens var. pumila, Au. ambigua, Au. granulata, Au. italica,* *Act. normanii*	*St. inflata,* *Ps. brevistriata, St. construens var. pumila, St. venter, Staurosirella martyi, St. neopinnata*	no	Classical offshore Litorina Sea indicators are absent. Instead, lagoon and delta assemblages show fresh-brackish epiphyte taxa

Stage	**Indicator species (Kabailienė et al., 2009)**	**3P core**	**CL_1/2017 core**	**Match**	**Notes**
Post-Litorina Sea	*Navicula digitoradiata, Pinnularia borealis var. minor,* *P. microstauron var. brebissonii*	*Ps. brevistriata, Staurosira binodis,* *St. construens var. pumila,* *St. inflata, Act. normanii, Au. ambigua, granulata, islandica*	*St. inflata, Melosira varians,* *Ps. brevistriata, St. construens var. pumila, St. venter, Staurosirella martyi, St. neopinnata*	no	Lagoon and delta succession do not record classic Post-Litorina Sea assemblages. Instead, eutrophic taxa appeared, and brackish-freshwater taxa peaked.

These differences are most likely caused by the local geomorphological and hydrological factors. The eastern and southern parts of the Curonian Lagoon functioned as freshwater-dominated systems during both the Litorina and Post-Litorina Sea stages, in contrast to offshore records, where brackish and marine taxa are clearly expressed (Kabailienė et al., 2009). Consequently, the diatom record of the CL_1/2017 core represents a local freshwater deltaic environment rather than the marine-brackish community observed in the open basin. Similarly, the 3P core reflects a local lagoonal setting, in which the brackish complexes of the Litorina and Post-Litorina Sea stages are replaced by freshwater planktonic and benthic assemblages.

CONCLUSIONS

The main research questions addressed in this study are how the SE Baltic region developed during the Late Glacial-Holocene, and how the sea level and climate fluctuations influenced its evolution.

1. The research on the coastal water's environment reveals that the Baltic Ice Lake and Litorina Sea stages can be identified in the sediment record, while the Yoldia Sea and Ancylus Lake stages cannot be properly distinguished. This is due to unstable palaeosedimentological conditions characterised by intense erosion, transport, and redeposition of sediments of various origins and ages. This complicates stratigraphic identification and the reliable reconstruction of palaeogeographic conditions.
2. A predominantly fresh-brackish benthic diatom complex developed in the south-western part of the Curonian Lagoon demonstrates the absence of the Litorina Sea brackish water intrusions and confirms the isolation of this part of the paleolagoon since the Middle Holocene. Variations in the diatom assemblages were primarily controlled by changes in the local hydrological regime.
3. The diatom flora and molluscs in the Nemunas River delta ecosystem developed in the shallow basin with relatively stable sedimentation since the Middle Holocene. The deltaic paleoenvironment was not affected by seawater intrusions due to the influence of the river's hydrological regime.
4. Diatom assemblages reflect the influence of different environmental parameters on the ecosystem development. High hydrodynamic activity in coastal waters resulted in erosion, transportation, and redeposition of deposits. In contrast, lagoon and delta sediments accumulated in more isolated parts of the lagoon, which have been affected by local hydrological changes and climatic factors.

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APPENDIX A. LIST OF IDENTIFIED DIATOM TAXA

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1/2017**
Achnanthes brevipes var. *intermedia*	(F.T. Kützing) P.T. Cleve 1895	benthic	brackish	+		
Achnanthes cf. *lemmermannii*	F. Hustedt 1933	benthic	fresh-brackish	+		+
Achnanthes minuscula	F. Hustedt 1945	benthic	fresh-brackish	+		+
Achnanthes cf. *punctulata*	F. Simonsen, nom. illeg. 2012	benthic	brackish	+		
Achnanthes sp.		benthic	unknown	+	+	
Achnanthidium minutissimum	(F.T. Kützing) D.B. Czarnecki 1994	benthic	fresh-brackish	+	+	+
Achnanthidium saprophilum	(H. Kobayasi & S. Mayama) F.E. Round & L. Bukhtiyarova 1996	benthic	fresh-brackish	+		
Achnanthidium spp.		benthic	unknown			+
Actinocyclus normanii	(W. Gregory ex R.K. Greville) F. Hustedt ex S.L. Van Landingham 1967	planktonic	brackish-freshwater	+	+	+
Actinocyclus octonarius	C.G. Ehrenberg 1837	planktonic	marine-brackish	+		
Actinoptychus senarius	(C.G. Ehrenberg) C.G. Ehrenberg 1843	planktonic	marine	+		
Adlafia minuscula var. *muralis*	(A. Grunow in H.F. Van Heurck) H. Lange-Bertalot in H. Lange-Bertalot & S.I. Genkal 1999	benthic	fresh-brackish	+		
Amphora aequalis	K. Krammer 1980	benthic	unknown	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Amphora cf. *calumetica*	(Thomas ex Wolle) M.Peragallo 1897	benthic	unknown	+		
Amphora commutata	A. Grunow in H.F. van Heurck 1880	benthic	brackish			+
Amphora copulata	(F.T. Kützing) F.R. Schoeman & R.E.M. Archibald 1986	benthic	fresh-brackish	+	+	+
Amphora delicatissima	G. Krasske 1930	benthic	brackish-marine	+		
Amphora inariensis	K. Krammer 1980	benthic	fresh-brackish	+	+	+
Amphora indistincta	Z. Levkov 2009	benthic	fresh-brackish	+	+	+
Amphora libyca	C.G. Ehrenberg ex F.T. Kützing 1844	benthic	brackish	+		
Amphora ovalis	(F.T. Kützing) F.T. Kützing 1844	benthic	brackish-freshwater	+	+	+
Amphora pediculus	(F.T. Kützing) A. Grunow in A. Schmidt et al. 1875	benthic	fresh-brackish	+	+	+
Amphora spp.		benthic	unknown	+	+	+
Aneumastus minor	H. Lange-Bertalot 1993	benthic	fresh-brackish	+		
Aneumastus rostratus	(F. Hustedt) H. Lange-Bertalot 2001	benthic	brackish-freshwater	+		
Aneumastus tusculus	(C.G. Ehrenberg) D.G. Mann et A.J. Stickle in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	fresh-brackish	+	+	
Anomoeoneis sphaerophora	(C.G. Ehrenberg) E.H.H. Pfitzer 1871	benthic	brackish-fresh		+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Astartiella bahusiensis	(A. Grunow) A. Witkowski, H. Lange-Bertalot & D. Metzeltin 1998	benthic	brackish-marine		+	
Aulacoseira alpigena	(A. Grunow) K. Krammer 1991	planktonic	freshwater		+	
Aulacoseira ambigua	(A. Grunow) R. Simonsen 1979	planktonic	fresh-brackish	+	+	+
Aulacoseira crassipunctata	K. Krammer 1991	unknown	unknown	+		+
Aulacoseira granulata	(C.G. Ehrenberg) R. Simonsen 1979	planktonic	fresh-brackish	+	+	+
Aulacoseira granulata var. *angustissima*	(G.F.O. Müller) R. Simonsen 1979	planktonic	fresh-brackish		+	
Aulacoseira distans	(C.G. Ehrenberg) R. Simonsen 1979	benthic	freshwater	+		
Aulacoseira islandica	(G.F.O. Müller) R. Simonsen 1979	planktonic	freshwater	+	+	+
Aulacoseira cf. *italica*	(C.G. Ehrenberg) R. Simonsen 1979	benthic	fresh-brackish		+	+
Aulacoseira cf. *muzzanensis*	(F. Meister) K. Krammer 1991	planktonic	freshwater			+
Aulacoseira subarctica	(G.F.O. Müller) E. Haworth 1988	planktonic	freshwater	+		
Aulacoseira spp.		unknown	unknown	+	+	+
Brebissonia lanceolata	(C.A. Agardh) R.K. Mahoney & C.W. Reimer 1986	benthic	brackish		+	
Caloneis aff. *aemula*	(A. Grunow) P.T. Cleve 1894	benthic	brackish-marine	+		
Caloneis bacillum	(A. Grunow) P.T. Cleve 1894	benthic	brackish-marine	+	+	+
Caloneis falcifera	H. Lange-Bertalot, S.I. Genkal & N.V. Vekhov 2004	benthic	fresh-brackish	+		

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Caloneis lancettula	(P. Schulz-Danzig) H. Lange-Bertalot & A. Witkowski in H. Lange-Bertalot & D. Metzeltin 1996	benthic	fresh-brackish	+		
Caloneis limosa	(F.T. Kützing) R.M. Patrick in R.M. Patrick & C.W. Reimer 1966	benthic	fresh-brackish	+		
Caloneis silicula	(C.G. Ehrenberg) P.T. Cleve 1894	benthic	fresh-brackish	+	+	
Caloneis thermalis	(A. Grunow) K. Krammer 1985	benthic	fresh-brackish	+		
Caloneis tenuis	(W. Gregory) K. Krammer 1985	benthic	fresh-brackish	+		
Caloneis sp.		benthic	unknown	+	+	+
Campylodiscus sp.		unknown	unknown	+		
Cavinula cocconeiformis	(W. Gregory ex R.K. Greville) D.G. Mann & A.J. Stickle in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	freshwater	+		
Cavinula jaernefeltii	(F. Hustedt) D.G. Mann & A.J. Stickle in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	fresh-brackish	+		
Cavinula pseudoscutiformis	(F. Hustedt) D.G. Mann & A.J. Stickle in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	fresh-brackish	+	+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Cavinula scutelloides	(W. Smith ex W. Gregory) H. Lange-Bertalot in H. Lange-Bertalot & D. Metzeltin 1996	benthic	fresh-brackish	+	+	+
Cavinula vincentii	D. Antoniades & P.B. Hamilton 2014	benthic	unknown	+		
Chactoceros sp.		unknown	unknown	+		
Cocconeis disculus	(J.H.K. Schumann) P.T. Cleve in P.T. Cleve & A. Jentzsch 1882	benthic	brackish-freshwater	+	+	+
Cocconeis euglypta	C.G. Ehrenberg 1854	benthic	fresh-brackish	+	+	+
Cocconeis lineata	C.G. Ehrenberg 1849	benthic	fresh-brackish	+	+	+
Cocconeis neodiminuta	K. Krammer 1991	benthic	fresh-brackish	+		+
Cocconeis neothumensis	K. Krammer 1991	benthic	freshwater	+		+
Cocconeis pediculus	C.G. Ehrenberg 1838	benthic	brackish-freshwater	+	+	+
Cocconeis peltoides	F. Hustedt 1939	benthic	marine-brackish	+		
Cocconeis placentula s.l.	C.G. Ehrenberg 1838	benthic	fresh-brackish	+		+
Cocconeis placentula var. *placentula*	C.G. Ehrenberg 1838	benthic	fresh-brackish	+		+
Cocconeis pseudolineata	(L. Geitler) H. Lange-Bertalot 2004	benthic	fresh-brackish	+		
Cocconeis pseudothumensis	E. Reichardt 1982	benthic	fresh-brackish	+		
Cocconeis scutellum	C.G. Ehrenberg 1838	benthic	brackish-marine	+		+

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Cocconeis stauroneisformes	(W. Smith) H. Okuno 1957	benthic	marine-brackish		+	
Cocconeis spp.		benthic	unknown	+	+	+
Craticula accomoda	(F. Hustedt) D.G. Mann in F.E. Round, R.M. Crawford & D.G. Mann 1990	planktonic	fresh-brackish	+		
Craticula cuspidata	(F.T. Kützing) D.G. Mann in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	brackish		+	
Cyclotella atomus	F. Hustedt 1937	planktonic	brackish-freshwater			+
Cyclotella caspia	A. Grunow 1878	planktonic	brackish-freshwater	+		
Cyclotella choctawhatcheeana	A.K.S.K. Prasad 1990	planktonic	brackish	+	+	
Cyclotella cyclopuncta	H. Håkansson & J.R. Carter 1990	unknown	brackish-freshwater	+		
Cyclotella distinguenda	F. Hustedt 1927	planktonic	fresh-brackish	+		
Cyclotella aff. *krammeri*	H. Håkansson 1990	unknown	freshwater	+		
Cyclotella spp.		unknown	unknown	+		+
Cyclostephanos dubius	(F. Hustedt) F.E. Round 1988	unknown	brackish-freshwater	+		
Cyclostephanos spp.		unknown	unknown	+		
Cymatopleura elliptica	(L.A. de Brébisson ex F.T. Kützing) W. Smith 1851	benthic	brackish-freshwater	+	+	+
Cymbella affinis	F.T. Kützing 1844	benthic	fresh-brackish	+	+	
Cymbella cistula	(C.G. Ehrenberg) O. Kirchner 1878	benthic	fresh-brackish		+	
Cymbella compacta	E.V. Østrup 1910	benthic	fresh-brackish	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Cymbella cymbiformis	C.A. Agardh 1830	benthic	fresh-brackish	+	+	
Cymbella dorsenotata	E.V. Østrup 1910	benthic	freshwater	+		
Cymbella hantzchiniana	K. Krammer 2002	benthic	fresh-brackish		+	
Cymbella helvetica	F.T. Kützing 1844	benthic	fresh-brackish	+		
Cymbella heteropleura	(C.G. Ehrenberg) F.T. Kützing 1844	benthic	fresh-brackish	+		
Cymbella laevis	C.W. Nägeli in F.T. Kützing 1849	benthic	fresh-brackish	+		
Cymbella neocistula	K. Krammer 2002	benthic	fresh-brackish	+		
Cymbella neolanceolata	W.J. da Silva in W.J. da Silva, M.G. Machado de Souza & C.E. Barnes Proena 2013	benthic	fresh-brackish	+		
Cymbella neoleptoceros	K. Krammer 2002	benthic	fresh-brackish	+		
Cymbella parva	(W. Smith) E.O.O. von Kirchner in F.J. Cohn 1878	benthic	fresh-brackish		+	
Cymbella proxima	C.W. Reimer in R.M. Patrick et C.W. Reimer 1975	benthic	freshwater	+		
Cymbella sp.		benthic	unknown	+	+	
Cymbellafalsa diluviana	(G. Krasske) H. Lange-Bertalot & D. Metzeltin 2009	benthic	fresh-brackish	+		
Cymbopleura amphicephala	(C.W. Nägeli) K. Krammer 2003	benthic	fresh-brackish	+		
Cymbopleura cuspidata	(F.T. Kützing) K. Krammer 2003	benthic	fresh-brackish	+		
Cymbopleura inaequalis	(C.G. Ehrenberg) K. Krammer 2003	benthic	fresh-brackish	+	+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Cymbopleura subaequalis	(A. Grunow in H.F. van Heurck) K. Krammer 2003	benthic	freshwater	+		
Denticula sp.		benthic	unknown	+		
Diploneis calcilacustris	H. Lange-Bertalot & A. Fuhrmann 2016	benthic	fresh-brackish	+		+
Diploneis domblittensis	(A. Grunow) P.T. Cleve 1894	benthic	brackish-freshwater	+	+	+
Diploneis dydima	(C.G. Ehrenberg) C.G. Ehrenberg ex P.T. Cleve 1894	benthic	brackish-marine	+		
Diploneis elliptica	(F.T. Kützing) P.T. Cleve 1894	benthic	fresh-brackish	+		
Diploneis oculata	(L.A. de Brébisson) P.T. Cleve 1894	benthic	fresh-brackish	+		
Diploneis ovalis	(F.W. Hilse) P.T. Cleve 1894	benthic	brackish-freshwater	+		
Diploneis parma	P.T. Cleve 1894	benthic	fresh-brackish	+		
Diploneis praetermissa	H. Lange-Bertalot & A. Fuhrmann 2016	benthic	unknown	+		
Diploneis pseudovalis	F. Hustedt 1930	benthic	brackish	+		
Diploneis smithii	(L.A. de Brébisson ex W. Smith) P.T. Cleve 1894	benthic	brackish	+	+	
Diploneis burgitensis	P. Prudent 1905	benthic	fresh-brackish	+		
Diploneis spp.		benthic	unknown	+	+	+
Ellerbeckia arenaria	(D. Moore ex J. Ralfs) R.M. Crawford 1988	benthic	freshwater	+		+
Encyonema caespitosum	F.T. Kützing 1849	benthic	fresh-brackish	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Encyonema elginense	(K. Krammer) D.G. Mann in F.E. Round, R.M. Crawford et D.G. Mann 1990	benthic	fresh-brackish	+		
Encyonema hebridicum	A. Grunow ex P.T. Cleve 1891	benthic	freshwater		+	
Encyonema leibleinii	(C. Agardh) W.J. Silva, R. Jahn, T.A.V. Ludwig et M. Menezes 2013	benthic	fresh-brackish	+		
Encyonopsis microcephala	(A. Grunow in H.F. van Heurck) K. Krammer 1997	benthic	fresh-brackish		+	
Encyonema minutum	(F.W. Hilse ex G.L. Rabenhorst) D.G. Mann in F.E. Round, R.M. Crawford et D.G. Mann 1990	benthic	fresh-brackish	+	+	
Encyonema silesiacum	(E. Bleisch in G.L. Rabenhorst) D.G. Mann in F.E. Round, R.M. Crawford et D.G. Mann 1990	benthic	fresh-brackish	+	+	
Encyonema vulgare	K. Krammer 1997	benthic	freshwater	+		
Encyonema spp.		benthic	unknown	+		
Encyonopsis microcephala	(A. Grunow in H.F. van Heurck) K. Krammer 1997	benthic	fresh-brackish	+		
Encyonopsis minuta	K. Krammer et E. Reichardt in K. Krammer 1997	benthic	fresh-brackish	+		
Epithemia adnata	(F.T. Kützing) G.L. Rabenhorst 1853	benthic	fresh-brackish	+	+	+
Epithemia goeppertiana	F.W. Hilse in G.L. Rabenhorst 1861	benthic	fresh-brackish	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Epithemia frickei	K. Krammer 1987	benthic	brackish-freshwater	+		+
Epithemia parallela	(A. Grunow) O. Müller 1895	benthic	freshwater	+		
Epithemia smithii	W. Carruthers 1864	benthic	fresh-brackish	+		
Epithemia sorex	F.T. Kützing 1844	benthic	brackish-freshwater	+	+	+
Epithemia turgida	(C.G. Ehrenberg) F.T. Kützing 1844	benthic	fresh-brackish	+	+	+
Epithemia turgida var. *granulata*	(C.G. Ehrenberg) J.-J. Brun 1880	benthic	fresh-brackish	+		
Epithemia turgida var. *westermannii*	(C.G. Ehrenberg) A. Grunow 1862	benthic	brackish-freshwater	+		
Epithemia spp.		benthic	unknown	+		+
Eucocconeis laevis	(E.V. Østrup) H. Lange-Bertalot 1999	benthic	freshwater	+		
Eunotia bidens	C.G. Ehrenberg 1843	benthic	freshwater	+		
Eunotia curtagrunowii	Nörpel-Schempp & H. Lange-Bertalot 1996	benthic	freshwater			+
Eunotia minor	(F.T. Kützing) A. Grunow in H.F. van Heurck 1881	benthic	freshwater	+		
Eunotia sudetica	G.F.O. Müller 1898	benthic	freshwater	+		
Eunotia spp.		benthic	unknown	+		+
Fallacia forcipata	(R.K. Greville) A.J. Stickle et D.G. Mann in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	marine-brackish	+		

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Fallacia litoricola	(F. Hustedt) D.G. Mann in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	marine	+		
Fallacia pseudolitoricola	H. Håkansson 1982	benthic	brackish			+
Fragilaria cf. *perminuta*	(A. Grunow in H.F. van Heurck) H. Lange-Bertalot in K. Krammer & H. Lange-Bertalot 2004	benthic	fresh-brackish			+
Fragilaria radians	(F.T. Kützing) D.M. Williams & F.E. Round 1988	benthic	fresh-brackish	+		+
Fragilaria vaucheriae	(F.T. Kützing) J.B. Petersen 1938	benthic	fresh-brackish	+	+	+
Fragilaria spp.		benthic	unknown	+	+	+
Fragilariforma constricta	(C.G. Ehrenberg) D.M. Williams & F.E. Round 1988	benthic	freshwater		+	
Fragilariforma mesolepta	(G. L. Rabenhorst) V.G. Kharitonov 2005	benthic	fresh-brackish		+	
Fragilariforma virescens	(J. Ralfs) D.M. Williams & F.E. Round 1988	benthic	freshwater	+		
Fragilariforma virescens var. *subsalina*	(A. Grunow in H.F. van Heurck) L. Bukhtiyarova 1995	benthic	brackish-freshwater		+	
Geissleria acceptata	(F. Hustedt) H. Lange-Bertalot & D. Metzeltin 1996	benthic	freshwater	+		+
Geissleria cummerowi	(L. Kalbe) H. Lange-Bertalot 2001	benthic	fresh-brackish	+		+

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Geissleria schoenfeldii	(F. Hustedt) H. Lange-Bertalot & D. Metzeltin 1996	benthic	fresh-brackish	+		
Geissleria sp.		benthic	unknown			+
Gliwiczia calcar	M.S. Kulikovskiy, H. Lange-Bertalot & A. Witkowski 2013	benthic	fresh-brackish	+		
Gogorevia exilis	(F.T. Kützing) M.S. Kulikovskiy & J.P. Kociolek in M.S. Kulikovskiy, Y. Maltsev, A. Glushchenko, I. Kuznetsova, D. Kapustin, E. Gusev, H. Lange-Bertalot, S.I. Genkal et J.P. Kociolek 2020	benthic	fresh-brackish		+	
Gomphonella olivacea	(J.W. Hornemann) G.L. Rabenhorst 1853	benthic	fresh-brackish	+	+	+
Gomphonema acuminatum	C.G. Ehrenberg 1832	benthic	fresh-brackish	+	+	
Gomphonema angustum	(F.T. Kützing) G.L. Rabenhorst 1864	benthic	fresh-brackish	+	+	
Gomphonema brebissonii	F.T. Kützing 1846	benthic	fresh-brackish	+	+	
Gomphonema capitatum	C.G. Ehrenberg 1838	benthic	fresh-brackish	+	+	
Gomphonema coronatum	C.G. Ehrenberg 1840	benthic	freshwater		+	
Gomphonema curtum	F. Hustedt 1945	benthic	fresh-brackish		+	

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Gomphonema elegantissimum	E. Reichardt et H. Lange-Bertalot in G. Hofmann, M. Werum & H. Lange-Bertalot 2011	benthic	fresh-brackish	+		
Gomphonema exilissimum	(A. Grunow) H. Lange-Bertalot & E. Reichardt in H. Lange-Bertalot & D. Metzeltin 1996	benthic	freshwater	+	+	
Gomphonema gracile	C.G. Ehrenberg 1838	benthic	fresh-brackish		+	
Gomphonema lateripunctatum	E. Reichardt in E. Reichardt et H. Lange-Bertalot 1991	benthic	fresh-brackish	+	+	
Gomphonema minusculum	G. Krasske 1932	benthic	fresh-brackish	+		
Gomphonema minutum	(C.A. Agardh) C.A. Agardh 1831	benthic	fresh-brackish			+
Gomphonema pala	E. Reichardt 2001	benthic	freshwater	+		
Gomphonema parvulum	(F.T. Kützing) F.T. Kützing 1849	benthic	fresh-brackish	+	+	
Gomphonema pumilum	(A. Grunow) E. Reichardt & H. Lange-Bertalot in E. Reichardt 1997	benthic	fresh-brackish	+	+	
Gomphonema pusillum	(A. Grunow) M.S. Kulikovskiy & Kociolek 2015	benthic	unknown	+		
Gomphonema sarcophagus	W. Gregory 1856	benthic	fresh-brackish		+	
Gomphonema subclavatum	A. Grunow in H.F. van Heurck 1880	benthic	fresh-brackish	+		
Gomphonema truncatum	C.G. Ehrenberg 1832	benthic	fresh-brackish	+	+	
Gomphonema vibrio	C.G. Ehrenberg 1843	benthic	fresh-brackish		+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Gomphonema spp.		benthic	unknown	+	+	+
Gomphonemopsis exigua	(F.T. Kützing) L.K. Medlin in L.K. Medlin & F.E. Round 1986	unknown	brackish-marine	+		
Grunowia tabellaria	(A. Grunow) G.L. Rabenhorst 1864	benthic	brackish-freshwater		+	
Gyrosigma acuminatum	(F.T. Kützing) G.L. Rabenhorst 1853	benthic	fresh-brackish		+	
Gyrosigma attenuatum	(F.T. Kützing) G.L. Rabenhorst 1853	benthic	fresh-brackish		+	+
Halamphora spp.		benthic	unknown			+
Hantzschia amphioxys	(C.G. Ehrenberg) A. Grunow 1877 sensu D.G. Mann 1977	benthic	fresh-brackish	+		
Hantzschia virgata	(F.C.S. Roper) A. Grunow 1877	benthic	brackish-marine		+	
Hantzschia spp.		benthic	unknown	+		
Hippodonta conspicua	A. Pavlov, Z. Levkov, D.M. Williams & M. Edlund 2013	benthic	fresh-brackish	+	+	+
Hippodonta costulata	(A. Grunow) H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	fresh-brackish	+		
Hippodonta hungarica	(A. Grunow) H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	fresh-brackish	+	+	
Hippodonta lesmonensis	(F. Hustedt) H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	brackish-freshwater		+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Hippodonta linearis	(E.V. Østrup) H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	brackish	+		
Hippodonta luneburgensis	(A. Grunow) H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	brackish-freshwater	+	+	
Hippodonta neglecta	H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	fresh-brackish			+
Hippodonta subcostulata	(F. Hustedt) H. Lange-Bertalot, D. Metzeltin & A. Witkowski 1996	benthic	freshwater	+		
Hippodonta spp.		benthic	unknown	+		
Iconella bifrons	(C.G. Ehrenberg) E.C. Ruck & T. Nakov 2016	benthic	fresh-brackish	+		
Iconella didyma	(F.T. Kützing) L. Bukhtiyarova 2021	benthic	brackish	+		
Iconella hibernica	(C.G. Ehrenberg) E.C. Ruck & T. Nakov 2016	benthic	fresh-brackish	+		+
Karayevia bottnica	(P.T. Cleve) H. Lange-Bertalot 2004	benthic	fresh-brackish	+		
Karayevia clevei	(A. Grunow) F.E. Round & L. Bukhtiyarova in L. Bukhtiyarova 1999	benthic	fresh-brackish	+	+	+
Karayevia laterostrata	(F. Hustedt) F.E. Round & L. Bukhtiyarova ex J.C. Kingston 2000	benthic	freshwater	+	+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Lacustriella lacustris	(W. Gregory) H. Lange-Bertalot & M.S. Kulikovskiy 2012	benthic	freshwater	+		
Lemnicola hungarica	(A. Grunow) F.E. Round & P.W. Basson 1997	unknown	fresh-brackish	+		
Lindavia aff. *antiqua*	(W. Smith) T. Nakov, W.X. Guillory, M.L. Julius, E.C. Theriot & A.J. Alverson 2015	planktonic	freshwater	+	+	
Lindavia comta	(C.G. Ehrenberg) T. Nakov, W.X. Guillory, M.L. Julius, E.C. Theriot & A.J. Alverson 2015	planktonic	freshwater		+	
Lindavia radiosa	(A. Grunow) G.B. De Toni & A. Forti 1900	planktonic	fresh-brackish	+	+	
Luticola cohnii	(F.W. Hilse) D.G. Mann in F.E. Round, R.M. Crawford & D.G. Mann 1990	benthic	brackish-freshwater	+		
Mastogloia albertii	E. Jovanovska, C.E. Wetzel, L. Ector & Z. Levkov 2016	benthic	fresh-brackish	+		
Mastogloia baltica	A. Grunow 1880	benthic	brackish	+		
Mastogloia danseyi f. *grevillei*	(W. Smith) M.B. Edlund & D.R.L. Burge 2019	benthic	fresh-brackish	+		
Mastogloia lacustris	(A. Grunow in O. Schneider) A. Grunow in H.F. van Heurck 1880	benthic	brackish-freshwater	+	+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Mastogloia smithii	G.H.K. Thwaites ex W. Smith 1856	benthic	brackish	+		
Melosira varians	C.A. Agardh 1827	benthic	fresh-brackish			+
Melosira spp.		unknown	unknown	+		
Meridion circulare	(R.K. Greville) C.A. Agardh 1831	benthic	fresh-brackish	+	+	
Navicula bipustulata	A. Mann 1925	benthic	marine-brackish	+		
Navicula cari	C.G. Ehrenberg 1838	benthic	brackish-freshwater	+	+	+
Navicula cincta	(C.G. Ehrenberg) J. Ralfs in A. Pritchard 1861	benthic	brackish-freshwater	+	+	
Navicula cryptocephala	F.T. Kützing 1844	benthic	fresh-brackish	+		
Navicula cryptotenella	H. Lange-Bertalot 1985	benthic	fresh-brackish		+	
Navicula digitoconvergens	H. Lange-Bertalot in H. Lange-Bertalot et S.I. Genkal 1999	unknown	brackish	+		
Navicula digitoradiata	(W. Gregory) J. Ralfs in A. Pritchard 1861	benthic	brackish	+		
Navicula exigua	F. Dujardin 1842	benthic	freshwater		+	
Navicula cf. *gregaria*	A.S. Donkin 1861	benthic	brackish-freshwater			+
Navicula jentzschii	A. Grunow 1882	benthic	fresh-brackish			+
Navicula lanceolata	C.G. Ehrenberg 1838	benthic	brackish-freshwater	+	+	
Navicula menisculus	J.H.K. Schumann 1867	benthic	fresh-brackish	+	+	
Navicula cf. *metareichardtiana*	H. Lange-Bertalot & W.-H. Kusber 2019	benthic	fresh-brackish	+		
Navicula oblonga	(F.T. Kützing) F.T. Kützing 1844	benthic	fresh-brackish	+	+	

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Navicula perminuta	A. Grunow in H.F. van Heurck 1880	benthic	brackish-marine	+		
Navicula platystoma	C.G. Ehrenberg 1838	benthic	brackish-freshwater	+		
Navicula phyllepta	F.T. Kützing 1844	benthic	marine-brackish	+		
Navicula radiosa	F.T. Kützing 1844	benthic	fresh-brackish	+	+	
Navicula recens	(H. Lange-Bertalot) H. Lange-Bertalot 1985	benthic	brackish-freshwater	+		
Navicula reinhardtii	(A. Grunow) A. Grunow in P.T. Cleve et J.D. Möller 1877	benthic	fresh-brackish	+		+
Navicula rhynchocephala	F.T. Kützing 1844	benthic	fresh-brackish	+		
Navicula rostellata	F.T. Kützing 1844	benthic	fresh-brackish	+		
Nmavicula cf. *salinarum*	A. Grunow in P.T. Cleve & A. Grunow 1880	benthic	brackish		+	+
Navicula slesvicensis	A. Grunow in H.F. van Heurck 1880	benthic	brackish-freshwater	+		
Navicula cf. *trophicatrix*	H. Lange-Bertalot in H. Lange-Bertalot & D. Metzeltin 1996	benthic	fresh-brackish			+
Navicula veneta	F.T. Kützing 1844	benthic	brackish-freshwater	+		
Navicula spp.		unknown	unknown	+	+	+
Navigeia decussis	(E.V. Østrup) L. Bukhtiyarova 2013	benthic	fresh-brackish	+	+	
Neidium ampliatum	(C.G. Ehrenberg) K. Krammer in K. Krammer & H.	benthic	fresh-brackish		+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
	Lange-Bertalot 1985					
Neidium calvum	E.V. Østrup 1910	benthic	unknown	+		
Neidium dubium	(C.G. Ehrenberg) P.T. Cleve 1894	benthic	fresh-brackish	+		
Neidium spp.		benthic	unknown	+		+
Nitzschia amphibia	A. Grunow 1862	benthic	fresh-brackish	+	+	
Nitzschia brevissima	A. Grunow in H.F. van Heurck 1881	unknown	brackish-freshwater	+		
Nitzschia denticula	A. Grunow 1880	benthic	fresh-brackish	+		
Nitzschia elegantula	A. Grunow in H.F. van Heurck 1881	benthic	brackish	+		
Nitzschia filiformis	(W. Smith) H.F. van Heurck 1896	benthic	brackish		+	
Nitzschia fonticola	(A. Grunow) A. Grunow in H.F. van Heurck 1881	benthic	fresh-brackish	+		
Nitzschia frustulum	(F.T. Kützing) A. Grunow 1880	benthic	brackish-freshwater		+	
Nitzschia microcephala	A. Grunow in P.T. Cleve & A. Grunow 1880	benthic	brackish-freshwater	+		
Nitzschia palea	(F.T. Kützing) W. Smith 1856	benthic	fresh-brackish	+	+	
Nitzschia paleacea	(A. Grunow) A. Grunow in H.F. van Heurck 1881	benthic	fresh-brackish	+		+
Nitzschia perminuta	(A. Grunow) M. Peragallo 1903	unknown	fresh-brackish	+	+	
Nitzschia recta	C.A. Hantzsch in G.L. Rabenhorst 1862	benthic	fresh-brackish	+		
Nitzschia solgensis	A. Cleve-Euler 1952	benthic	fresh-brackish			+
Nitzschia spp.		unknown	unknown	+	+	+

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Opephora aff. *mutabilis*	sensu K. Sabbe & W. Vyverman, 1995	unknown	brackish	+	+	
Pantocsekiella ocellata	(J. Pantocsek) K.T. Kiss & É. Ács in É. Ács, E. Ari, M. Duleba, M. Dressler, S.I. Genkal, É. Jakó, F. Rimet, L. Ector et K.T. Kiss 2016	benthic	freshwater	+	+	
Pantocsekiella aff. *schumannii*	(A. Grunow) K.T. Kiss & E. Ács 2016	planktonic	freshwater	+		
Pantocsekiella spp.		benthic	unknown			+
Paralia sulcata	(C.G. Ehrenberg) P.T. Cleve 1873	planktonic	marine	+		+
Paraplaconeis minor	(A. Grunow) H. Lange-Bertalot 2017	benthic	fresh-brackish	+		
Paraplaconeis placentula	(C.G. Ehrenberg) M.S. Kulikovskiy & H. Lange-Bertalot 2012	benthic	fresh-brackish	+		
Pinnularia borealis var. *borealis*	C.G. Ehrenberg 1843	benthic	fresh-brackish	+		
Pinnularia brebissonii	(F.T. Kützing) G.L. Rabenhorst 1864	benthic	brackish-freshwater	+		
Pinnularia halophila	K. Krammer 1992	benthic	brackish	+		
Pinnularia intermedia	(N.G.W. Lagerstedt) P.T. Cleve 1895	benthic	freshwater	+		
Pinnularia major	(F.T. Kützing) G.L. Rabenhorst 1853	benthic	fresh-brackish		+	
Pinnularia microstauron	(C.G. Ehrenberg) P.T. Cleve 1891	benthic	freshwater	+	+	

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Pinnularia rupestris	C.A. Hantzsch in G.L. Rabenhorst 1861	benthic	freshwater	+		
Pinnularia sublanceolata	(J.B. Petersen) A. Cleve 1955	benthic	freshwater	+		
Pinnularis subrupestris	K. Krammer 1992	benthic	freshwater	+		
Pinnularia superdivergentissima	H. Germain & J. - P. Chaumont 1976	benthic	freshwater	+		
Pinnularia viridis	(C.L. Nitzsch) C.G. Ehrenberg 1843 sensu H. Lange-Bertalot 2000	benthic	fresh-brackish	+	+	
Pinnularia viridiformis	K. Krammer 1992	benthic	fresh-brackish	+		
Pinnularia spp.		benthic	unknown	+	+	+
Placoneis amphibola	(P.T. Cleve) E.J. Cox 2003	benthic	fresh-brackish	+		
Placoneis clementis	(A. Grunow) E.J. Cox 1988	benthic	brackish	+	+	+
Placoneis clementioides	(F. Hustedt) E.J. Cox 1988	benthic	brackish-freshwater	+		+
Placoneis clementispronina	H. Lange-Bertalot & A.Z. Wojtal 2014	benthic	brackish	+		
Placoneis gastrum	(C.G. Ehrenberg) K.S. Mereschkowski 1903	benthic	fresh-brackish	+		
Placoneis aff. *gastrum*	(C.G. Ehrenberg) K.S. Mereschkowski 1903	benthic	fresh-brackish	+		+
Placoneis elginensis	(W. Gregory) E.J. Cox 1988	benthic	fresh-brackish	+	+	
Placoneis paraelginensis	H. Lange-Bertalot in U. Rumrich, H. Lange-Bertalot & M. Rumrich 2000	benthic	fresh-brackish	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Placoneis spp.		benthic	unknown	+	+	+
Planothidium capitatum	(O. Müller) B. Van de Vijver, K. Kopalová, C.E. Wetzel & L. Ector 2014	benthic	fresh-brackish		+	
Planothidium delicatulum	(F.T. Kützing) F.E. Round & L. Bukhtiyarova 1996	benthic	brackish	+		
Planothidium distinctum	(Messikommer) H. Lange-Bertalot 1999	benthic	unknown	+		
Planothidium dubium	(A. Grunow in P.T. Cleve & A. Grunow) F.E. Round & L.Bukhtiyarova 1996	benthic	brackish-freshwater	+		
Planothidium frequentissimum	(H. Lange-Bertalot) H. Lange-Bertalot 1999	benthic	fresh-brackish	+	+	+
Planothidium joursacense	(J. Héribaud) H. Lange-Bertalot 1999	benthic	fresh-brackish			+
Planothidium lanceolatum	(L.A. de Brébisson ex F.T. Kützing) H. Lange-Bertalot 1999	benthic	fresh-brackish	+	+	
Planothidium cf. *pumilum*	M. Bąk & H. Lange-Bertalot 2015	benthic	freshwater			+
Planothidium reichardtii	H. Lange-Bertalot & M. Werum in M. Werum & H. Lange-Bertalot 2004	benthic	fresh-brackish	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1/2017**
Planothidium rostratoholarcticum	H. Lange-Bertalot & M. Bak in M. Bak & H. Lange-Bertalot 2014	benthic	fresh-brackish	+		+
Planothidium rostratum	(E.V. Østrup) F.E. Round & L. Bukhtiyarova ex H. Lange-Bertalot 1999	benthic	fresh-brackish		+	
Planothidium spp.		benthic	unknown			+
Planoplatessa joursacensis	(J. Héribaud) M.S. Kulikovskiy, A.M. Glushchenko & J.P. Kociolek 2022	benthic	fresh-brackish	+		
Platessa conspicua	H. Lange-Bertalot in K. Krammer & H. Lange-Bertalot 2004	benthic	fresh-brackish		+	+
Platessa oblongella	(E.V. Østrup) C.E. Wetzel, H. Lange-Bertalot & L. Ector 2017	benthic	fresh-brackish	+		
Prestauroneis cf. *protracta*	(A. Grunow in P.T. Cleve & A. Grunow) I.W. Bishop, A.D. Minerovic, Q. Liu & J.P. Kociolek 2017	benthic	brackish	+		+
Prestauroneis spp.		unknown	unknown	+		
Psammothidium cf. *levanderi*	(F. Hustedt) L. Bukhtiyarova & F.E. Round 1996	benthic	freshwater	+		
Psammothidium rossii	(F. Hustedt) L. Bukhtiyarova & F.E. Round 1996	benthic	freshwater	+		
Psammothidium subatomoides	(F. Hustedt) L. Bukhtiyarova & F.E. Round 1996	benthic	freshwater			+

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Psammothidium spp.		benthic	unknown			+
Pseudosolenia calcar-avis	(M. Schultze) B.G. Sundström 1986	planktonic	marine-brackish	+		
Pseudostaurosira brevistriata	(A. Grunow in H.F. van Heurck) D.M. Williams & F.E. Round 1988	benthic	fresh-brackish	+	+	+
Pseudostaurosira elliptica	(J. Schumann) M.B. Edlund, E.A. Morales & S.A. Spaulding 2006	benthic	fresh-brackish		+	+
Pseudostaurosira parasitica	(W. Smith) E.A. Morales 2003	benthic	fresh-brackish	+	+	
Punctastriata lancettula	(J. Schumann) P.B. Hamilton & P.A. Siver 2008	benthic	fresh-brackish			+
Reimeria uniseriata	S.E. Sala, J.M. Guerrero & M.E. Ferrario 1993	benthic	fresh-brackish	+		+
Reimeria sinuata	(W. Gregory) J.P. Kociolek & E.F. Stoermer 1987	benthic	fresh-brackish	+		
Rhabdonema minutum	F.T. Kützing 1844	benthic	marine			+
Rhizosolenia spp.		planktonic	unknown	+		
Rhoicosphenia abbreviata	(C. Agardh) H. Lange-Bertalot 1980	benthic	brackish-freshwater	+	+	+
Rhopalodia gibba	(C.G. Ehrenberg) G.F.O. Müller 1895	benthic	brackish-freshwater	+	+	
Rhopalodia musculus	(F.T. Kützing) G.F.O. Müller 1900	benthic	brackish	+		
Sellaphora atomoides	(A. Grunow) C.E. Wetzel & B. van de Vijver in C.E. Wetzel, L. Ector, B. Van de Vijver,	benthic	fresh-brackish	+		

Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
	P. Compère & D.G. Mann 2015					
Sellaphora bacillum	(C.G. Ehrenberg) D.G. Mann 1989	benthic	fresh-brackish	+		
Sellaphora laevissima	(F.T. Kützing) D.G. Mann 1989	benthic	freshwater	+	+	
Sellaphora parapupula	H. Lange-Bertalot in H. Lange-Bertalot & D. Metzeltin 1996	benthic	fresh-brackish	+		
Sellaphora pupula	(F.T. Kützing) K.S. Mereschkowski 1902	benthic	fresh-brackish	+	+	
Sellaphora cf. *raederae*	(H. Lange-Bertalot) C.E. Wetzel 2015	benthic	fresh-brackish	+		+
Sellaphora rotunda	(F. Hustedt) C.E. Wetzel, L. Ector, B. van de Vijver, P. Compère & D.G. Mann 2015	benthic	fresh-brackish	+	+	
Sellaphora cf. *stroemii*	(F. Hustedt) H. Kobayasi 2002	benthic	fresh-brackish			+
Sellaphora utermoehlii	(F. Hustedt) C.E.Wetzel & D.G.Mann 2015	benthic	fresh-brackish	+		
Sellaphora spp.		benthic	unknown	+		+
Skabitschewskia oestrupii	(A.Cleve) M.S. Kulikovskiy & H. Lange-Bertalot 2015	benthic	freshwater	+		+
Skabitschewskia peragalloi	(Brun & Héribaud) M.S. Kulikovskiy & H. Lange-Bertalot 2015	benthic	freshwater		+	
Skeletonema sp.		unknown	unknown	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Stauroforma exiguiformis	(H. Lange-Bertalot) R.J. Flower, V.J. Jones & F.E. Round 1996	unknown	freshwater	+		
Stauroforma schulzii	(C. Brockmann) R.M. Gogorev 2014	benthic	brackish			+
Stauroforma sp.		benthic	unknown			+
Stauroneis anceps var. *linearis*	(C.G. Ehrenberg) J. Brun 1880	benthic	freshwater	+		
Stauroneis phoenicenteron	(C.L. Nitzsch) C.G. Ehrenberg 1843	benthic	fresh-brackish		+	
Stauroneis reichardtii	H. Lange-Bertalot, P. Cavacini, N. Tagliaventi & S. Alfinito 2003	benthic	fresh-brackish	+		
Stauroneis separanda	H. Lange-Bertalot & M. Werum 2004	benthic	fresh-brackish	+		
Stauroneis smithii	A. Grunow 1860	benthic	fresh-brackish	+	+	
Staurosira binodis	(C.G. Ehrenberg) H. Lange-Bertalot 2011	benthic	fresh-brackish	+	+	+
Staurosira construens	C.G. Ehrenberg 1843	benthic	fresh-brackish	+	+	+
Staurosira construens var. *pumila*	(A. Grunow) J.C. Kingston 2000	benthic	fresh-brackish	+	+	+
Staurosira inflata	(H. Heiden) A. Rusanov, E. Ács, E. Morales & L. Ector 2018	benthic	brackish-freshwater	+	+	+
Staurosira inflata var. *istvanffyi*	(J. Pantocsek) A. Zalat & J. Nitychoruk 2022	benthic	fresh-brackish	+	+	+
Staurosira leptostauron	(C.G. Ehrenberg) M.S. Kulikovskiy	benthic	fresh-brackish	+	+	+

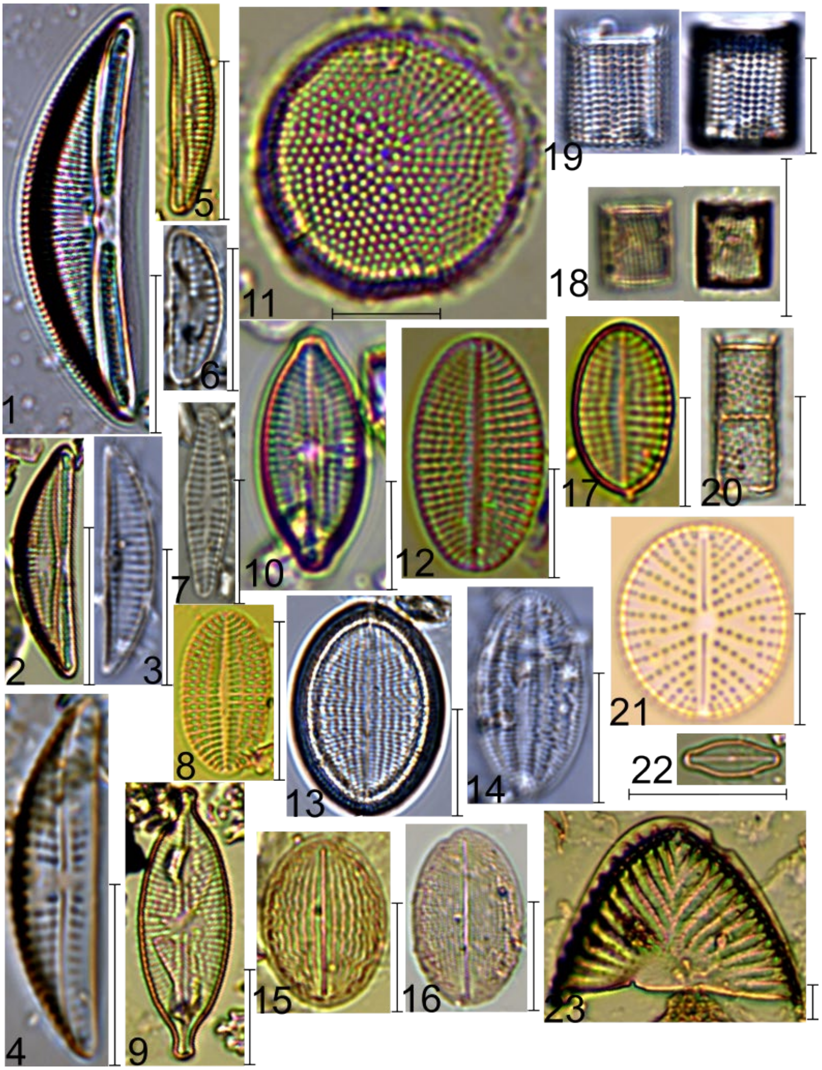
Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
	& S.I. Genkal 2011					
Staurosira aff. *sviridae*	M.S. Kulikovskiy, S.I. Genkal & T.M. Mikheeva 2011	benthic	freshwater	+		+
Staurosira cf. *subsalina*	(F. Hustedt) H. Lange-Bertalot 2004	benthic	brackish	+		+
Staurosira tabellaria	(W. Smith) G. Leuduger-Fortmorel 1878	benthic	fresh-brackish			+
Staurosira venter	(C.G. Ehrenberg) P.T. Cleve & J.D. Möller 1879	benthic	fresh-brackish			+
Staurosira spp.		benthic	unknown	+	+	+
Staurosirella dubia	(A. Grunow) E.A. Morales Luizaga & K.M. Manoylov 2010	benthic	freshwater	+		
Staurosirella lapponica	(A. Grunow) D.M. Williams & F.E. Round 1988	benthic	fresh-brackish	+	+	
Staurosirella aff. *martyi*	(J. Héribaud) E.A. Morales Luizaga & K.M. Manoylov 2006	benthic	fresh-brackish	+		
Staurosirella martyi	(J. Héribaud) E.A. Morales & K.M. Manoylov 2006	benthic	fresh-brackish	+	+	+
Staurosirella minuta	E.A. Morales & M.B. Edlund 2003	benthic	fresh-brackish	+		
Staurosirella cf. *oldenburgiana*	(F. Hustedt) E.A. Morales 2005	benthic	freshwater	+		+
Staurosirella neopinnata	E.A. Morales, C.E. Wetzel, E.Y. Haworth & L. Ector 2019	benthic	fresh-brackish	+	+	+
Staurosirella spp.		benthic	unknown	+		+

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1 /2017**
Stephanocyclus meneghinianus	(F.T. Kützing) M.S. Kulikovskiy, S. Genkal & Kociolek 2022	benthic	brackish-freshwater	+	+	+
Stephanodiscus hantzschii	A. Grunow 1880	planktonic	fresh-brackish	+	+	+
Stephanodiscus medius	H. Håkansson 1986	planktonic	fresh-brackish		+	
Stephanodiscus minutulus	(F.T. Kützing) P.T. Cleve & J.D. Möller 1882	planktonic	fresh-brackish	+	+	+
Stephanodiscus neoastraea	H. Håkansson & B. Hickel 1986	planktonic	fresh-brackish	+	+	+
Stephanodiscus parvus	E.F. Stoermer & H. Håkansson 1984	unknown	fresh-brackish	+	+	+
Stephanodiscus rotula	(F.T. Kützing) N.I. Hendey 1964	planktonic	brackish	+	+	
Stephanodiscus spp.		planktonic	unknown	+	+	+
Surirella angusta	F.T. Kützing 1844	benthic	fresh-brackish	+		
Surirella brebissonii	K. Krammer & H. Lange-Bertalot 1987	benthic	brackish-freshwater		+	
Surirella librile	(C.G. Ehrenberg) C.G. Ehrenberg 1845	benthic	fresh-brackish	+	+	
Surirella microlibrile	B. Van de Vijver, M. Pottiez & I. Jüttner 2024	benthic	fresh-brackish	+		
Surirella hibernica	(W. Smith) D.A. Kapustin & O.N. Kryvosheia 2019	benthic	brackish-freshwater	+		
Surirella cf. *minuta*	L.A. de Brébisson ex F.T. Kützing 1849	benthic	brackish-freshwater	+	+	
Surirella robusta	(C.G. Ehrenberg) C.G. Ehrenberg 1842	benthic	fresh-brackish	+		

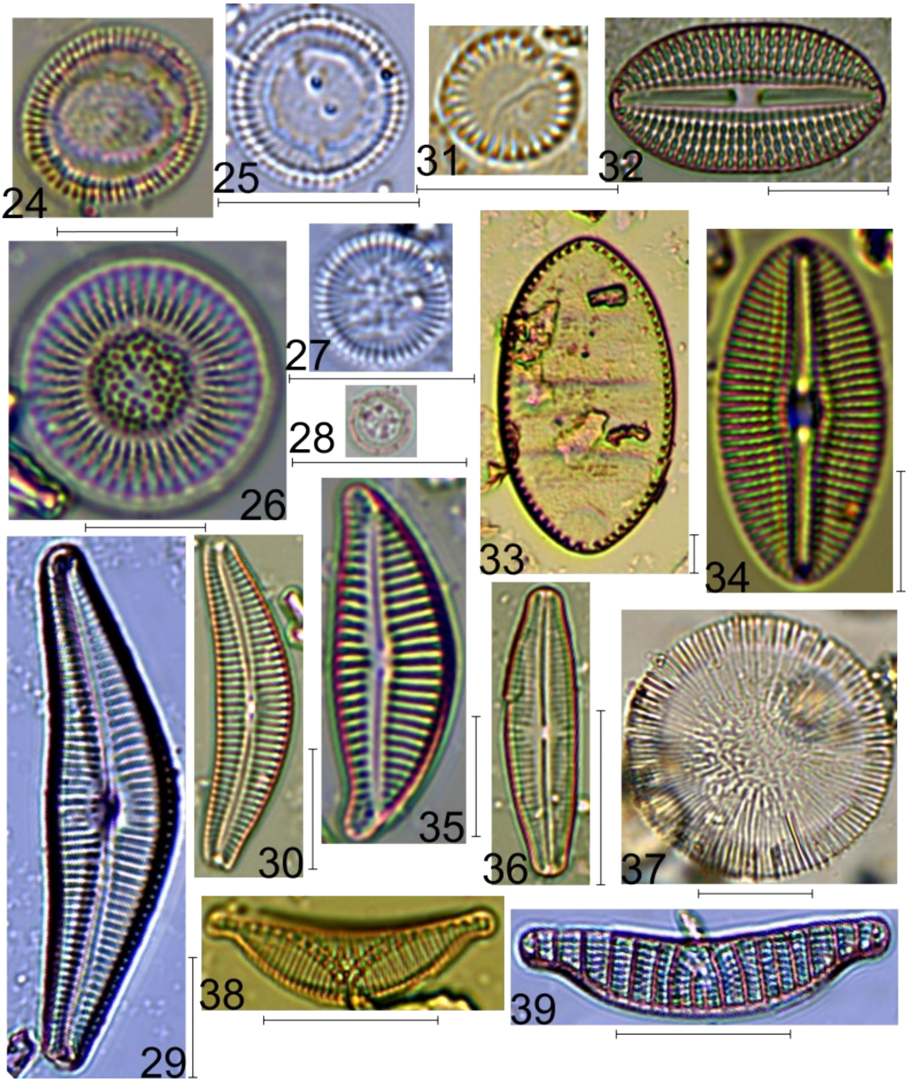
Diatom name	Authors	Habitat	Salinity	66370	3P	CL_1 /2017
Synedra famelica	F.T. Kützing 1844	unknown	fresh-brackish	+		
Synedra spp.		benthic	unknown		+	
Tabellaria flocculosa	(A.G. Roth) F.T. Kützing 1844	benthic	freshwater		+	
Tabularia fasciculata	(C.A. Agardh) D.M. Williams & F.E. Round 1986	benthic	brackish	+		
Thalassiosira hyperborea var. *lacunosa*	G.R.Hasle 1989	planktonic	brackish	+		
Thalassiosira lacustris	(A. Grunow) G.R. Hasle 1977	planktonic	brackish-freshwater		+	
Tryblionella acuminata	W. Smith 1853	planktonic	marine-brackish	+	+	
Tryblionella angustata	W. Smith 1853	benthic	fresh-brackish	+		
Tryblionella brunoi	(H. Lange-Bertalot) M. Cantonati & H. Lange-Bertalot 2017	benthic	fresh-brackish	+		
Tryblionella levidensis	W. Smith 1856	benthic	brackish-freshwater		+	
Tryblionella sp.		unknown	unknown	+		+
Ulnaria acus	(F.T. Kützing) M. Aboal, M. Álvarez-Cobelas, J. Cambra & L. Ector 2003	benthic	fresh-brackish		+	
Ulnaria biceps	(F.T. Kützing) P. Compère 2001	benthic	fresh-brackish		+	
Ulnaria capitata	(C.G. Ehrenberg) P. Compère 2001	benthic	fresh-brackish	+	+	
Ulnaria delicatissima	(W. Smith) M. Aboal & P.C. Silva 2004	benthic	fresh-brackish	+		

Diatom name	**Authors**	**Habitat**	**Salinity**	**66370**	**3P**	**CL_1/2017**
Ulnaria ulna	(C.L. Nitzsch) P. Compère 2001	benthic	fresh-brackish	+	+	
Ulnaria sp.		benthic	unknown	+		+
Witkowskia anglophila	(H. Lange-Bertalot) M.S. Kulikovskiy, A. Glushchenko, A. Mironov & J.P. Kociolek 2024	benthic	brackish-freshwater	+		+

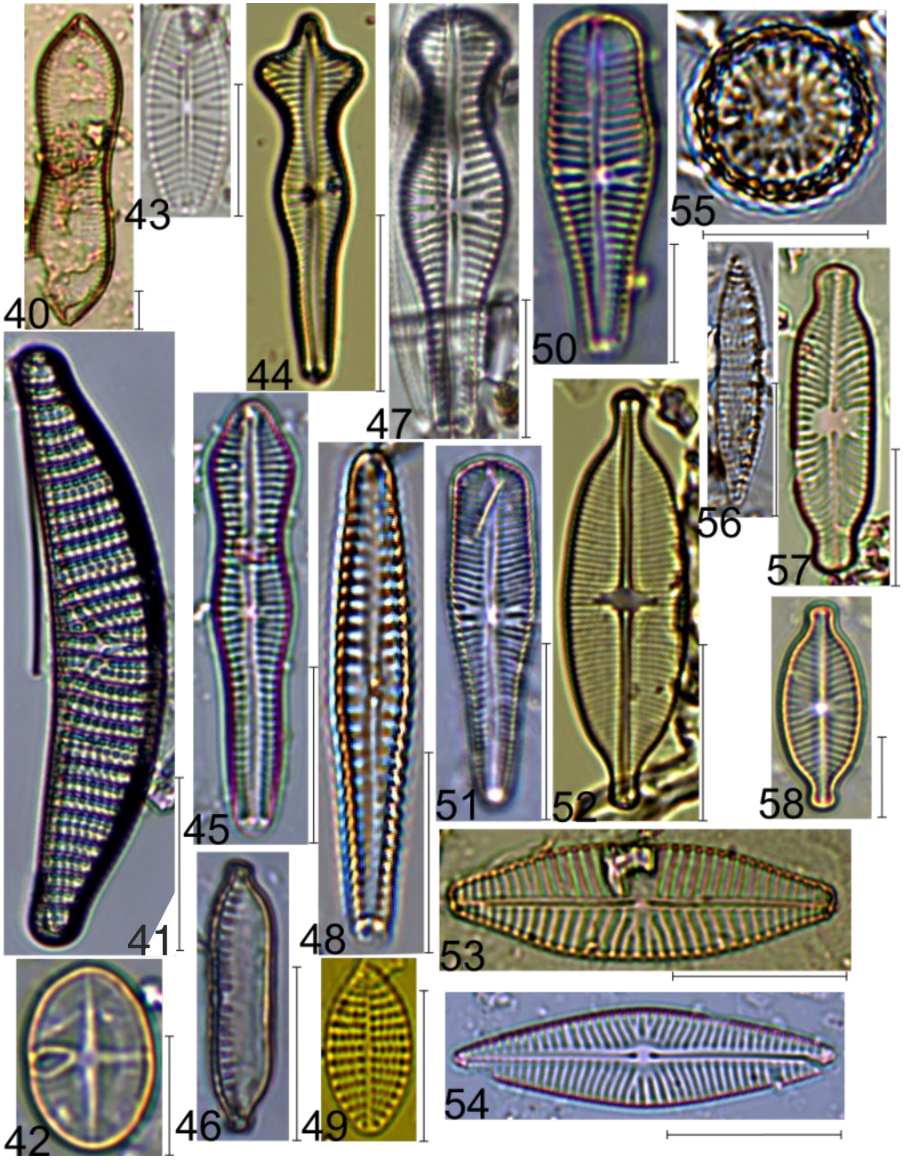
APPENDIX B. REPRESENTATIVE IMAGES OF IDENTIFIED DIATOM TAXA



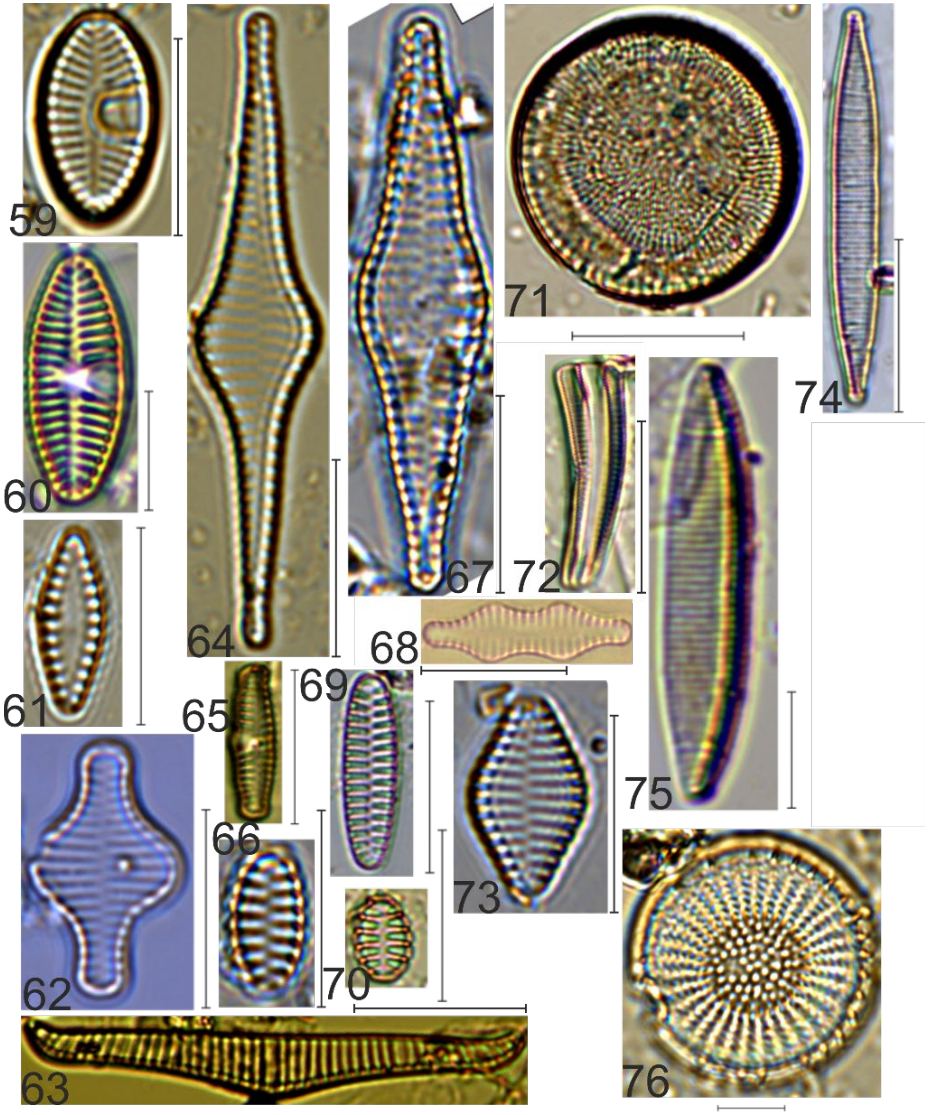
1 – *Amphora ovalis*, 2 – *Amphora* sp., 3 – *Amphora eximia*, 4– *Amphora copulata*, 5 – *Amphora* sp. 2, 6 – *Amphora pediculus*, 7 – *Achnanthidium minutissimum*, 8 – *Cocconeis disculus*, 9 – *Aneumastus tusculus*, 10 – *Aneumastus minor*, 11 – *Actinocyclus normanii*, 12 – *Cocconeis scutellum*, 13 – *Cocconeis euglypta*, 14 – *Cocconeis placentula*, 15 – *Cocconeis lineata*, 16 – *Cocconeis placentula* s.l., 17 – *Cocconeis neothumensis*, 18 – *Aulacoseira ambigua*, 19 – *Aulacoseira islandica*, 20 – *Aulacoseira granulata*, 21 – *Cavinula scutelloides*, 22 – *Adlafia* sp., 23 – *Campylodiscus hibernicus*.



The scale bar is 10 µm in all pictures. 24 – *Cyclotella schumannii*, 25 – *Cyclotella* sp., 26 – *Cyclostephanos dubius*, 27 – *Cyclotella choctawhatcheana*, 28 – *Cyclotella* sp. 2, 29 – *Cymbella neocistula*, 30 – *Cymbella* sp., 31 – *Cyclotella meneghiniana*, 32 – *Diploneis domblittensis*, 33 – *Cymatopleura elliptica*, 34 – *Diploneis calcilacustris*, 35 – *Encyonema silesiacum*, 36 – *Cymbopleura subaequalis*, 37 – *Ellerbeckia arenaria*, 38 – *Epithemia sorex*, 39 – *Epithemia adnata*. The scale bar is 10 µm in all pictures.



40 – *Cymatopleura solea*, 41 – *Epithemia turgida*, 42 – *Gliwiczia calcar*, 43 – *Geissleria cummerowi*, 44 – *Gomphonema acuminatum*, 45 – *Gomphonema brebissonii*, 46 – *Hantzschia amphioxys*, 47 – *Gomphonema capitatum*, 48 – *Gomphonema* sp., 49 – *Karayevia clevei*, 50 – *Gomphonema truncatum*, 51 – *Gomphonema pala*, 52 – *Mastogloia albertii*, 53 – *Navicula reichardtiana*, 54 – *Navicula* sp., 55 – *Paralia sulcata*, 56 – *Nitzschia amphibia*, 57 – *Placoneis paraelginensis*, 58 – *Placoneis pseudanglica*. The scale bar is 10 µm in all pictures.



59 – *Planothidium joursacense*, 60 – *Planothidium lanceolatum*, 61 – *Pseudostaurosira brevistriata*, 62 – *Staurosira construens*, 63 – *Rhopalodia gibba*, 64 – *Staurosira inflata*, 65 – *Reimeria uniseriata*, 66 – *Staurosira construens* var. *pumila*, 67 – *Staurosira inflata* var. *istvanffyi*, 68 – *Staurosira binodis*, 69 – *Staurosirella martyi*, 70 – *Staurosirella neopinnata*, 71 – *Thalassiosira baltica*, 72 – *Rhoicosphenia abbreviata*, 73 – *Staurosira tabellaria*, 74 – *Tryblionella angustata* 75 – *Tryblionella brunoi*, 76 – *Stephanodiscus neoastraea*. The scale bar is 10 µm in all pictures.

SANTRAUKA

SANTRUMPOS

^{14}C	–	radioaktyvusis anglies izotopas (anglis-14)
AD	–	Anno Domini (lot. Viešpaties metais), metų skaičius pagal Julijaus ir Grigaliaus kalendorius
AMS	–	akceleratoriaus masių spektrometrija
pr. KR	–	prieš Kristų, metai iki numanomo Jėzaus Kristaus gimimo
ž.j.l.	–	žemiau jūros lygio
BLE	–	Baltijos ledyninis ežeras
pr. d.	–	metai prieš dabartį (skaičiuojant nuo 1950 m.)
kal. m. pr. d.	–	kalibruoti metai prieš dabartį (skaičiuojant nuo 1950 m.)
L1, L2, L3	–	pirma, antra, trečia Litorinos jūros transgresijos
LDAZ	–	vietinės titnagdumblių bendrijų zonos
LOI	–	kaitinimo nuostolis/ praradimas deginant – metodas nuosėdų sudėties nustatymui (%)
MS	–	magnetinis imlumas
OSL	–	optiškai stimuliuota liuminiscensija
spp.	–	kelios rūšys
sp.	–	viena, neapibrėžta rūšis
var.	–	taksonominis rangas
U1, U2, U3, U4	–	nuosėdų litologiniai vienetai (išskirti autorės)

ĮVADAS

Tyrimo problematika. Baltijos jūra yra viena iš geriausiai ištirtų jūrų Europoje, kurios holoceno laikotarpio raida buvo sudėtinga ir pažymėta keliais svarbiais vystymosi etapais. Nors pagrindiniai Baltijos jūros vystymosi etapai yra nustatyti, vis dar lieka nemažai neaiškumų dėl jų pobūdžio ir perėjimo iš vieno etapo į kitą laiko, ypač skirtingose baseino dalyse.

Vienas iš labiausiai diskutuojamų klausimų yra perėjimo iš Ancyliaus ežero į Litorinos jūrą laikas ir pobūdis. Šis perėjimas Baltijos jūroje vyko ne vienu metu t.y. asinchroniškai (Andrén et al., 2000; Kostecki et al., 2015), o jo atkūrimas kai kuriuose regionuose yra gan sudėtingas dėl intensyvios erozijos, nuosėdų perklostymo ir glacioizostazijos procesų (Vaikutienė et al., 2025; Mojski, 2000). Prie neišspręstų klausimų – sūraus vandens patekimo į Baltijos jūrą keliai bei druskingumo kaita Litorina jūros metu (Björck, 1995; Rößler et al., 2011; Ning et al., 2017). Dar vienas svarbus klausimas yra susijęs su holoceno priekrantės lagūnų hidrologiniu režimu. Naujausi tyrimai pietryčių Baltijos jūroje rodo, kad Kuršių marių lagūna buvo izoliuota nuo vidurinio holoceno pradžios (8200 kalendorinių metų pr. m. e.), įskaitant kelis epizodinius Litorinos jūros vandens įsiveržimus (Damušytė, 2011). Tačiau vis dar nėra aišku, kaip tai paveikė vandens apykaitą, druskingumo gradientus ir ekosistemos funkcionavimą, taip pat ar šie pokyčiai vyko vienu metu pietinėje ir šiaurinėje lagūnos dalyse.

Šių problemų sprendimas reikalauja kompleksinių tyrimų, kur titnagdumblių analizė atlieka svarbų vaidmenį. Ji yra vienas iš informatyviausių paleontologinių metodų ir jau dešimtmečius plačiai naudojama biostratigrafiniuose ir paleogeografiniuose tyrimuose (Denys ir de Wolf, 2001). Kadangi titnagdumblių sankaupos jautriai reaguoja į druskingumo ir vandens gylio pokyčius, jų sudėtis nuosėdų įrašuose gali būti patikimas santykinio vandens lygio pokyčių, jūros vandens įsiveržimų indikatorius bei padėti atskirti trumpalaikius ar ilgalaikius hidrologinius pokyčius Baltijos jūros evoliucijos metu.

Todėl, norint išspręsti klausimus, susijusius su Baltijos jūros raida ir pakrančių dinamika, būtina gilinti mūsų supratimą apie pietryčių Baltijos pakrantės aplinkos raidą, ypač naudojant aukštos skiriamosios gebos titnagdumblių rekonstrukcijas.

Tyrimo aktualumas. Titnagdumblių pagrindu atlikta trijų skirtingų priekrančių ekosistemų rekonstrukcija prisideda prie Pietryčių Baltijos jūros regiono raidos pažinimo. Nauji chronologiniai duomenys ir informacija apie nuogulų kaupimosi sąlygas papildo esamas paleosedimentologinių sąlygų ir priekrančių formavimosi koncepcijas. Be mokslinės reikšmės, šie rezultatai turi ir svarbią praktinę vertę, nes padeda geriau suprasti ilgalaikę priekrančių dinamiką, kuri yra esminė prognozuojant tolesnius kranto linijos ir klimato pokyčius. Tokios žinios sudaro pagrindą efektyviam kranto zonos valdymui bei prisideda prie gamtos apsaugos ir ekosistemų atkūrimo planavimo.

Pagrindinis tikslas ir uždaviniai

Pagrindinis šio mokslinio projekto **tikslas** – rekonstruoti, taikant kompleksinius tyrimus, Pietryčių Baltijos paleoaplinkos raidą vėlyvojo ledynmečio-holoceno laikotarpiu daugiausia dėmesio skiriant vandens lygio svyravimams ir klimato sąlygotiems pokyčiams.

Siekiant minėto tikslo buvo iškelti šie **uždaviniai**:

- išanalizuoti nuosėdų sekas gręžinių pjūviuose iš skirtingų aplinkų, siekiant išsiaiškinti sedimentacines sąlygas;
- išanalizuoti titnagdumblių bendrijas ir nustatyti paleoaplinkos sąlygų kaitą;
- susieti tyrimų rezultatus su regioniniais paleoaplinkos pokyčiais;
- susieti identifikuotas aplinkos sąlygas su Baltijos jūros raidos stadijomis ir globaliais klimato svyravimais.

Ginamieji teiginiai

1. Titnagdumblių bendrijos gali būti Baltijos ledyninio ežero ir Litorinos jūros stadijų indikatoriais PR Baltijos jūros priekrantės vandenyse, tuo tarpu Joldijos jūros ir Ancyliaus ežero stadijas sunku atskirti dėl nestabilių paleosedimentologinių sąlygų;
2. Pietvakarinės Kuršių marių dalies titnagdumblių kompleksas nuo vidurinio holoceno pradžios laikotarpio vystėsi baseine, izoliuotame nuo jūros;
3. Nemuno deltos titnagdumblių floros vystymasis nebuvo įtakojamas jūros vandens intruzijų dėl upės hidrologinio režimo poveikio;
4. Pietryčių Baltijos regiono titnagdumblių kompleksai pasižymi heterogeniškumu skirtingose aplinkos sąlygose.

Tyrimo naujumas. Disertacijoje pateikiama nauja, titnagdumbliais pagrįsta trijų Pietryčių Baltijos jūros ekosistemų rekonstrukcija, interpretuojanti jų raidą po paskutinio apledėjimo vietinių aplinkos veiksnių poveikio kontekste. Pietvakarinėje Kuršių marių dalyje titnagdumblių tyrimai atlikti pirmą kartą. Buvo sudaryti du nauji amžiaus-gylio modeliai, suteikiantys informaciją apie nuogulų kaupimosi greičius ir sąlygas. Koreliuojant titnagdumblių duomenis su stratigrafiniu kontekstu ir absoliutaus amžiaus datomis, atskleista sudėtinga Pietryčių Baltijos regiono raida, pasižyminti minimalia jūros įtaka tiek lagūnos, tiek deltos ekosistemoms net ir maksimalios Litorinos jūros transgresijos metu. Taip pat nustatyta laipsniška Kuršių marių izoliacija ir eutrofikacija vidurinio–vėlyvojo holoceno laikotarpiu. Gauti rezultatai papildo esamas Pietryčių Baltijos jūros regiono raidos poledynmečiu koncepcijas.

Mokslinis darbo rengimas. Tyrimas buvo pradėtas 2021 m. kaip doktorantūros projekto dalis Valstybiniame mokslinių tyrimų institute Gamtos tyrimų centre (GTC), finansuojamame Lietuvos Respublikos. Šis darbas pagrįstas nauja geologine medžiaga, kurios dalis buvo surinkta dalyvaujant autorei, taip pat kitų tyrėjų pateikta medžiaga. Autorės supratimą apie Baltijos jūros sistemą papildomai sustiprino dalyvavimas INTIMATE–INQUA vasaros mokykloje (Turku, Suomija, 2022 m. rugsėjis). Nauji duomenys, apibūdinantys nuosėdų litologinius ypatumus (LOI, MS, $CaCO_3$) duomenys buvo gauti ir išanalizuoti autorės. Titnagdumblių tyrimų metodika buvo įsisavinta vadovaujant dr. Vaidai Šeirienei, o taksonominio identifikavimo įgūdžiai tobulinti tarptautiniuose mokymuose ir seminaruose: "Europos Brachysira taksonų revizija" (Meise botanikos sodas, Briuselis, 2023 m. gegužė); "Staurosirella & Staurosira" (Ochridas, Šiaurės Makedonija, 2024 m. gegužė) ir 7-ąjį Šiaurės šalių titnagdumblių rūšių interkalibracijos seminarą (Norrtälje, Švedija, 2024 m. sausis). Autorė paruošė 128 mėginius titnagdumblių analizei, juos išanalizavo ir identifikavo 424 titnagdumblių taksonus, priklausančius 95 gentims. Remiantis AMS radiokarboninio datavimo rezultatais, autorė sudarė du naujus amžiaus-gylio modelius.

Darbo aprobavimas. Tyrimo rezultatai, kartu su bendraautoriais, buvo pristatyti penkiose tarptautinėse ir vienoje nacionalinėje mokslinėje konferencijoje. Taip pat buvo publikuoti du straipsniai recenzuojamuose ir ISI Web of Science indeksuojamuose mokslo žurnaluose.

Darbo struktūra. Disertaciją parengtą anglų kalba, sudaro įvadas, 6 skyriai, išvados, literatūros sąrašas, 2 priedai, publikacijų disertacijos tema sąrašas, santrauka (lietuvių kalba) ir autorės gyvenimo aprašymas (CV). Darbo apimtis 94 puslapiai, 21 paveikslas ir 7 lentelės.

1. PIETRYTINĖS BALTIJOS PALEOGEOGRAFINIŲ TYRIMŲ RAIDA

Pirmieji fundamentalūs tyrimai buvo atlikti XIX a. antroje pusėje vokiečių-prūsų geologų, iš kurių ypač išsiskiria G. Berendt (1869) darbai. Jis pirmasis apibendrino Kuršių marių ir jų apylinkių geologinę sandarą, pasiūlė kvartero nuogulų klasifikaciją ir nustatė jų santykinę chronologinę seką. Šiame darbe taip pat buvo pateiktas vienas ankstyviausių Kuršių marių raidos modelių.

XX a. pradžioje paleogeografinių koncepcijų vystymą tęsė A. Tornquist (1910), kuris detaliai išanalizavo Sambijos pusiasalio geologinę sandarą ir pirmą kartą pasiūlė išilginės (išilgai kranto) sąnašų pernašos modelį. H. K. H. von Wichdorf (1919) dar labiau išplėtė regionines žinias, sudarydamas Pietryčių Baltijos pakrantės geologinį žemėlapį ir tyrinėdamas Kuršių nerijos, Kuršių marių bei Nemuno deltos sandarą. Tarpukario laikotarpiu intensyvūs Kuršių nerijos kilmės ir morfologijos tyrimai buvo vykdomi K. Andrée (1932), K. Beurlen (1933) ir O. Pratje (1935; 1948). Reikšminga pažanga buvo pasiekta ir biostratigrafiniuose tyrimuose – W. Benrath (1934) pirmasis panaudojo fosilinių augalų duomenis Kuršių marių regiono stratigrafijai geochronologiškai pagrįsti bei sukūrė ankstyvą žiedadulkių floros raidos schemą. Sistemingi Lietuvos tyrėjų darbai buvo vykdomi XX a. 6–9 dešimtmečiais. V. Gudelis (1959; 1979) sukūrė išsamų Pietryčių Baltijos pakrantės paleogeografinės raidos modelį, išskirdamas tris pagrindinius vystymosi etapus – nuo prieledyninių ežerų iki Kuršių marių susiformavimo. Jis pasiūlė segmentuotą Kuršių nerijos raidos modelį ir įvertino glacioizostatinio kilimo bei neotektoninių judesių įtaką pakrančių raidai. V. Gudelis taip pat pateikė detalią Kuršių marių dugno sedimentologinę schemą ir parodė, kad šiaurinė ir pietinė Kuršių nerijos dalys formavosi skirtingomis sąlygomis. M. Kabailienė (1967) pirmoji pritaikė titnagdumblių analizę Baltijos pakrančių ir lagūnų nuoguloms, aprašė skirtingiems Baltijos jūros raidos etapams būdingas titnagdumblių bendrijas ir rekonstravo Litorinos jūros raidos fazes. Jos darbai prisidėjo prie senųjų lagūninių krantų evoliucijos supratimo ir atskirų lagūnos raidos etapų išskyrimo. Svarbų indėlį įnešė R. Kunskas (1970), kuris rekonstravo Nemuno deltos raidos etapus holoceno laikotarpiu. Jis pabrėžė, kad vidurinio holoceno metu deltinių salų ir nerijinių darinių kompleksai sudarė morfologinį pagrindą Kuršių nerijos formavimuisi, galiausiai lėmusiam marių izoliaciją.

J. Kasperovičienė (1990) reikšmingai prisidėjo prie titnagdumblių tyrimų Lietuvos vandens telkiniuose, ypač Kuršių marių ir vidaus ežerų studijomis. J. Lavrušinas (1993) pasiūlė hipotezę apie galimą Kuršių nerijos glaciotektoninę kilmę. Vėliau A. Blažčišinas (1998) atliko plataus masto regioninius tyrimus, kuriuose integravo seismostratigrafinius, litologinius ir mikrofosilijų duomenis, siekdamas rekonstruoti buvusių pakrančių zonų morfologiją, ankstyvųjų smėlio barjerų formavimąsi ir kranto linijos dinamiką Ancyliaus ežero ir Litorinos jūros etapais. Šiuose darbuose pateiktos vienos ankstyviausių Pietryčių Baltijos krantų rekonstrukcijų ir detali Litorinos transgresijų seka.

XXI a. tyrimai išsiplėtė ir į jūrinę atvirojo šelfo zoną. D. Ūsaitytė (2001) reikšmingai prisidėjo prie vėlyvojo kvartero nuogulų Pietryčių Baltijos pakrantės zonoje biostratigrafinių tyrimų, apibendrindama radioanglies datavimo, titnagdumblių analizės ir žiedadulkių duomenis. Baltijos jūros paleogeografinių sąlygų kaita vėlyvojo ledynmečio–holoceno laikotarpiu buvo plačiai tirta pasitelkiant titnagdumblių analizę; svarų indėlį į šiuos tyrimus įnešė G. Vaikutienė (2003), kurios darbai buvo orientuoti į centrinės ir Pietryčių Baltijos titnagdumblių bendrijų koreliaciją ir parodė, kad titnagdumblių bendrijos yra aukštos skiriamosios gebos indikatoriai druskingumo, vandens gylio, trofinės būklės ir antropogeninio poveikio rekonstrukcijoms per visą Baltijos jūros geologinę raidą (Trimonis et al., 2008; Kabailienė et al., 2009; Emelyanov ir Vaikutienė, 2013; Kaminskas et al., 2019; Vaikutienė et al., 2025).

L. Ž. Gelumbauskaitė (2009; 2010) taikė geofizinius metodus santykinio jūros lygio kaitos erdviniam modeliui sudaryti ir atskleidė ryškų kranto linijos diachroniškumą, nulemtą tiek glacioizostatinio kilimo, tiek neotektoninių procesų. Jos tyrimuose taip pat buvo rekonstruota paleo-Nemuno deltos raida nuo preborealio laikotarpio ir parodyta, kad dabartinėje deltos teritorijoje jūrinė akumuliacija yra beveik nepasireiškusi. J. Šečkus (2009) sukūrė keturmatį (4D) Lietuvos pakrantės modelį ir nustatė asinchronines transgresijos–regresijos sekas išilgai visos kranto linijos. Šie tyrimai patvirtino, kad Litorinos jūros etapo dinamika skirtinguose Lietuvos pakrantės sektoriuose buvo nevienoda ir ją lėmė vietiniai tektoniniai bei geomorfologiniai veiksniai. Reikšmingi tyrimai taip pat buvo atlikti Lietuvos geologijos tarnybos geologų grupės, dirbusios plataus masto Lietuvos pakrantės regiono kartografavimo projekte (Bitinas et al., 1997; 2000; 2002; 2004; Bitinas ir Damušytė, 2004). Šio projekto metu buvo tirti įvairūs pakrantės zonos geologiniai aspektai, kurie lėmė svarbius atradimus ir kartu atskleidė iki šiol neišspręstus kranto zonos raidos klausimus.

Vienas reikšmingiausių pastarojo dešimtmečio indėlių yra A. Damušytės (2011) darbas, kuriame buvo panaudoti absoliutaus datavimo, moliuskų bendrijų analizės ir geomorfologiniai duomenys. Autorė išskyrė aštuonis sedimentacinių paleoaplinkų tipus ir, remdamasi išsamia Baltijos priekrantės tyrimų palyginamąja analize, pasiūlė trijų Litorinos transgresijų (L1, L2, L3) modelį. Šiame tyrime taip pat buvo pabrėžtas Ancyliaus ežero etapo interpretavimo sudėtingumas Lietuvos pakrantėje. Naujausi regioniniai tyrimai apima ir A. Sergejevo (2015) pasiūlytą Pietryčių Baltijos paleogeografinį modelį, kuriame aprašoma pietinė Kuršių nerijos dalis, lagūnos raidos etapai bei pagrindinės Litorinos jūros hidrodinaminės transformacijos, įskaitant jūrinio vandens įsiskverbimą į lagūną ir smėlio barjerų evoliuciją. Pietryčių Baltijos raidos istoriją papildo tarptautiniai tyrimai iš Lenkijos, Latvijos ir Estijos. S. Uścinowicz (2006) sudarė santykinio jūros lygio kaitos kreivę pietinei Baltijos daliai, o A. Witkowski (2000) reikšmingai išplėtė regioninius titnagdumblių biostratigrafijos tyrimus. Latvijoje I. Grudzinska (2015), analizuodama lagūnų titnagdumblių bendrijas, parodė, kad jūros lygio pokyčiai tiesiogiai kontroliuoja vandens apykaitą tarp vietinių lagūninių baseinų. Estijoje A. Rosentau ir kt. (2023) rekonstravo ilgalaikę kranto linijos evoliuciją nuo ankstyvojo holoceno, integruodami lito-, biostratigrafinius ir chronologinius duomenis su nuotoliniais tyrimais ir geofiziniais duomenimis.

2. TITNAGDUMBLIŲ ANALIZĖ KAIP PATIKIMAS PALEOAPLINKOS REKONSTRUKCIJŲ ĮRANKIS

Titnagdumbliai – tai mikroskopiniai dumbliai, priklausantys Bacillariophyta skyriui ir Bacillariophyceae klasei. Jiems būdingi silicio dioksido šarveliai, turintys unikalią mikrostruktūrą. Titnagdumblių šarvelį sudaro du vožtuvėliai, tarpusavyje sujungti juosmenėliu (5 pav.). Titnagdumblių taksonominiam identifikavimui būtinas išsamus šarvelio morfologijos supratimas. Taksonominė identifikacija atliekama remiantis ląstelių forma, smulkiąja (mikro) struktūra ir dydžiu, naudojant šviesos mikroskopiją (Battarbee et al., 2001; Lange-Bertalot et al., 2017). Šarveliai praktiškai nėra jautrūs laiko ar cheminių pokyčių poveikiui, todėl titnagdumbliai puikiai išsilaiko dugno nuosėdose ir tampa neįkainuojamais paleoaplinkos indikatoriais (Smol ir Stoermer, 2010; de Wolf, 1982; van Dam et al., 1994; Denys, 1991; Vos ir de Wolf, 1993).

Titnagdumbliai aptinkami beveik visose vandens ekosistemose – nuo gėlavandenių iki jūrinių aplinkų. Ekologiniu požiūriu jie skirstomi į šias grupes:

- planktonas – tai rūšys, kurios pasyviai, visą gyvenimo ciklą praleidžia vandens stulpelyje;
- meroplanktonas – tai rūšių, kurios vieną dalį gyvenimo ciklo (dažniausiai būdamos ramybės stadijoje) praleidžia bentose, o kitą-planktone, visuma;

- tychoplanktonas – tai rūšys, kurios paprastai gyvena prisitvirtinusios (bentosas), bet atsitiktinai patenka į planktoną, pavyzdžiui, dėl audrų, srovių ar kitų aplinkos veiksnių;
- bentosinės – tai rūšys, kurios visą gyvenimo ciklą praleidžia prisitvirtinusios prie įvairių substratų:
  - epilitai – ant kietų substratų (riedulių, uolų, akmenų);
  - epifitai – ant vandens augalų ir makroskopinių dumblių;
  - epipsamitai – gyvena smėlyje arba jo paviršiuje;
  - epipelitai – gyvena ant suirusio organinio substrato (detrito).

Būtent substrato tipas ir jo stabilumas lemia titnagdumblių bendrijų struktūrą. Pavyzdžiui, epilito bendrijos yra ilgalaikės ir įvairios, o epifitinės - sezoninės, priklausančios nuo augmenijos būklės. Smėlio substratuose vyrauja smulkios, atsparios rūšys, gebančios išgyventi dinamiškose sąlygose. Šios savybės leidžia titnagdumbliams atspindėti tiek greitus, tiek ilgalaikius aplinkos pokyčius, o jų ekologiniai optimumai, kiekybiškai įvertinus, naudojami paleoaplinkos rekonstrukcijoms. Tai daro juos puikiu rodikliu paleoekologiniuose tyrimuose (Denys, 1991; Vos ir de Wolf, 1993). Fosilinės titnagdumblių bendrijos leidžia rekonstruoti daugelį aplinkos parametrų, įskaitant temperatūrą, pH, druskingumą, šviesos prieinamumą ir vandens gylį, hidrodinamines sąlygas (turbulenciją, bangavimą, sedimentacijos režimą), maistinių medžiagų kiekį ir deguonies sąlygas. Baltijos jūros raidos tyrimuose titnagdumbliai yra vienas svarbiausių paleoekologinių įrankių (Kabailienė, 2006).

Šiame darbe titnagdumbliai pasirinkti kaip pagrindinis paleoaplinkos indikatorius dėl: jų ekologinės amplitudės, puikaus kiautelių išlikimo, galimybės patvirtinti sedimentologinius ir geochemijos duomenis ir plataus pritaikomumo skirtingose sedimentacinėse aplinkose. Fosilinių titnagdumblių kompleksų analizė leidžia išsamiai interpretuoti fizinius ir cheminius paleobaseinų parametrus, suteikia galimybę identifikuoti tiek regioninius holoceno įvykius, tiek vietinius ekosistemų kaitos faktorius, kurie anksčiau buvo menkai dokumentuoti.

3. TYRIMŲ RAJONAS, TYRIMO MEDŽIAGA IR METODAI

Tyrimas apima tris skirtingas Pietryčių Baltijos kranto zonos ekosistemas, leidžiančias rekonstruoti įvairių sedimentacinių aplinkų raidą holoceno laikotarpiu (6 pav.).

Pirmoji tyrimų vieta yra „priekrantės vandenyse“. Gręžinys 66370 yra giliau litoralės, t. y. Baltijos jūros atveju – giliau nei kranto povandeninis šlaitas, kuris tęsiasi nuo kranto linijos iki gylio, kurį veikia audrų bangos (Gudelis, 1993). Todėl, norint apibūdinti nuosėdų kaupimąsi konkrečiomis priekrantės sąlygomis giliau litoralės, vartojamas terminas „priekrantės vandenys“ (Vaikutienė et al., 2025). Šiame tyrime terminas „priekrantės vandenys“ reiškia jūros dugno plotą nuo kranto linijos iki minimalaus jūros lygio Joldijos jūros stadijos metu, t. y. maždaug 60–65 m žemiau dabartinio jūros lygio. Šiame plote buvo ištirta 5 m gylio gręžinio 66370 nuosėdų kolonėlė.

Antroji tyrimų vieta yra pietvakarinėje Kuršių marių dalyje. Vandens gylis čia labai kinta – nuo 1–2 m rytinėje dalyje iki 4 m vakarinėje dalyje. Marių hidrologinį režimą lemia upių prietaka, vietinės srovės, vėjo režimas ir ribota vandens apykaita su Baltijos jūra. Šis regionas yra jautrus tiek jūros lygio svyravimams, tiek Nemuno deltinių procesų dinamikai. Iš šios teritorijos buvo išanalizuota 4,14 m ilgio gręžinio 3P nuosėdų kolonėlė.

Trečioji tyrimų vieta apima Nemuno deltos žemupį, kuriame geomorfologinė ir hidrologinė dinamika atspindi intensyvius holoceno sedimentacijos procesus (6 pav.). Delta pasižymi dideliais akumuliacijos tempais, dažnais potvyniais ir daugiakanale sistema, kurioje natūraliai formuojasi salos ir kanalai. Iš šios teritorijos buvo ištirta 1,9 m ilgio gręžinio CL_1/2017 nuosėdų kolonėlė.

Siekiant užtikrinti patikimą aplinkos ir sedimentacijos pokyčių rekonstrukciją, buvo naudota kompleksinė metodika. Nuogulų savybėms ir sedimentacijos sąlygoms įvertinti buvo atlikti šie tyrimai: nuogulų litologinis aprašymas ir jų suskirstymas į litologinius vienetus, magnetinio imlumo (MS) matavimai bei kaitinimo nuostolio (LOI) analizė. Absoliučiam nuogulų amžiui nustatyti keli mėginiai buvo datuoti radioanglies metodu, taikant greitintuvo masių spektrometriją (AMS), o gauti duomenys kalibruoti naudojant atmosferinę IntCal20 kalibravimo kreivę (Reimer et al., 2020). Gręžinyje 66370 dėl akivaizdaus nuosėdų perklostymo patikimo amžiaus-gylio modelio sudaryti nepavyko. Gręžiniams 3P ir CL_1/2017 buvo gautos tinkamos radiokarboninės datos, o amžiaus–gylio modeliai sudaryti naudojant *rbacon* paketą (R Core Team, 2022).

Titnagdumblių rūšinės sudėties kaitos analizė buvo pagrindinis paleoaplinkos rekonstrukcijų įrankis. Titnagdumblių analizė atlikta laikantis standartinių mėginių paruošimo procedūrų ir remiantis taksonominio identifikavimo literatūra (Battarbee et al., 2001; Snoeijs et al., 1993–1998;

Krammer ir Lange-Bertalot, 1986–1991; Lange-Bertalot et al., 2017; Witkowski et al., 2000). Taksonominiai duomenys buvo sugrupuoti į ekologines kategorijas pagal buveinės tipą (bentosiniai, planktoniniai) ir druskingumo toleranciją (Mertens et al., 2025). Titnagdumblių procentinio pasiskirstymo pjūvyje diagramos sudarytos naudojant Tilia programinę įrangą (Grimm, 1992). Suskirstymas į vietines zonas nustatytas vizualiai ir naudojant klasterinę analizę, naudojant CONISS metodą (Grimm, 1987). Gręžinyje CL_1/2017 210–310 cm gylyje buvo nustatyta gausi moliuskų bendrija, kurią identifikavo A. Damušytė. Litologiniai ir biostratigrafiniai vienetai buvo koreliuoti su nustatytais Baltijos jūros raidos etapais ir holoceno stratigrafiniais padaliniais (9 pav.).

4. REZULTATAI

4.1. Gręžinys 66370

Nuogulos suskirstytos į keturis litologinius vienetus (U1–U4, 10 pav.). U1 (gylis 500–340 cm) sudaro pilkai rudas molis su pavieniais smėlio ir žvyro tarpsluoksniais bei organinės medžiagos priemaiša. Didėjantis $CaCO_3$ kiekis ir ryškus magnetinio imlumo pikas viršutinėje U1 vieneto dalyje rodo padidėjusį detritinės medžiagos prinešimą. Ryškus perėjimas į aleuritą su smėlingais lęšiais U2 (340–300 cm), kartu su didėjančiu karbonatų kiekiu ir svyruojančiomis magnetinio imlumo reikšmėmis, žymi pereinamąjį etapą, kuriam būdingas padidėjęs mineralinės medžiagos kiekis. U3 vienetą (300–10 cm) sudaro labai smulkus smėlis su FeS dėmėmis; jam būdingas mažėjantis organinės medžiagos kiekis, $CaCO_3$ procentas ir mažėjančios magnetinio imlumo reikšmės. U4 (10–0 cm) sudarytas iš labai smulkaus, limonitizuoto smėlio, pasižyminčio minimaliu organinės medžiagos ir karbonatų kiekiu. Gręžinio 66370 mėginių radiokarboninis datavimas parodė anomaliai seną amžių, kuris galimai siejaas su senesnės organinės anglies perklostymu jaunesnėse nuogulose (1 lentelė). Šis reiškinys Baltijos jūros regione yra gana dažnas ir aprašytas kitų tyrėjų tyrimuose (Uścinowicz et al., 2000; Häusler et al., 2017; Lougheed et al., 2013; Ponomarenko et al., 2024; Rößler et al., 2011; Suteerasak et al., 2017). Todėl analizuotų nuogulų koreliacijai su pagrindiniais Baltijos jūros raidos etapais buvo remtasi litologinėmis nuosėdų savybėmis ir titnagdumblių bendrijų analizės duomenimis.

Remiantis titnagdumblių rūšinės sudėties pokyčiais, buvo išskirtos trys vietinės titnagdumblių bendrijų zonos (LDAZ, 11 pav.). **LDAZ I** (500–

300 cm) zonoje dominuoja bentosiniai gėlo-apysūrio vandenstaksonai, įskaitant epipsamitinę *Staurosirella martyi* (apie 39,3 %), epifitinę *Pseudostaurosira brevistriata* (daugiau nei 20 %), *Staurosirella neopinnata* (iki 16,8 %) ir *Amphora pediculus* (didžiausias kiekis – 14 %). Zonos viršutinėje dalyje gausėja apysūrės jūrinės rūšies *Cocconeis scutellum* (iki 9,4 %), taip pat atsiranda jūrinis taksonas *Paralia sulcata*. Apskritai bentosiniai taksonai sudaro 76–99,8 % bendros sumos, o apie 80 % taksonų pasižymi gėlo-apysūrio vandens tolerancija (12 pav.). **LDAZ II** (300–100 cm) zona, remiantis titnagdumblių bendrijų taksonominiais pokyčiais, suskirstyta į dvi subzonas (IIa ir IIb). Abiejose subzonose stebimi dideli *S. martyi* ir *P. brevistriata* kiekiai. Visoje zonoje stebimas planktoninių taksonų *Aulacoseira ambigua* (1,2–9,7 %) ir *A. islandica* (1,4–23,2 %) gausėjimas. **LDAZ IIa** (300–155 cm) būdingas dominuojančių taksonų pasikeitimas – nuo gėlavandenėsapysūrės rūšies *S. martyi* į apysūrės-gėlavandenės rūšies *Staurosira inflata* (iki 55 %, 11 pav.). Planktoniniai taksonai sudaro 0,4–32 % nuo bendros sumos, tačiau ir toliau vyrauja bentosinės rūšys, sudarančios 70,3–99,4 %. Vyrauja apysūrio-gėlo vandens taksonai (vidutiniškai 43,5 %), tačiau padidėja ir gėlavandenių taksonų kiekis, kuris vidutiniškai siekia 9,4 % (12 pav.). **LDAZ IIb** (155–100 cm) zonoje atsiranda gėlavandenė bentosinė rūšis *Ellerbeckia arenaria*, o *Staurosirella neopinnata* išnyksta, kas rodo aplinkos sąlygų pasikeitimą (11 pav.). Šiai subzonai būdingi keli lygiai, kuriuose ryškiai sumažėja titnagdumblių kiautelių gausa. Planktoniniai taksonai sudaro 2,8–19,6 %, tačiau ir toliau dominuoja bentosinės formos, sudarančios 79–97 % nuo bendros sumos (12 pav.). **LDAZ III** (100–0 cm) zonai būdingas labai mažas titnagdumblių kiekis ir epizodiniai druskėtos planktoninės rūšies *Cyclotella choctawhatcheeana* pikai. Tik trijuose nuosėdų gyliuose buvo gauti statistiškai patikimi rezultatai.

4.2. Gręžinis 3P

Šiame gręžinyje buvo išskirti trys litologiniai vienetai (13 pav.). U1 vienetą (gylis 654–568 cm) sudaro smėlingas molis. U2 (568–275 cm) vienetą sudaro besikaitaliojančios durpių ir sapropelio nuogulos. U3 vienetas (275–245 cm) apima aleuritingas nuogulas su moliuskų liekanomis. Dvi radiokarboninės datos (2 lentelė) ir šiuolaikinio paviršiaus data (2021 m.) leido sudaryti patikimą amžiaus–gylio modelį. Nuosėdų seka apima beveik visą holoceną (~10 000 metų) ir fiksuoja vykusius aplinkos pokyčius (14 pav.).

Remiantis titnagdumblių bendrijų struktūros kaita, dominuojančiomis ekologinėmis grupėmis bei pagrindinių taksonų atsiradimu ar išnykimu, buvo išskirtos trys vietinės titnagdumblių bendrijų zonos (15 pav.). **LDAZ I** (660–565 cm) zonoje dominuoja gėlavandenės-apysūrės bentosinės rūšys, tokios kaip *Pseudostaurosira brevistriata*, *Staurosirella martyi*, *Staurosirella neopinnata* ir *Staurosira construens* var. *pumila*. Gėlo-apysūrio vandens taksonai sudaro daugiau kaip 80 % visos titnagdumblių sumos, tuo tarpu apysūrio-gėlo vandens taksonai nesiekia 10 % (16 pav.). **LDAZ II** (565–320 cm) pasižymi ryškiu dominuojančių rūšių kintamumu ir titnagdumblių stokojančiais intervalais, rodančiais, kad besikeičiančios aplinkos sąlygos įtakojo titnagdumblių produktyvumą ir jų išlikimą nuogulose. Kai kuriuose intervaluose *Pseudostaurosira brevistriata* viršija 50 % (15 pav). Kiti dažni bentosiniai taksonai yra *Staurosira binodis* (vidutiniškai 17,6 %) ir *S. inflata* (6,8–25,2 %), o *S. construens* var. *pumila* (~8 %), *Staurosirella neopinnata* (<3 %) ir *S. martyi* (<1 %) santykinis kiekis mažėja. Taip pat stebimas nedidelis, bet nuoseklus planktoninės gėlavandenės-apysūrės *Aulacoseira* spp. ir apysūrės-gėlavandenės *Actinocyclus normanii* gausėjimas (iki ~7 %). Planktoninių taksonų kiekis svyruoja, tačiau turi didėja (17,4–33,7 %), nors bentosinės rūšys išlieka dominuojančios (16 pav.). Ši tendencija koreliuoja su druskingumo grupių dinamika, kai apysūrio–gėlo vandens taksonai tampa reikšmingesni (8,8–25,3 %), nors gėlo-apysūrio vandens taksonai vis dar vyrauja. **LDAZ III** (320–240 cm) žymi tolesnę titnagdumblių bendrijų transformaciją (15 pav.). Nors *Aulacoseira*, *Pseudostaurosira* ir *Staurosira* gentys išlieka dominuojančios, fiksuojami keli svarbūs pokyčiai. *Staurosirella neopinnata* kiekis nedaug, bet stabiliai didėja (0,1–5,8 %). Viršutinėje zonos dalyje pasirodo ir gausėja planktoniniai titnagdumbliai: apysūrė-gėlavandenė *Actinocyclus normanii* (0–17 %), gėlavandenė *Aulacoseira islandica* (iki 3 %), gėlavandenės-apysūrės *Stephanodiscus hantzschii* (iki 2,2 %), *S. minutulus* (iki 2,4 %) ir *S. neoastraea* (iki 3 %). Šie pokyčiai aiškiai atsispindi tiek buveinių, tiek druskingumo grupių kreivėse, kuriose planktoninių taksonų pikas (iki 38 %) bei apysūrių-gėlavandenių ir gėlavandenių taksonų didėjimas glaudžiai koreliuoja su minėtų rūšių gausėjimu (16 pav.).

4.3. Gręžinys Nr. CL_1/2017

Buvo išskirti trys litologiniai vienetai (17 pav.). U1 vienetas (gylis 375– 315 cm) sudarytas iš durpių, kuriose organinės medžiagos kiekis viršija 84 %. $CaCO_3$ kiekis yra nedidelis (3–6 %), o magnetinis imlumas – minimalus. U2 vienetą (315–210 cm) sudaro smėlingas aleuritas, praturtintas moliuskų kriauklėmis; jam būdingas mažas organinės medžiagos kiekis (2–19 %), kintantis $CaCO_3$ procentas (1–9 %) ir nežymiai didėjanti magnetinio imlumo tendencija. U3 (210–190 cm) sudarytas iš homogeniško aleurito, kuriame didėja organinės medžiagos kiekis (~14 %) ir magnetinio imlumo reikšmės, o $CaCO_3$ kiekis kinta. Amžiaus–gylio modelis sudarytas remiantis dviem radioanglies datomis (3 lentelė) ir žinomu paviršiaus amžiumi (2017 m.). Tirto gręžinio nuosėdos kaupėsi nuo vidurinio holoceno (18 pav.).

Moliuskų bendrija (310–210 cm) apima tiek dvigeldžius, tiek pilvakojus (4 lentelė). Taksonominė sudėtis rodo vidutinį rūšių turtingumą, taip pat nustatyti natūralizuoti svetimžemiai taksonai – *Lithoglyphus naticoides* ir *Dreissena polymorpha*. Dauguma moliuskų yra būdingi gėlavandenėms aplinkoms.

Titnagdumblių analizė buvo atlikta tik lagūninėse nuogulose, atitinkančiose paskutinę Litorinos ir post-Litorinos jūros transgresijas (315–190 cm), kur druskingumo ir hidrologinio ryšio pokyčiai yra informatyviausi rekonstruojant deltinės ekosistemos raidą. Atsižvelgiant į titnagdumblių komplekso sudėties kaitą, buvo išskirtos dvi lokalios titnagdumblių zonos (19 pav.). **LDAZ I** (310–220 cm) zonoje dominuoja gėlavandenė-apysūrė rūšis *Pseudostaurosira brevistriata*, kurios gausumas svyruoja nuo 17 iki 39 %. Šiai zonai taip pat būdingas didesnis *Staurosirella martyi* kiekis viršutinėje zonos dalyje (14–36 %). Kiti, šiek tiek mažesniais kiekiais pasitaikantys taksonai, yra gėlavandenės-apysūrės *Staurosira construens*, *S. construens* var. *pumila* ir *S. venter*. Taip pat fiksuojami du ryškūs apysūriųgėlavandenių taksonų *Staurosira inflata* (17,7 %) ir *Navicula cari* (2,6 %) pikai (19 pav.). Beveik absoliučiai dominuoja bentosiniai taksonai, o bendrai vyrauja gėlo-apysūrio vandens taksonai, nors taip pat stebimas ryškus apysūrio-gėlo vandens taksonų pikas (17,8 %) (20 pav.). **LDAZ II** (220–190 cm) zonoje stebimas ryškus gėlavandenės-apysūrės rūšies *Melosira varians* pikas (24,2 %), lydimas didėjančio *Staurosirella neopinnata* kiekio (iki 10 %) ir sumažėjusio *S. martyi* kiekio (žemiau 10 %). Aiškūs apysūrių-gėlavandenių taksonų *Staurosira inflata* kiekio svyravimai – reikšmės didėja iki 16,6 %, o vėliau sumažėja iki 3–4 % (19 pav.). Bendras bentosinių taksonų kiekis išlieka nuolat aukštas (20 pav.).

5. VĖLYVOJO LEDYNMEČIO IR HOLOCENO PALEOAPLINKOS PIETRYTINĖJE BALTIJOJE.

5.1. Jūros pakrantės paleoaplinka

Gręžinio 66370 nuogulos atspindi itin dinamišką pakrantės aplinką, kuriai būdinga erozija, sąnašų pernaša ir hidrodinaminis nestabilumas (21 pav.), todėl paleoaplinkos rekonstrukcija yra sudėtinga.

Apatinėje pjūvo dalyje slūgsantis limnoglacialinis molis (U1) greičiausiai susiformavo po Baltijos ledyninio ežero (BLE) regresijos ir susiklojo gana ramioje sedimentacinėje aplinkoje, kuriai būdingas minimalus karbonatų prinešimas. Čia klestėjo gėlo-apysūrio vandens bentosinė titnagdumblių bendrija, dominuojant rūšiai *Staurosirella martyi* – kas laikoma vienu pagrindinių BLE požymių (Kabailienė, 1995). Nors Joldijos jūros nuogulas aiškiai atskirti sudėtinga, viršutinėje U1 litologinio vieneto nuogulų dalyje galima atsekti keletą transgresijos požymių: magnetinio imlumo ir karbonatų pikai, jūrinės rūšies *Paralia sulcata* pasirodymas ir planktoninių taksonų gausėjimas. Daugelis tyrėjų daro išvadą, kad šioje teritorijoje anksčiau egzistavo kelios gėlavandenės lagūnos, kurių krantai vėliau buvo ardomi Ancyliaus ežero transgresijos metu (Blazhchishin et al., 1974; Gelumbauskaitė, 2010; Kabailienė, 1995; Žulkus et al., 2020). Aukščiau slūgsančiame aleurito sluoksnyje (U2) pastebimai sumažėja dominuojančios gėlavandenės-apysūrės rūšies *Staurosirella martyi*. Šis mažėjimas kartu su apysūrės-jūrinės *Cocconeis scutellum* pasirodymu gali rodyti transgresijos pradžią. Vis dėlto, matomai, teritorijos raida išliko sudėtinga, todėl Ancyliaus ežero etapas, remiantis gautais duomenimis, negali būti patikimai išskirtas. U2 litologinio vieneto nuosėdose ryški kontaktinė zona ties 300 cm gyliu greičiausiai atspindi transgresinį paviršių, virš kurio nusėdo labai smulkus smėlis. Šis pokytis aiškiai siejamas su Litorinos jūros etapu (Rößler, 2006; Uścinowicz, 2014). Nustatyti FeS pėdsakai yra svarus įrodymas apie redukcines (anoksines) sedimentacijos sąlygas po gilesniu, silpniau ventiliuojamu vandens stulpu (Boman et al., 2010). Todėl titnagdumblių kompleksas, kuriame dominuoja apysūrė-gėlavandenė epifitinė *Staurosira inflata*, kartu pasitaikant planktoniniams taksonams ir pasirodant gėlavandenei *Ellerbeckia arenaria*, leidžia interpretuoti sublitoralinę pakrantės aplinką su gerai išsivysčiusia makrofitų danga ir pelaginėmis zonomis. Palaipsniui kylant jūros lygiui, bentosiniai ir epifitiniai titnagdumbliai prarado prieigą prie pakankamo šviesos kiekio, kas turėjo atsispindėti jų santykinio kiekio mažėjime. Be to, gėlavandenių titnagdumblių pasirodymą druskėtoje aplinkoje galima aiškinti perklostytos medžiagos priemaiša, bangų ir priekrančių srovių sąveikos metu. Alternatyviai, stiprūs potvyniai galėjo lemti aliuvinių nuogulų pernašą toli į atvirą jūrą (Szcześniak et al., 2023). Aiškus post-Litorinos etapo išskyrimas yra sudėtingas dėl ryškių litologinių ir geocheminių požymių stokos. Be to, kai kurie tyrėjai pateikia įrodymų apie holoceninių nuogulų eroziją, kurią sukėlė giliavandenių srovių aktyvumas (Harin ir Zukovskaya, 2013; Gelumbauskaitė, 2009).

5.2. Lagūninė paleoaplinka

Gręžinio 3P duomenys rodo, kad holoceno laikotarpiu pietvakarinė Kuršių marių dalis patyrė laipsniškus hidrologinius ir ekologinius pokyčius (21 pav.). Iki ~8850 kal. m. pr. d. čia kaupėsi smėlingo priemolio nuogulos, rodančios ramią, seklią aplinką, atitinkančią Baltijos jūros Ancyliaus ežero stadiją (Gudelis, 1979). *Pseudostaurosira brevistriata*, *Staurosira construens* var. *pumila* ir *Staurosirella neopinnata* dominavimas rodo žemą druskingumą (~1 ‰), o nedidelis bentosinių *Amphora* ir *Epithemia* taksonų kiekis leidžia spręsti apie nedidelį vandens gylį ir menką epifitinę dangą. Dideli *S. neopinnata* ir *Staurosirella martyi* kiekiai kartu su bentosinių rūšių dominavimu (>80 %) rodo gerai aeruotas, šaltas ir oligotrofines sąlygas (Mertens et al., 2025). Nemuno deltos ir Kuršių nerijos žiedadulkių duomenys atskleidžia apylinkėse augus mišrius pušų-beržų miškus, susiformavusius šylančio, bet palyginti sauso ankstyvojo holoceno klimato sąlygomis (Kabailienė, 2006; Napreenko-Dorokhova, 2015; Kaminskas et al., 2019; Damušytė et al., 2021). Apskritai, ankstyvajame holocene šioje vietoje galėjo būti gėlavandenio ežero pakraštys arba upės veikiama estuarinė aplinka. Nuo ~8850 kal. m. pr. d. baseinas patyrė spartų perėjimą nuo ežerinių prie sausuminių sąlygų, ką rodo žemapelkių durpių su medienos liekanomis kaupimasis. Tai siejama su vėlyvąja Ancyliaus ežero stadija ir vidurinio holoceno pradžia. Šie sedimentologiniai pokyčiai stipriai paveikė titnagdumblių bendrijos sudėtį: ženkliai padidėjo epifitinės *Pseudostaurosira brevistriata* rūšies, kuri susijusi su nendrynais ir viksvomis turtingais substratais, taip pat fiksuojami epizodiniai planktoninių (*Aulacoseira* spp., *Actinocyclus normanii*) ir apysūrių-gėlavandenių (*Staurosira inflata*) taksonų pikai, besikeičiantys su titnagdumblių stokojančiais intervalais. Šie svyravimai gali būti interpretuojami kaip atsakas į vandens lygio kaitą, maistinių medžiagų prieinamumą ir klimato poveikį izoliuotoje šlapynės sistemoje. Nors kai kurie planktoninių taksonų pikai laike sutampa su Litorinos transgresijos fazėmis, regioninės jūros lygio kaitos rekonstrukcijos ir nuoseklus grynai gėlavandenių titnagdumblių bendrijų dominavimas leidžia atmesti reikšmingas jūrinio vandens intruzijas (Sergeev, 2015). Baseinas vidurinio holoceno metu vystėsi kaip seklus, mažos energijos pakrantės šlapynės kompleksas, kurio raidą daugiausia lėmė klimato kaita ir upinė prietaka, kaip ir panašiose Nemuno deltos bei gretimose Kuršių regiono aukštapelkių sistemose (Damušytė et al., 2021; Napreenko et al., 2019; Napreenko-Dorokhova, 2015). Vėlyvajame holocene, po ~3000 kal. m. pr. d., lagūninės sąlygos stabilizavosi, vyko užliejimas ir smėlingo aleurito kaupimasis, siejamas su post-Litorinos transgresija (Damušytė, 2011). Apatinėje smėlingo dumblo dalyje yra moliuskų kiautelių, kuriuos sąlyginai galima būtų interpretuoti kaip *Dreissena polymorpha* ir *Valvata piscinalis*, remiantis Benrath (1934) duomenimis gautais iš to paties ploto. Jų buvimas liudytų apie gėlavandenes ar silpno druskingumo bei seklios aplinkos sąlygas. Titnagdumblių bendrijos rodo baseino gilėjimą ir didėjančią eutrofikaciją, ką patvirtina rūšies *Actinocyclus normanii* pasirodymas ir padidėjęs *Stephanodiscus minutulus* kiekis – kuri gerai žinoma kaip mezo- iki eutrofinių ir antropogeniškai paveiktų vandens telkinių indikatorius (Reavie et al., 2000). Lagūninės nuosėdos atspindi ilgalaikį perėjimą nuo seklios gėlavandenės sistemos prie pusiau uždaro lagūninio baseino, kurio raidą vis labiau kontroliavo gruntinio vandens lygio svyravimai, durpėjimo fazės ir laipsniškas baseino seklėjimas, o ne tiesioginė jūros įtaka.

5.3. Deltinė paleoaplinka

Gręžinio CL_1/2017 nuosėdos kaupėsi ekologiškai stabilioje ir gėlavandenėje aplinkoje nuo vidurinio iki vėlyvojo holoceno (21 pav.). Pasikeitus sedimentacijos pobūdžiui ir greičiui (~6015 kal. m. pr. d.), ankstyvąjame lagūnos vystymosi etape vyko mineralinės medžiagos sedimentacija. Nuo šio laikotarpio titnagdumblių bendrijose nuosekliai vyrauja epifitiniai ir smulkūs bentosiniai gėlo-apysūrio vandens taksonai, būdingi sekliai, makrofitais turtingai aplinkai (Vos ir de Wolf, 1993). Gausi bentosinių titnagdumblių flora kartu su moliuskų bendrija patvirtina ramias sedimentacijos sąlygas, gausiame vandens augalais ir sekliame vandens telkinyje. Intervalai, kuriuose aptinkama padidintam druskingumui tolerantiška *Dreissena polymorpha*, matomai rodo epizodinius padidėjusio hidrologinio aktyvumo laikotarpius, tačiau neatspindi tikrų druskingumo padidėjimo sąlygų. Jų stratigrafinė padėtis leidžia manyti, kad tai buvo trumpalaikiai aplinkos pokyčiai, susiję su upės dinamikos svyravimais, o ne su jūrine įtaka. Jūrinių ar apysūrių titnagdumblių nebuvimas patvirtina ekosistemos izoliaciją. Net ir aukštesnio jūros lygio laikotarpiais Nemuno deltos geomorfologija ir stiprus upės nuotėkis neleido sūriems vandenims prasiskverbti į šią Nemuno deltos dalį.

6. TITNAGDUMBLIŲ KOMPLEKSAI KAIP BALTIJOS JŪROS RAIDOS STADIJŲ INDIKATORIAI: LYGINAMOJI ANALIZĖ

Poledyninė Baltijos jūros raidos istorija skirstoma į kelias stadijas, apibrėžiamas druskingumo pokyčiais ir kiekvienai būdingomis specifinėmis titnagdumblių bendrijomis, kurios naudojamos kaip hidrologinių sąlygų ir kranto linijos poslinkių indikatoriai (5 lentelė; Snoeijs, 2001). Šiame tyrime šie nusistovėję indikatoriniai taksonai buvo palyginti su priekrantės vandenų gręžinio 66370 titnagdumblių įrašu, siekiant įvertinti, kiek šioje aplinkoje atsispindi Baltijos jūros raidos stadijos. Palyginimas parodė, kad nors kai kurie būdingi požymiai yra atpažįstami, gręžinio 66370 titnagdumblių bendrijos ženkliai skiriasi nuo klasikinių modelių, indikuodamos stiprią vietinių sedimentacijos ir hidrodinaminių sąlygų įtaką (6 lentelė).

Baltijos ledyninio ežero ir Joldijos jūros stadijoms būdingi požymiai gręžinyje 66370 yra gana silpni. Nors aptinkama *Aulacoseira islandica*, kiti būdingi šaltoms gėlavandenėms ir jūrinėms planktoninėms sąlygoms taksonai (*A. alpigena*, *Stephanodiscus rotula*, *Thalassiosira baltica*, *Diploneis spp.*, *Grammatophora oceanica*) neidentifikuoti. Bendrijose dominuoja gėlavandeniai ir gėlo-apysūrio vandens bentosiniai taksonai, tik sporadiškai pasitaikant *Actinocyclus normanii*. Tai leidžia manyti, kad Joldijos laikotarpiu jūros įtaka šioje vietoje buvo labai ribota, greičiausiai dėl pakrančių ar lagūnos dalinės izoliacijos padėties ir ribotos vandens apykaitos. Panašiai ir Ancyliaus ežero stadija daugiausia atspindi gėlavandenes sąlygas, tačiau tipiški litoralės epifitiniai taksonai yra menkai paplitę arba visai neaptinkami, tikėtina, dėl netinkamo substrato, deltinių-lagūninių buveinių struktūros ar trapios šarvelių struktūros. Pradinė Litorinos jūros stadija (Mastoglojos jūra) yra išreikšta aiškiau. *Mastogloia* spp., *Epithemia turgida* ir *Stephanodiscus neoastraea* pasirodymas rodo jūrinės įtakos pradžią, nors mažas Mastogloia šarvelių kiekis leidžia manyti, kad šios stadijos raiška yra silpnesnė nei klasikiniuose įrašuose. Pagrindinės Litorinos jūros stadijos metu atviroms Baltijos jūros sąlygoms būdingos pilnai jūrinės planktoninės bendrijos neaptinkamos. Titnagdumblių bendrijai būdingi epizodiniai *Cocconeis scutellum* pikai Litorinos stadijai priskiriamo litologinio vieneto apatinėje dalyje, o aukščiau pasirodo *Actinocyclus octonarius*, *Pseudosolenia calcar-avis* ir *Cyclotella choctawhatcheeana*, rodantys laipsnišką, tačiau ribotą jūrinės įtakos didėjimą eutrofinėmis sąlygomis. Apskritai gręžinys 66370 atspindi lagūnosdeltos pakraštį su ribotu jūriniu ryšiu, kuriame regioninės Baltijos jūros transgresijos yra fiksuojamos labai modifikuota forma, sąlygojamos vietinės hidrodinamikos, nuosėdų perklostymo ir gėlo vandens prietakos. Jose nėra išreikštos klasikinės jūrinės titnagdumblių sukcesijos.

Tuo tarpu lagūniniai ir deltiniai titnagdumblių kompleksai, kurie greičiausiai atspindi dalinai izoliuotas baseino dalis, buvo koreliuoti su Kuršių marių aplinką apibūdinančiomis indikatorinėmis rūšimis (7 lentelė). Ankstyvojo holoceno titnagdumblių bendrija glaudžiai atitinka Ancyliaus ežero stadijos indikatorinius taksonus, įskaitant *Staurosirella martyi*, *Amphora pediculus* ir *Pseudostaurosira brevistriata*, kurie rodo seklias gėlavandenes sąlygas su gausia litoraline augalija. Viduriniame holocene perėjimas į Litorinos jūros stadiją išreiškiamas ne tipine jūrinio-apysūrio vandens planktonine bendrija, bet *Aulacoseira taksonų* gausėjimu kartu su dominuojančiais bentosiniais titnagdumblių atstovais (*P. brevistriata*, *Staurosira construens* var. *pumila*). Klasikiniai Litorinos jūros stadijos indikatoriai, tokie kaip *Grammatophora marina* ir *Diploneis* spp., neaptinkami, kas rodo ribotą vandens apykaitą su atvira jūra ir stiprią facijinę kontrolę seklioje, augalija apaugusioje lagūninėje aplinkoje. Nemuno deltos gręžinio CL_1/2017 titnagdumblių bendrija dar labiau skiriasi nuo literatūroje pateikiamų Litorinos stadijos indikatorių. Joje nuosekliai dominuoja epilitiniai ir epifitiniai *Staurosira*, *Staurosirella* ir *Pseudostaurosira* genčių taksonai, atspindintys deltinę aplinką, kurios raidą pirmiausia lėmė upių prietaka, o ne jūriniai procesai. Tokia sudėtis rodo, kad rytinė Kuršių marių dalis vidurinio holoceno metu išliko gėlavandenė ar tik silpno druskingumo bei turtinga makrofitais net ir Litorinos transgresijos laikotarpiu. Vėlyvojo holoceno 3P gręžinio titnagdumblių kompleksas dar labiau skiriasi nuo klasikinio post-Litorinos, kuriam paprastai būdinga apysūrių taksonų, „šiuolaikinėms“ sąlygoms artima bendrija su *Navicula digitoradiata* ir retais apysūriais taksonais, tokiais kaip *Pinnularia borealis* var. *minor* ir *P. microstauron* var. *brebissonii*. Vietoje to tirtoms nuosėdoms būdingas nuolatinis gėlo-apysūrio vandens taksonų dominavimas, rodantis progresuojančią lagūnos izoliaciją ir hidrologines sąlygas, kontroliuojamas upinės prietakos ir didėjančios eutrofikacijos. Panaši tendencija stebima ir CL_1/2017 gręžinio nuosėdose, kur taip pat vyrauja gėlo-apysūrio vandens bendrijos (7 lentelė), atspindinčios upės dominuojamas lagūnines sąlygas tik su minimalia ir epizodine jūrinio vandens įtaka. Šiuos skirtumus pirmiausia lemia vietinės geomorfologinės ir hidrologinės sąlygos. Tiek Litorinos, tiek post-Litorinos stadijų metu rytinė ir pietinė Kuršių marių dalys funkcionavo kaip gėlavandenės sistemos, priešingai nei atviros jūros zonose, kur druskėti ir jūriniai taksonai yra gausiai paplitę (Kabailienė et al., 2009). Atitinkamai, CL_1/2017 gręžinio nuosėdos indikuoja vietinę gėlavandenę deltinę aplinką, o ne klasikinę jūrinę su jūrine-druskėta titnagdumblių bendrija. Panašiai ir 3P gręžinio nuosėdos atspindi lagūninę aplinką, kurioje gėlavandenės planktoninės ir bentinės bendrijos pakeičia tipinius Litorinos ir post-Litorinos titnagdumblių kompleksus, atspindėdamos silpną Baltijos jūros raidos stadijų raišką pakrantės lagūninėje aplinkoje.

IŠVADOS

1. Priekrantės vandenų aplinkos nuogulų pjūvio tyrimai leidžia identifikuoti Baltijos ledyninio ežero ir Litorinos jūros raidos stadijas, tuo tarpu Joldijos jūros ir Ancyliaus ežero stadijos aiškiai neišsiskiria. Tai lemia nestabilios paleosedimentacinės sąlygos, pasižyminčios intensyvia erozija, nuosėdų pernaša ir skirtingos kilmės bei amžiaus nuogulų perklostymu, apsunkinančios stratigrafinę interpretaciją ir patikimas paleogeografines rekonstrukcijas.
2. Pietvakarinės Kuršių marių dalies titnagdumblių kompleksas vystėsi kintant vietiniam hidrologiniam režimui. Gėlavandenių- apysūrių titnagdumblių rūšių dominavimas ir vyraujančios bentosinės buveinės rodo lagūnos izoliaciją nuo vidurinio holoceno laikotarpio.
3. Nemuno deltos aplinkoje titnagdumblių flora kartu su moliuskų bendrijomis vystėsi sekliame baseine, pasižyminčiame santykinai stabiliomis sedimentacijos sąlygomis, susidariusiomis nuo vidurinio holoceno metu. Deltinė ekosistema nepatyrė jūrinio vandens intruzijų dėl upės hidrologinio režimo įtakos.
4. Pietryčių Baltijos jūros regiono titnagdumblių kompleksų sudėtis atspindi įvairių aplinkos parametrų įtaką ekosistemų raidai. Priekrantės vandenyse nuosėdų kaupimąsi daugiausia lėmė erozija, pernaša ir perklostymas, tuo tarpu lagūninėje ir deltos aplinkose vyraujantį vaidmenį atliko vietinis hidrologinis režimas ir regioninė klimato kaita.

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Peer-reviewed journal articles:

1. Vaikutienė G., **Sosnina I.**, Grigienė A., Damušytė A., Šeirienė V., Skuratovič Ž., Bitinas A., 2025. The effects of redeposition phenomena on the reconstruction of palaeoenvironment in the southeastern Baltic Sea. Quaternary International, 743: 109922. DOI: 10.1016/j.quaint.2025.109922
2. **Sosnina I.**, Grigienė A., Šeirienė V., 2024. Holocene environmental changes inferred from palaeobotanical data of Curonian Lagoon sediments. Baltica, 37: 77–86. DOI: 10.5200/baltica.2024.1.8

Other publications:

1. Napreenko M.G., Orlov A.V., Napreenko-Dorokhova T.V., Subetto D.A., **Sosnina I.,** 2020. Preliminary data on formation and depositional environments of lake Chaika in the central part of the Curonian Spit (Kaliningrad Region, Russia, South-Eastern Baltic). IOP Conference Series: Earth and Environmental Science, Vol. 438: 012019. doi:10.1088/1755-1315/438/1/012019.
2. **Sosnina I.**, 2025. Diatoms: A key to understanding the history of aquatic environments. CPN/INCP Newsletter. 2025. Issue 31, 6.

RESEARCH PROJECTS

2023–present	**Chironomidae studies of Lithuanian lakes for modelling past temperature change (CLIMTS)** Lithuanian Science Foundation, No. S-MIP-23-22 Role: research team member
2020–2021	**Reconstructing the conditions for the formation of coastal ecosystems in the Curonian Spit** Student research individual project, IKBFU Role: Project leader
2019–2021	**Reconstructing the development of natural conditions of geologically unstable natural formations of the Baltic coast during the Holocene** Russian Scientific Foundation, №18-77-00030 Role: research team member
2019–2020	**Correlation of key climatic events of the Holocene in the north Atlantic Ocean and Baltic Sea** Russian Scientific Foundation, №18-77-10016 Role: Research team member

INTERNSHIPS AND TRAINING

- **Short course on Geochronology**, 3rd Paleolimnology and Limnogeology International Symposium, Aix-les-Bains, France, 2025
- **Taxonomic Diatom Workshop “Staurosirella & Staurosira”**, 15th European Diatom Meeting, Ohrid, North Macedonia, 2024
- **7th Nordic Diatom intercalibration (NorBAF),** Norrtälje, Sweden, 2024
- **Taxonomic Workshop “Revision of the European *Brachysira* taxa”**, 14th European Diatom Meeting, Brussel, Belgium, 2023
- **Data Analysis with R Workshop**, The Micropalaeontological Society Annual Conference, Bremen, Germany, 2022
- **INTIMATE-INQUA Summer School**, Turku, Finland, 2022

PARTICIPATION IN SCIENTIFIC CONFERENCES

International conferences:

1. Sosnina I., Šeiriene V., Damušytė A., 2025. Middle-to-Late Holocene palaeoenvironmental reconstruction of the Nemunas River Delta from diatom and mollusc data.
   3rd Paleolimnology & Limnogeology International Symposium, France (poster)
2. Sosnina I., Šeiriene. V., 2024. Main patterns in the diatom biodiversity of Lithuanian littoral sediments.
   15th European Diatom Meeting, North Macedonia (poster)
3. Sosnina I., Šeiriene. V., 2023 Preliminary diatom data on estuarine ecosystem development in the south-eastern Baltic Sea.
   14th European Diatom Meeting, Belgium (poster)
4. Sosnina I., Šeiriene. V., Napreenko-Dorokhova T., Napreenko. M., 2022. Palaeoenvironmental changes of the Curonian Lagoon (SE Baltic Sea) inferred from the diatom data.
   The Micropalaeontological Society Annual Conference, Germany (poster)
5. Sosnina I., Napreenko-Dorokhova T., Napreenko M., 2022. The palaeoenvironmental study of the Southwestern part of the Curonian Lagoon inferred from diatom data.
   Quaternary of the Eastern Baltic region – International Field Symposium, Latvia-Lithuania (poster)
6. Druzhinina O., Golyeva A., Napreenko M., Napreenko-Dorokhova T., Sosnina I., 2021. Phytolith (microbiomorphic) analysis in the Curonian Lagoon (southeastern Baltic) bottom sediments study.
   27th Annual Meeting of the European Association of Archaeologists, Germany (poster)
7. Napreenko-Dorokhova T.V., Napreenko M.G., Sosnina I.A., Druzhinina O., Sapozhnikov P.V., 2021. Preliminary results of complex study of sediments from the Curonian Lagoon.
   International scientific and practical conference LXXIV Herzan readings, Saint Petersburg (poster)

Additional 4 national conference presentations (2020–2021)

NOTES

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