



**CHANGES IN ABUNDANCE AND DIVERSITY OF
CLADOCERA COMMUNITIES IN THE OXBOW
LAKE**

Thesis for the Degree of Doctor of Philosophy (PhD)

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Debrecen, 2025

Hereby I declare that I prepared this thesis within the Doctoral Council of Natural Sciences and Engineering, Doctoral School of Pál Juhász-Nagy, University of Debrecen in order to obtain a PhD Degree in Natural Sciences/Engineering at Debrecen University.

The results published in the thesis are not reported in any other PhD theses.

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I also declare that the results published in the thesis are not reported in any other theses.

I support the acceptance of the thesis.

Debrecen, 2025.07.02

.....
signature of the supervisor

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COMMUNITIES IN THE OXBOW LAKE**

Dissertation submitted in partial fulfilment of the requirements for the doctoral (PhD)
degree
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LIST OF ABBREVIATIONS

FS-1	Fishing site-1	Ba²⁺	Barium
NS	Natural site	NO₂⁻	Nitrite
FS-2	Fishing site-2		
KMT	Kis-Morotva oxbow lake		
SZA	Szabolcs oxbow lake		
TI	Timár oxbow lake		
LOI₉₅₀	Loss of ignition at 950		
LOI₅₅₀	Loss of ignition at 550		
KOH	Potassium hydroxide		
Chl_a	Chlorophyll_a		
Al³⁺	Aluminum		
Cu²⁺	Copper		
Ca²⁺	Calcium		
SO₄²⁻	Sulfate		
TDS	Total dissolved solids		
TSS	Total suspended solids		
Cl⁻	Chloride ions		
Na²⁺	Sodium		
K⁺	Potassium		
NH₄⁺	Ammonium-ions		
Mg²⁺	Magnesium		
PO₃⁻	Phosphate		
ORP	Oxidation-reduction potential		
BOD₅	Biochemical oxygen demand		
ODO	Optical dissolved oxygen		
Cr²⁺	Chromium		
Pb²⁺	Lead		
Sr²⁺	Strontium		
HCO₃	Hydrogen carbonate		

1. INTRODUCTION

One of the most significant and urgent issues of our day is still the inadequate, neither regionally nor globally, protection of the environment. First, we would have to start by discussing ‘What is ecology?’. The answer used in Krebs’s (Kreb, 1985) definition is, Ecology is a complex field of scientific study that determines the interactions between organisms and their environment. It is rooted in evolutionary concepts such as natural selection, adaptation, and speciation, which are essential to understanding the distribution and abundance of organisms. Organisms have connections with water and sediment.

Water availability is one of the most basic needs for life as we know it on earth. All living things, including people, plants, and animals, depend on water to survive. As with drinking water quality, the health of aquatic ecosystems and the animals that live in them depends on the state of the water in rivers, lakes, and seas (Pham and Utsumi, 2018; Poff et al., 2006; Postel et al., 1998). Aquatic life may suffer, and water quality may be reduced as a result of pollutants building up in water bodies from sources like sewage, industrial discharges, and agricultural runoff (Ahmed et al., 2021; Singh et al., 2020; Pham and Utsumi, 2018). Furthermore, climate change may have a detrimental effect on water quality, which could have far-reaching effects on ecological function and human health (Whitehead et al., 2009). As the planet warms, precipitation patterns change, and extreme weather events like floods and droughts become more frequent and intense. These changes have an impact on water availability and quality as well as nutrient and pollutant cycles (Allan et al., 2020; Bouraoui et al., 2004; Imaoka et al., 2010). The

functioning of aquatic bodies may then be greatly impacted by these changes (Kundzewicz, 2008; Tang, 2020). Changes in precipitation patterns have the capacity to adversely affect the quality of water through two supplementary mechanisms, namely sediment discharge and nutrient discharge (Zhang and Zhi, 2020). The rainy season can have various impacts on water quality, including the induction of chemical alterations in water sources (Rani et al., 2021). Also, fluctuations in precipitation patterns can potentially alter the hydrological dynamics of rivers and streams, thereby inducing shifts in the composition of pollutants and nutrients present in the water (Trenberth, 2011). The flow patterns and temperatures of streams and rivers can undergo changes due to various factors, including the melting of glaciers and snowpack, as well as periods of drought (Deelstra et al., 2011; Zwolsman and Van Bokhoven, 2007). The potential consequences of fluctuations in water temperature on aquatic ecosystems are significant due to the distinct temperature requirements for survival and egg development among various species of fish and other aquatic organisms (Poloczanska et al., 2008; Wilson et al., 2015).

The aquatic ecosystem has been affected by increasing anthropogenic pressures and pollution (Wetzel, 1992). Anthropogenic pressures such as fish farming, urbanization, industrialization, and agricultural activities commonly relate changes in biological communities and significantly to the pollution of aquatic ecosystems (Alberti et al., 2007; Goodsell et al., 2009). In the realm of water quality, there is the possibility of influencing the physical-chemical parameters.

Sediments derived from lakes encompass both organic and inorganic remnants, which serve as valuable indicators for investigating the historical

trajectory of a lake or its surrounding drainage basin. Additionally, these sediments enable the assessment of paleoecological patterns and fluctuations in climate (Abrantes et al., 2006). Furthermore, sediments obtained from the deepest section of the lake, consisting of single cores, offer a highly accurate depiction of the ecological interactions within the aquatic communities across the entire lake (Dodson et al., 2010). Fossils are generated within sedimentary deposits subsequent to a series of transformative processes that alter the organic remnants of deceased organisms.

In order to assess changes in the environment over a specific time period, it is necessary to utilize ecological indicators. These indicators provide valuable insights into the magnitude and rate of environmental changes, enabling a more precise understanding of the underlying causes (Dale and Beyeler, 2001). In this scenario, the indicator must exhibit prompt responsiveness and effectively generate a distinct and unambiguous reaction to the changing environmental variable (Carignan and Villard, 2002). The indicator characteristics under consideration pertain to the utilization of branch tentacle crabs as indicator organisms. In our study, we selected a number of species of freshwater crustaceans belonging to the Cladocera order that are found in various moist habitats and freshwater aquatic environments.

The subphylum Crustacea is a constituent of the phylum Arthropoda, encompassing the class Branchiopoda. Within this, the Diplostraca superorder consists of the Cladocera superorder (WoRMS, 2020). The Cladocera taxonomic group exhibits substantial global species diversity, with a potentially extensive range of species. Flößner (1972), initially provided a summary description encompassing approximately 440 species, a number

that Forró et al., (2008) later expanded to 620 based on subsequent research findings. According to Smirnov (2014), it has been asserted that there are more than 700 known species. Previous studies have posited that the present quantity is approximately 720 (Kotov A., 2019; Xiang et al., 2015). Furthermore, according to Vadadi-Fülöp et al., (2010), the researchers provide an estimate of the number of species to exceed 2,000. However, it is suggested by Adamowicz and Purvis (2005) as well as Petrussek et al., (2004) that the actual number of species could be much higher, particularly in the case of the Cladocera group. Based on the findings documented in Bledzki and Rybak, (2016), the number of Cladocera species documented in Europe as of July 2015 amounted to 199. These counts encompassed all Cladocera species found in marine, coastal, and freshwater environments.

Water fleas (Cladocera) play a crucial role in the freshwater ecosystem, serving as vital constituents of the fauna. Their significance is particularly pronounced in stagnant water bodies, where they occupy a key position in the food web (Forró et al., 2008).

1.1 Problem statement

Oxbow lakes are frequently characterized as bodies of water that are small in size or have limited depth and are representative of stagnant water features commonly observed in low-lying areas. As well as they are remnants of fluvial processes that exhibit distinct characteristics in comparison to traditional lakes (Kuczyńska-Kippen and Nagengast, 2006; Meerhoff et al., 2003). Oxbow lakes are hydrological features that possess a vulnerability to external influences, thereby exerting a direct impact on the biodiversity and ecological dynamics of the encompassing region. These water bodies provide a diverse array of habitats suitable for a range of aquatic organisms, including macrophytes and invertebrates (Berta et al., 2019). Therefore, it is plausible to deduce insights regarding the state of the environment by examining the composition of communities and the diversity of aquatic species present (Biggs et al., 2017).

Oxbow lakes are predominantly utilized for agricultural purposes such as irrigation and water reservoirs, as well as for fishing activities including fish farming and angling. Additionally, they serve as reservoirs for human consumption. These human activities have resulted in heightened levels of human activity and pollution within the freshwater ecosystem (Wetzel, 1992). Hence, increased nutrient levels and pollution can contribute to the development of eutrophic conditions, which are conducive to the proliferation of phytoplankton (Carpenter et al., 1999; Heisler et al., 2008). According to recorded research, the introduction of nutrients from non-point sources, such as fishing, agriculture, and chemical-based fertilizer; this has resulted in a

considerable impact on the lake ecosystem, leading to a substantial increase in eutrophication (Havens, 1995).

1.2 Objectives

The point of our study is to look at samples of filtered water, recent sediment, and core sediment to see how the Cladocera community's abundance and diversity change over time, as well as the physical and chemical changes that happen because of use and the environment. Therefore, we have pursued the following specific objectives to drive the study:

- Is it necessary to simultaneously investigate the Cladocera community of filtered water samples and recent sediment samples in order to determine the impact (angling and anthropogenic) of different sites within Nagy-Morotva oxbow lake?
- Did the Cladocera assemblages and physical-chemical parameters exhibit variation across different sites within the Nagy-Morotva oxbow lake?
- Can we use subfossil Cladocera to characterize the past condition of a shallow oxbow lake?

2. LITURATURE REVIEW

2.1 Paleolimnology

Lakes are influenced by several forces of external and internal that control their evolution throughout time. These forces include climate, the composition of the surrounding bedrock, phenomena of volcanic and tectonic, flora, aquatic life, and activities of human. Lakes serve as repositories of geological records documenting the history of the Earth. It is important to note that these factors have a strong influence on each other. For instance, human activities may have a significant impact on the vegetation in a watershed and water life. Generally, we identify the historical fluctuations of these variables via the use of paleolimnology.

Paleolimnology is a scientific discipline that utilizes sediment samples from freshwater bodies to recreate historical environmental conditions. Freshwater bodies vary greatly in size and characteristics, ranging from tiny, shallow ponds to big, open lakes. They may be found in stagnant marshlands or in the fast-moving currents of major rivers. Additionally, freshwater can have varying levels of electrical conductivity, from low levels in certain bodies of water to higher levels in salt lakes.

Paleolimnological investigations enable the monitoring of environmental changes over extended periods, such as hundreds to thousands of years ago, even in the absence of previous measurements. The growing concern over the deterioration of Earth's environmental conditions, primarily due to human activities, has led to a greater demand for environmental evaluations and the ability to regulate human-induced actions in a manner that reduces damage to the environment. Many research efforts that concentrate

on the inherent progression of ecosystems investigate matters such as the effects of climate change and associated topics. These studies aim to comprehend the natural cycle and establish a reference point to distinguish between the impacts caused by human actions and those that occur naturally. Investigations of paleolimnological can support to determine the magnitude of the examined influence and the rate at which the environment is changing, in order to evaluate the present state of circumstances. It is important to have a comprehensive understanding of how situations have evolved over time (Douglas, 2007). So, paleolimnology is a field of study that helps us understand historical environmental conditions. It does this by employing proxy indicators to extend the instrumental record, allowing us to analyse different environmental variables (Douglas, 2007). On the other hand, paleolimnology has been defined more precisely by geologists and paleoecologists, who place emphasis on sedimentological or geomorphic data that are valuable for comprehending the physical progression of lake basins or the ecological development within lakes (Edmondson, 1969). By using these extended recordings, it is possible to measure the initial environmental conditions and evaluate the inherent fluctuations of the system. Through the process of recreating paleoenvironmental circumstances, it becomes feasible to explore several subjects related to both historical and contemporary environmental conditions.

Typically, when studying Cladoceran assemblages via paleolimnological studies, researchers gather sediment profiles from the middle or deepest area of a basin. The procedure is founded on the observation that the remains of Cladoceran species from various

microhabitats in the littoral zone are carried away passively towards the coast (for example, through currents caused by wind), and combined with the remains of limnetic species before they are deposited in the sediments (Frey, 1988). Therefore, it is believed that sediment produced in the middle region of a lake provides a comprehensive and combined sample of the Cladoceran populations that have inhabited various habitats within the lake throughout time (Frey, 1988).

Frey, (1988) and Hann, (1989) provided comprehensive overviews of the primary stages involved in the process of preparing and examining method of Cladocera. Paleolimnology research possesses a wide range of tools to collect samples from the preserved records of lakes. These technologies vary in their capacity to address various paleolimnological issues. Sampling tools included a chamber sampler, gravity, box and multicore corers, piston core, and freezing sampler. These are the instruments used for paleolimnology studies.

The most prevalent technique for acquiring paleolimnological data is sediment coring. Cores are sediment columns that have a single dimension. It offers an overview of the geographical variety of sedimentary records found in a lake. When it comes to acquiring physical samples from existing lakes, cores are the most practicable method available.

2.2 Indicator for the Paleolimnology

Cladocera exhibit favourable characteristics for paleolimnological investigations, primarily owing to their exoskeletons composed of chitin. These exoskeletons tend to be adequately conserved in lake sediments, although the extent of preservation may vary among different families owing

to changes in the composition of chitin (Korhola and Rautio, 2001a). Following an individual's demise or during the process of exoskeleton shedding in growth, the remains become disarticulated and subsequently become part of the sediment record. The remains of each species exhibit variation, but commonly consist of the carapace, claw, mandible, headshield, postabdomen, and postabdominal (Korhola and Rautio, 2001a). Cladocerans' remains could be obtained from sediment samples and usually categorized at the genus or species level.

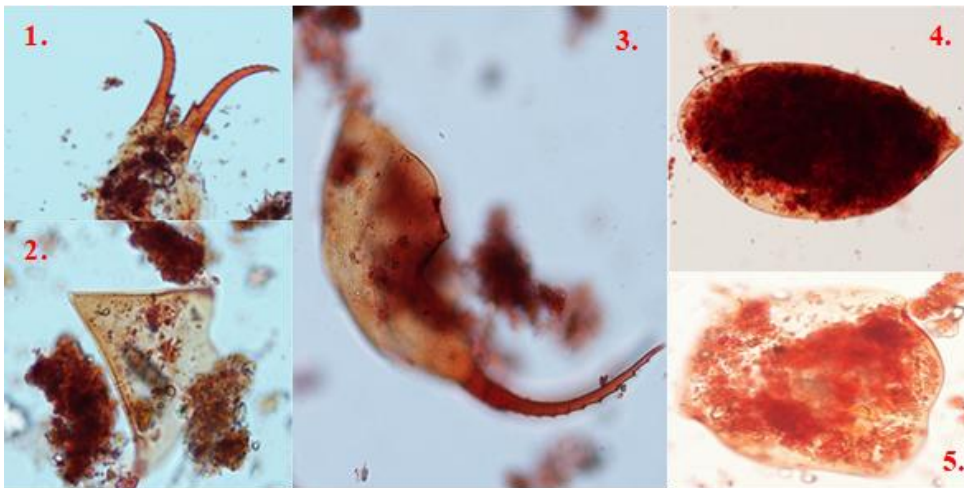


Figure 1. The subfossil head shields. 1. *Bosmina longirostris*; 2. *Chydorus sphaericus*; 3. *Eubosmina longispina*; 4. *Pseudochydorus globus*; 5. *Alona rectangular*; Source from: (Tumurtoogoo et al., 2022)

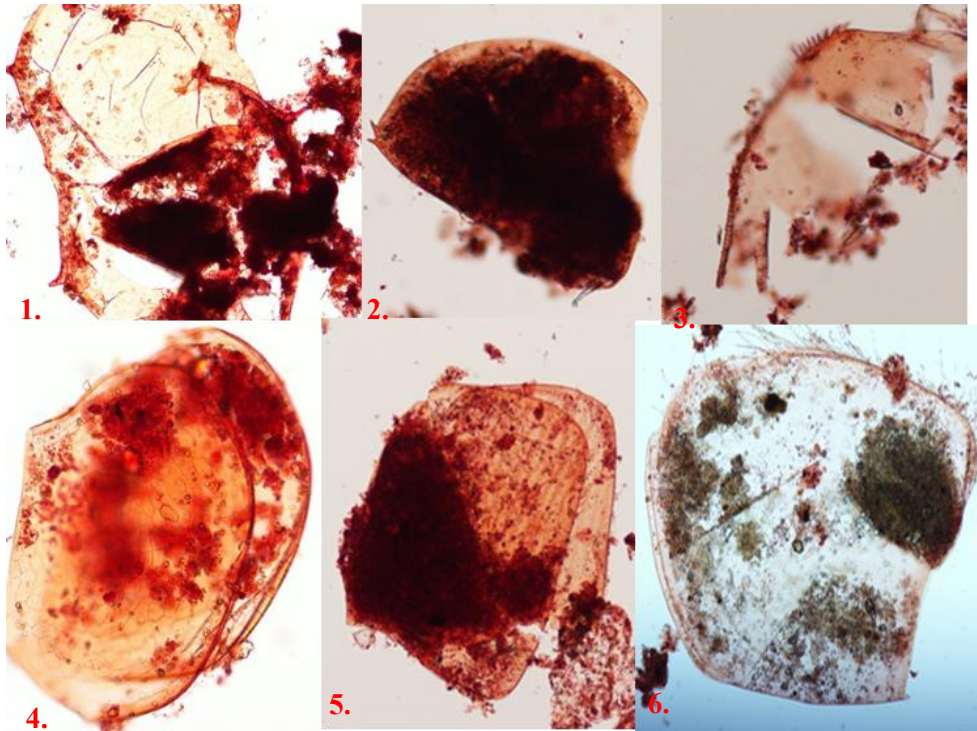


Figure 2. The subfossil carapace. 1. *Bosmina longirostris*; 2. *Graptoleberis testudinaria*; 3. *Pleuroxus truncatus*; 4. *Chydorus sphearicus*; 5. *Alona rectangulara*; 6. *Alona intermedia*;
Source from: (Tumurtoogoo et al., 2022)

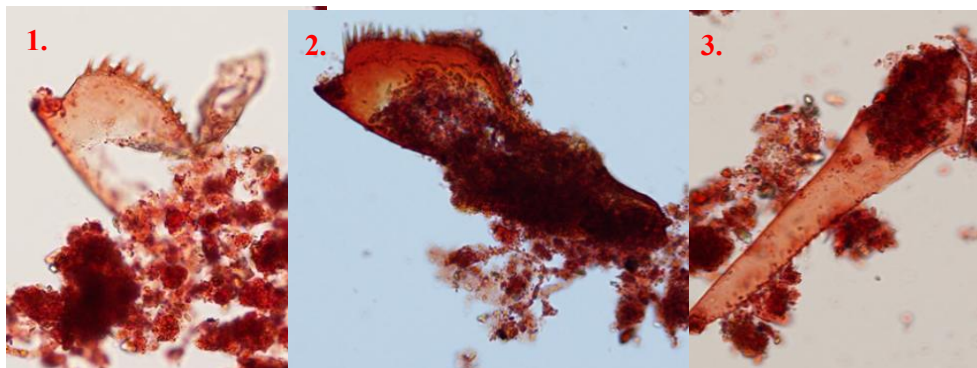


Figure 3. Subfossil claws. 1. *Alona affinis*; 2. *Alonella nana*; 3. *Camptocercus rectirostris*;
Source from: (Tumurtoogoo et al., 2022)

In the field of paleolimnology, Cladocera are among the aquatic microorganisms utilized to identify changes in the physical, chemical, and biological features of lakes. This is because they are very sensitive to many environmental conditions. Therefore, the water chemistry parameters pH (Keller and Pitblado, 1984; Krause-Dellin and Steinberg, 1986), dissolved organic carbon (DOC) (Nevalainen et al., 2015), salinity (Bos et al., 1999a, 1996), nutrient status (Bos and Cumming, 2003; Brodersen et al., 1998), and calcium concentration (Jeziorski et al., 2015, 2008; Jeziorski and Smol, 2017) have all been inferred from Cladoceran-based paleolimnological studies.

Cladocera investigations often involve the regular monitoring of lake depth, which is a physical variable of interest. Therefore, it is often estimated by examining the proportion of littoral to pelagic species found in sediment samples (Bos et al., 1999b; Hofmann, 1998; Nevalainen et al., 2011). The monitoring of Cladocera has allowed for the tracking of water temperature, which is a physical characteristic of lakes. This is because different species of Cladocera have specific temperature preferences for their growth and reproduction. Numerous investigations, including those by Bos and Cumming, (2003), Lotter et al., (1997) and Sweetman et al., (2010) have shown this.

Changes in the composition of Cladoceran species and the size of their bodies have been utilized to reconstruct biological inferences, such as the temporal shifts in predation regimes (Brooks and Dodson, 1965; Kitchell and Kitchell, 1980; Korosi et al., 2013, 2010, 2008; Labaj et al., 2013; Sweetman and Finney, 2003). By reason of the assemblages of Cladocera have a significant ecological importance within aquatic ecosystems, as they serve as

a vital food source for higher taxonomic levels, such as fish and invertebrates. Additionally, they contribute to the overall structure of aquatic food webs (Abrantes et al., 2006; Dodson et al., 2010). Omnivorous fishes, acting as predators with size-selective habits, possess a significant capacity to influence the structure of Cladoceran assemblages. In other words, lakes harboring fish species that primarily feed on zooplankton are predominantly populated by Cladocera species of smaller size (Brooks and Dodson, 1965; Confer and Applegate, 1979; Hrbáček et al., 1961). In lakes devoid of fish, the zooplankton communities are primarily characterized by the prevalence of a more significant number of species (Pociecha et al., 2018). This phenomenon was also corroborated by Liu et al., (2022), who observed a reduction in the morphological characteristics of Bosmids (specifically, the carapace length, antennule length, and mucro length) when the population size of planktivorous fish assemblage grew to a considerable extent. Consequently, Cladocerans employ a defensive strategy against fish predation by seeking refuge within macrophyte beds during daylight hours. This behavior facilitates the maintenance of a substantial grazing pressure on phytoplankton populations (Lauridsen et al., 1996; Pociecha et al., 2018; Wilk-Woźniak et al., 2019). Additionally, certain littoral-benthic species are found in association with macrophytes and derive sustenance from them (Barker et al., 2010). In addition, submerged vegetation plays a crucial role in the absorption of nutrients derived from algae and the surrounding water, thereby facilitating the establishment of a well-balanced aquatic ecosystem. It is worth noting that numerous species of fish, crabs, and aquatic macroinvertebrates heavily rely on submerged vegetation for their survival.

2.3 Cladocera

The earliest records pertaining to Cladocera can be traced back to the 17th century (Dumont and Negrea, 2002; Korovchinsky, 1997). The Cladocera taxon is believed to have originated during the Palaeozoic era, as stated by Dumont and Negrea (2002). However, the fossilized remains of Cladocera that can be definitively attributed to this group are only found in the Mesozoic era, as documented by Smirnov, (1992, 1971) and Kotov and Korovchinsky, (2006). The initial documented study on this subject is credited to Forró et al., (2008), who, through his research, made an observation that distinct aquatic environments with varying characteristics can support the development of diverse fauna. According to (Kotov and Korovchinsky, 2006), the Cladocera fauna exhibits a greater degree of diversity in both shallow and deep water bodies, particularly when subjected to high temperatures.

Most species of Cladocerans are found in shallow, littoral environments characterized by substrates such as mud, sand, rock, and vegetation. However, certain taxa like *Daphnia spp.* and *Bosmina spp.* are specifically associated with the open-water habitat found in the pelagic zone (Korhola and Rautio, 2001b). The majority of Cladocera species exhibit a feeding behavior characterized by the consumption of algae, which they obtain through filter feeding or by scraping detritus. However, there are exceptions to this pattern, as certain Cladocera species display a carnivorous diet, primarily preying on small zooplankton taxa (Korhola and Rautio, 2001b; Smirnov, 2017). Cladocerans are frequently targeted by invertebrate predators and planktivorous fish, thus playing a crucial role as a significant component

within aquatic food webs. Cladocerans, due to their intermediate trophic position, exhibit sensitivity towards alterations in both bottom-up factors such as food supply, and top-down factors such as predation, within the food web (Hessen et al., 1995). This characteristic renders them valuable indicators for assessing the overall trophic dynamics of a lake.

3. MATERIALS AND METHODS

3.1 The verification of recent environmental conditions at various utilization sites of an oxbow lake through the analysis of Cladocera in sediment and surface water samples

3.1.1 Characteristic of the study area

Nagy-Morotva oxbow lake is situated in North-East Hungary, between the cities of Tiszanagyfalu and Rakamaz (Figure 4).

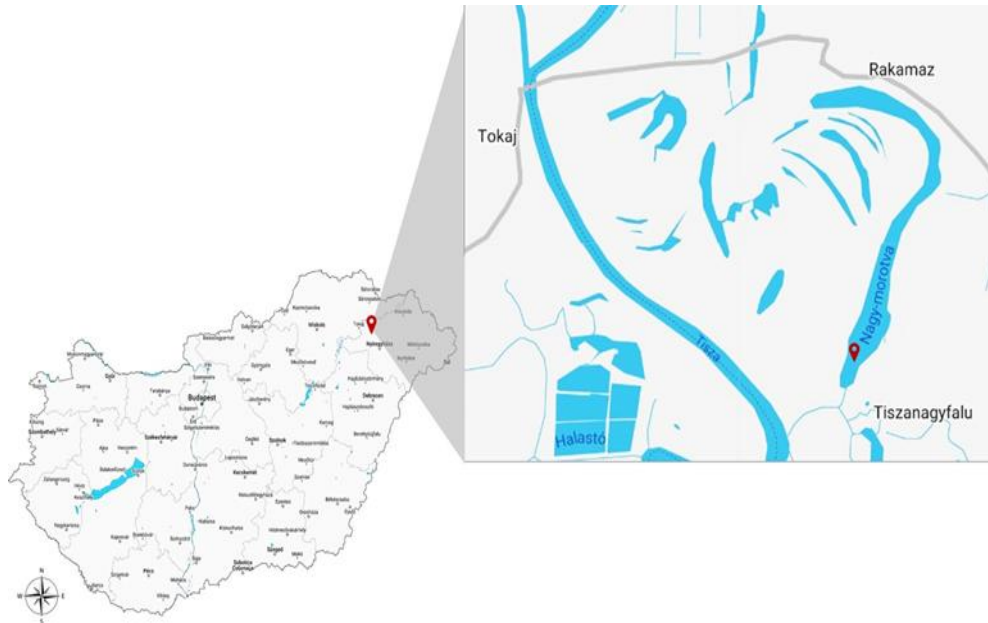


Figure 4. Nagy-Morotva oxbow lake in Hungary depicted on a map

There are settlements located both at the northern and southern ends of the lake, including Rakamaz on the northern end, and Tiszanagyfalu on the southern end, as well as it is surrounded by large open water areas at both ends. The majority of the water supply is derived from flooded sections of the Tisza River, which have formed the oxbow lake covering a surface area of

100 hectares. It measures 5 km in length and ranges in width from 100 to 330 meters. Depending on the level of the water, the depth ranges from 80 to 150 cm (Tumurtoogoo et al., 2022). The oxbow is located on the floodplain of the Tisza River, and its exposure to flooding is mitigated to some extent by a summer dam. Consequently, inundation occurs solely during periods of exceptionally high river levels. The lake lacks a direct hydraulic linkage with the river, and its water supply is limited to periods of intense flooding or artificial pumping from the Tisza River (Tóth et al., 2012).

The Nagy-Morotva oxbow lake represents a versatile aquatic environment that serves multiple purposes, including irrigation, environmental conservation within the central region of the oxbow lake, fishing, and various recreational activities (Kiss et al., 2006). As far as fish stock is concerned, the oxbow lake contains most of Hungary's natural fish species. A wide variety of fish species inhabit this area, including bream (*Abramis brama*), common carp (*Cyprinus carpio*), crucian carp (*Carassius carassius*), grass carp (*Ctenopharyngodon idella*), and pike perch (*Sander lucioperca*). Aquatic vegetation covers a large part of the study area, and this plant mass contributes to large amounts of organic matter being generated each year, which accelerates the sedimentation process. A high percentage of macrovegetation occurs during the summer season, ranging from 80 to 90%. However, the middle part of the oxbow lake was not covered by macrovegetation during the fall season. On the other hand, the natural site was covered with 80–90% vegetation during the entire planting period. During the fieldwork, there was a lower level of vegetation coverage in the fishing sites than in the natural site. Only the littoral zone of fishing sites

contains macrophytes. There was the most prevalent macrophytes presence of the white-water lily (*Nymphaea alba*) and water pumpkin (*Nuphar lutea*) at the fishing sites. Besides white-water lily (*Nymphaea alba*), water soldier (*Stratoites alloides*), and hornwort (*Ceratophyllum demersum*), a wide variety of macrophytes species were found at the natural site. The oxbow lake's shoreline was filled with only lesser bulrushes (*Typha angustifolia*), reed sweetgrasses (*Glyceria maxima*), and common reeds (*Phragmites australis*).

3.1.2 Investigation process of the remains and composition of Cladocera in soft sediments and surface water from different utilization sites of oxbow lake

Selecting sampling points that were well distributed across both spatial and temporal scales was crucial to ensure that the collected samples accurately captured the diverse landscape and nature of Nagy-Morotva. At the oxbow lake, samples were collected from twenty-one sampling points across three separate sites (Fishing site-1: FS-1, Natural site: NS, and Fishing site-2: FS-2). Using cross-sections by moving from one side to another, three different sites used for different purposes were sampled (Figure 5).

- The fishing site-1 (FS-1) included the sampling points of RAK1, RAK2, RAK3, RAK4, RAK5, and RAK6. This site is classified as an open water zone and is utilized for the purposes of fishing activities (angling).
- The natural site (NS) included the sampling points of RAK7, RAK8, RAK9, RAK10, RAK 11, RAK12, RAK13, RAK14, and RAK15. This site is a natural protected area and characterized by

the presence of microvegetation, primarily consisting of water soldier and submerged vegetation.

- The fishing site-2 (FS-2) included the sampling points of RAK16, RAK17, RAK18, RAK19, RAK20, and RAK21. This site is an open water zone and is utilized for the purposes of fishing activities (angling).

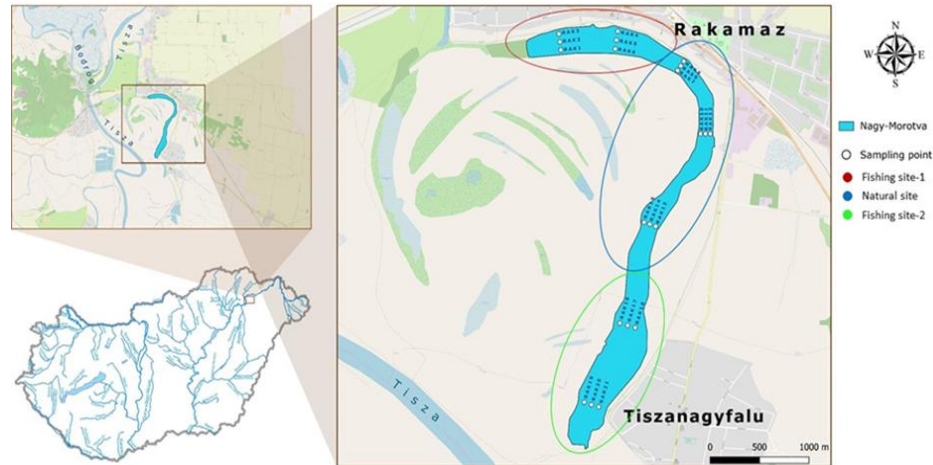


Figure 5. The map of the Nagy-Morotva oxbow lake displays the locations of the sampling points.

The research methods utilized in this research were a field sampling method to assess assemblages of Cladocera, environmental variables measurements, as well as a method of laboratory for chemical analysis of the collected samples. A sample collection was conducted in October 2019.

As a tool for investigating the contemporary Cladoceran community, filtered samples were obtained at each sampling point. These samples were acquired from the top layer of water using plankton traps of Schindler-Patalas with a hole measuring 35 micrometers of a volume of 30 liters (Schindler, 1969). In other words, 30 liters of water were filtered at every sampling point.

It is possible to capture individuals of the smallest size range as well as parts of their bodies. These samples were placed into tubes. The next step was the preservation of filtered samples in 70% ethanol, to prevent the growth of fungi or bacterial organisms on the samples. Following the preparation of the samples, it was necessary to identify each Cladocera species on a species-by-species basis. Every sample was applied to the slides by using an automatic pipette for every 100 microliters. In order to determine the species, a light microscope such as Olympus BX 53 type (Olympus Europe Holding GMBH, Hamburg, Germany) was used under a magnification of 100. Cladocera abundance and diversity were determined by samples collected. Therefore, at least 200 species individuals were counted from each of the twenty-one samples. To identify the contemporary Cladocera species, we used the identification keys of studies conducted by Frey (1987), Gulyás (1974), Szeroczyńska and Sarmaja-Korjonen (2007) as well as Bledzki and Rybak, (2016).

In the field, we collected sediment samples from twenty-one sampling points. The gravity-corer device was utilized to gather sediment samples (Glew, 1991). It should be noted that the amount of sediment used in this research was not the entire sediment column, only the top layer of 1 centimeter of soft and fresh sediment was collected. By doing so, it was intended to avoid including remains that date back several years or decades in this research. Until the samples reached the laboratory, we kept them in lockable containers. A dilution procedure was performed in the laboratory. In order to analyze each sediment sample. It was carried out according to the standard method of Korhola and Rautio (2001b). An amount of sediment

equivalent to one cubic centimeter was obtained from every sample, which was treated with 100 mL of 10% KOH (potassium hydroxide) solution in a plastic beaker. Following the mixing of these solutions, it was warmed up to 100 °C on a hot plate for 30 minutes with careful stirring to avoid damaging the remains. On completion of the heating process, each sample was sieved through a mesh screen (35 micrometers) to eliminate a majority of the organic particles, after which the samples were rinsed with distilled water. Distilled water was used to place the samples into 50-milliliter tubes. The next step was to preserve samples with 70% ethanol, with five drops of a solution of safranin-glycerin added to aid in identification. Following this, the prepared samples were allowed to settle for 24 hours, after which the excess distilled water was sucked off until 25-milliliter and ready for investigation. This procedure is important because treatment with KOH causes chitin to become completely transparent, making it almost imperceptible under a microscope without Safranin-glycerin staining, and preservation prevents fungi from growing in the samples (Kattel and Augustinus, 2010; Sweetman and Smol, 2006). As a result of these preparations, Cladocera residues were identified according to their species. Every sample was applied to the slides by using an automatic pipette for every 100 microliters. In order to determine the species, a light microscope such as Olympus BX 53 type (Olympus Europe Holding GMBH, Hamburg, Germany) was used under a magnification of 100. Cladocera abundance and diversity were determined by samples collected. Therefore, at least 200 species individuals were counted from each of the twenty-one samples. To identify the contemporary Cladocera species, we used the identification keys of studies conducted by Frey (1987), Gulyás

(1974), Szeroczyńska and Sarmaja-Korjonen, (2007), as well as Bledzki and Rybak (2016). A conversion was made to individual/cm³ based on our results.

3.1.3 Determination process of the physical-chemical parameters

While collecting the samples, samples of unfiltered water were collected from 50 cm above the water surface and placed in plastic bottles capable of holding one and a half liters and kept in a cold condition until being analyzed in a laboratory. Additionally, the fieldwork also included the determination of some vital environmental variables related to depth and transparency by using Secchi disks (Preisendorfer, 1986) and a YSI EXO-2-S3 multiparameter instrument (Xylem Company, USA) for measuring chlorophyll_a, optical dissolved oxygen content, water temperature, turbidity, total dissolved solids, and conductivity at each sampling site.

A chemical analysis was conducted on samples of non-filtered water in the laboratory. At the time of the laboratory phase, TSS (the total suspended solids) concentrations were determined utilizing the Hungarian Standard (MSZ 260-3:1973).

The method of Németh (1998) was used to estimate chloride ions (Cl⁻). Tests of total phosphorus, orthophosphate-ion (PO₄³⁻), and total hardness were conducted as per the MSZ 12750-17:1974 standard of Hungarian. MSZ 12750-16:1974, 1484-13:2009, 7150- 1:1992, and 260-12:1987 standards of Hungarian were used to estimate the ammonium-ions (NH₄⁺), Kjeldahl-nitrogen (KJN), nitrate-nitrogen (NO₃⁻-N), and nitrite-nitrogen (NO₂⁻-N). In accordance with ISO 15923-1:2013, sulfate ion (SO₄²⁻) was estimated, and the MSZ EN 1899-2:2000 standard of international was used to determine biochemical oxygen demand (BOD₅). Based on MSZ 448-11:1986 standard

of Hungarian, total alkalinity was estimated and the MSZ 448- 20:1990, and ISO 6060: 1991 standards of Hungarian were used to determine chemical oxygen demand (CODsMn and CODCr) and the MSZ 448-11:1986 standard of Hungarian was used to determine hydrogen carbonate (HCO_3^-) and carbonate (CO_3^{2-}) content. A method prescribed by Tisza River Regional Waterworks Ltd. HKE-3: 2002 for measuring humic acid content was used. Hot methanol extraction and spectrophotometry were used to determine chlorophyll_a content. Furthermore, MP-AES (Microwave Plasma Atomic Emission Spectrometry) was used to determine macro-elements (including Ca^{2+} (calcium), K^+ (potassium), Mg^{2+} (magnesium), and Na^+ (sodium)), and micro-elements (including Al^{3+} (aluminum), Ba^{2+} (barium), Cd^{2+} (cadmium), Cr^{2+} (chromium), Cu^{2+} (copper), Mn^{2+} (manganese), Fe^{2+} (iron), Li^+ (lithium), Ni^{2+} (nickel), Pb^{2+} (lead), Sr^{2+} (strontium), and Zn^{2+} (zinc)).

Laboratory analysis of samples of sediment was performed to estimate the contents of organic matter and calcium carbonate (CaCO_3), and elemental composition. As a first part, the determination of the calcium carbonate (CaCO_3) and organic matter contents was carried out in accordance with Dean's (1974) and Heiri's (2001) standard methods. In the first step, from each sample, approximately 5 grams of sediment were weighed and placed in petri dishes, then weighted samples were dried at 105 °C in a drying oven. The dried samples are powdered in an agate mortar to obtain a sample of completely similar consistency. Then, each powdered sediment sample was measured out 1 gram into a known mass of ceramic cups. The samples were subjected to combustion at a temperature of 550 °C for a duration of four hours in an oven to ascertain their organic matter content. Using the weight

loss of the samples, organic matter content per original weight was determined.

The formula used for counting is as follows:

$$\text{Organic matter content: } \mathbf{LOI_{550}} = \left(\frac{\mathbf{WT_{105}} - \mathbf{WT_{550}}}{\mathbf{WT_{105}}} \right) * \mathbf{100}$$

Markings: LOI₅₅₀ – loss (as a percentage); WT₁₀₅ – the dry mass at 105 °C; WT₅₅₀ – the dry mass at 550 °C;

After measuring the sample's mass, the ceramic cups containing the samples were located in the oven, where samples were heated for four hours until at 950 °C. The calcium carbonate content was determined by comparing a weight loss here to the initial weight.

The formula used for counting is as follows:

$$\text{Calcium carbonate content: } \mathbf{LOI_{950}} = \left(\frac{\mathbf{WT_{550}} - \mathbf{WT_{950}}}{\mathbf{WT_{105}}} \right) * \mathbf{100}$$

Marking: LOI₉₅₀ – loss (as a percentage); WT₅₅₀ – the dry mass at 550 °C; WT₉₅₀ – the dry mass at 950 °C; WT₁₀₅ – dry mass at 105 °C;

As part of the determination of the chemical parameters, the elemental composition was estimated in the dry sediment samples. Initially, Precisa ES 225SM-DR of analytical balance was used to measure the dry sediment samples, and 0.2 grams were measured. In the chemical preparation of the samples, a solution consisting of 1.0 ml (H₂O₂ 30%) (reagent grade, Merck) and 5.0 ml (HNO₃ 65%) (reagent grade, Scharlau) was employed for the wet digestion method before elemental analysis. Immediately after digestion, the results of digestion were diluted to a volume of 25.00 ml using water of

ultrapure (Synergy UV Millipore) in plastic centrifuge containers equipped with volume calibration. For further elemental analysis, the solutions were stored at the ambient temperature after their production. After chemically preparing the sediment samples, we used MP-AES 4200, Agilent Technologies model of spectrometry of microwave plasma atomic emission to accurately measure the element content. While the measurements were taking place, nitrogen generators (Agilent Technologies 4107) continuously provided plasma gas. By using an automatic sampler, standard and sample solutions were applied, and each sample solution was washed with 0.1 M HNO₃ solution made in water of ultrapure for 30 seconds between each sample.

3.1.4 Data analysis

In the current research, Paleontological Statistics (PAST) (Hammer et al., 2001) and R (R core Team, 2018) programs were used to perform the statistical analyses. The PAST software was utilized to compute the species richness and domination of both remain and contemporary subfossil of assemblages of Cladocera. The physical-chemical variable patterns of variation were investigated in this research using Bray-Curtis similarity in Principal Components Analysis (PCA). Also, remain and contemporary assemblages of Cladocera were clarified by principal coordinate analysis (PCoA) utilizing vegan package of Jaccard similarity (capscale() function) (Oksanen et al., 2013). The dispersion of the groups was evaluated through the analysis of permutational multivariate, specifically the method of Adonis, which was carried out utilizing Jaccard distances. The Martinez function (Rodriguez-Martinez et al., 2018) was used to perform pairwise comparisons,

using Benjamini & Hochberg ("fdr") adjusted p-values. The current research used analysis of distance-based redundancy (dbRDA) using the `capscale()` function in the `vegan` package. Identical similarity matrices were used to determine the elements that had the most significant correlations with the patterns seen in Cladoceran assemblages.

3.2 Verifying the past state of oxbow lakes using subfossil Cladocera with geochemical parameters in sediment samples.

3.2.1 Characteristics of the study areas

The lakes studied were in the Tisza River catchment, near the region of Rakamaz, Kis-Morotva oxbow lake, Szabolcs oxbow lake and Timár Morotva oxbow lake in North-East Hungary. The following oxbow lakes were studied: Kis-Morotva (KMT), Szabolcs (SZA), and Timár Morotva (TI) (Figure 6).

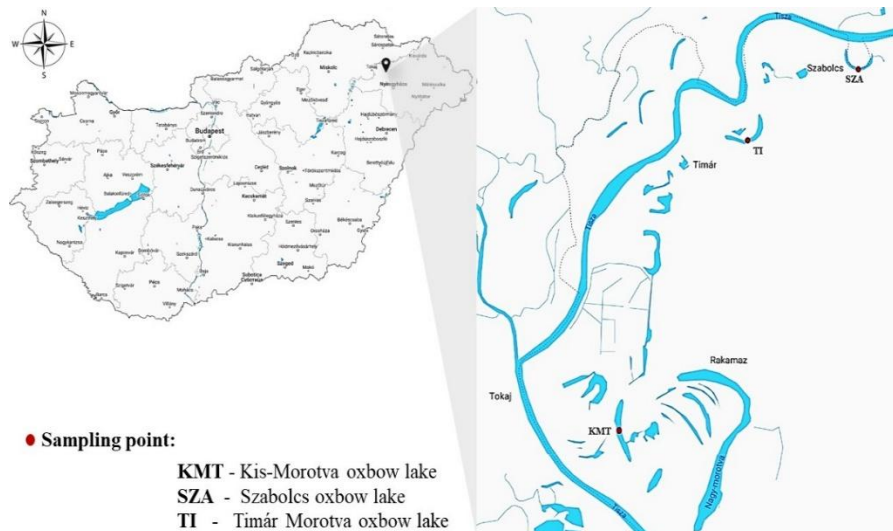


Figure 6. Showing the study areas and sampling points

Lakes have the potential to receive replenishment from the Tisza River through direct inflows from floods and inland water sources. Tisza river's

total catchment area of 157,186 km², the length of the Hungarian section of the river is 597 km, while its total length is 946 km. The river's water regime is extremely unpredictable, and significant floods can happen in the river basin at any point during the year as a result of rainstorms, snowmelt, or a combination of both. Significant inundations occur with more frequency throughout the latter part of winter and the beginning of spring. The period from May to October, characterized by warm weather, is responsible for approximately 35% of all floods, while the period from November to April, characterized by cold weather, accounts for the remaining 65%.

The lakes are naturally produced and eutrophic, with a shallow depth. The research was conducted in two different types of lakes. The oxbow lake of KMT is considered intermittent. The SZA and TI oxbow lakes are marked by permanent.

Oxbow lake of Kis-Morotva is located between Tiszanagyfalu and Rakamaz cities. It is naturally formed and currently eutrophic. The maximum depth of the lake is 1.2 meters, while its surface area is estimated to be roughly 14 hectares, and its length is approximately 1223 meters. It is situated within a natural protection area that is protected under the Nature 2000 program, with no permitted utilization and land use activities. It can be classified as an intermittent water feature due to the phenomenon of drying out, which occurred in 2012. During the spring season of 2013, the Tisza River facilitated the replenishment of the lake. As of the present moment, it has not undergone the process of desiccation once more.

Szabolcs oxbow lake (SZA) is situated on the left bank of the Tisza River and is within the jurisdiction of the Szabolcs town. Currently, the length

of the lake is 957 meters, with an average width of 60 meter. The water's surface covers an area of 5.60 hectares and maintains an average water depth of 1.3 meter (Lóczy et al., 2018) and max depth 2.5 meter. The area is without natural conservation protection. It is used as intensive fishing activity (especially for angling). The oxbow lake harbors a diverse array of fish species, such as bream, carp, grass carp, pike, perch, and wels. The shoreline is encircled by dense reed belts. Moreover, the lake is encompassed by cattails, bulrushes, and sedges. It can be classified as a permanent water feature due to it has not undergone the process of desiccation.

Timár Morotva oxbow lake (TI) is situated the Tisza River and is within the jurisdiction of the Timár town. Currently, the length of the lake is 1058 meter, with an average width of 60 meters. The water's surface covers an area of nine hectares and maintains the deepest water depth of 2.2 meter. Also, it can be classified as a permanent water feature due to it has not undergone the process of desiccation. The TI oxbow is an unutilized natural lake that is also protected under the Natura 2000 program. Over half of the lake's surface is occupied by emergent, submergent, and floating leaf macrophytes.

3.2.2 Investigation process of the subfossil Cladocera and geochemical parameters in short-core sediments from lakes

A Single-core sediment samples were used as a gravity core to collect an 11 cm short core from each oxbow lake of Kis-Morotva (KMT), Szabolcs (SZA), and Timár Morotva (TI). The intact cores were encased in plastic and aluminum foils and kept at a temperature of 4°C until they were processed.

Respectively, the sediment cores were cut into slices at 1 cm intervals, and each slice of sediment was processed for analysis in the laboratory,

specifically for the subfossil Cladocera. We counted the subfossil Cladoceran preserved in each sediment layer (33 slides samples in total) to examine the structure of the Cladoceran community. It was carried out according to the standard method of Korhola and Rautio (2001b). An amount of sediment equivalent to one cubic centimeter was obtained from every sample, which was treated with 100 mL of 10% KOH (potassium-hydroxide) solution in a plastic beaker. Following the mixing of these solutions, it was warmed up to 100°C on a hot plate for 30 minutes with careful stirring to avoid damaging the remains. On completion of the heating process, each sample was sieved through a mesh screen with a hole size of 35 µm (micrometer) to eliminate a majority of the organic particles, after which the samples were rinsed with distilled water. Distilled water was used to place the samples into 50-milliliter tubes. The next step was to preserve samples with 70% ethanol, with five drops of a solution of safranin-glycerin added to aid in identification. Following this, the prepared samples were allowed to settle for 24 hours, after which the excess distilled water was sucked off until 25-milliliter and ready for investigation. This procedure is important because treatment with KOH causes chitin to become completely transparent, making it almost imperceptible under a microscope without Safranin-glycerin staining, and preservation prevents fungi from growing in the samples (Kattel and Augustinus, 2010; Sweetman and Smol, 2006). As a result of these preparations, Cladocera residues were identified according to their species. Every sample was applied to the slides by using an automatic pipette for every 100 microliters. In order to determine the species, a light microscope such as Olympus BX 53 type (Olympus Europe Holding GMBH, Hamburg,

Germany) was used under a magnification of 100. Cladocera abundance and diversity were determined by samples collected. Therefore, at least 100 species individuals, approximately 200-250 subfossil were counted from each of the thirty-three samples. To identify the Cladocera species remains (carapaces, headshields, postabdomens, postabdominal claws), we used the identification keys of studies conducted by Frey (1987), Gulyás (1974) and Szeroczyńska and Sarmaja-Korjonen (2007), as well as Bledzki and Rybak, (2016). A conversion was made to individual/cm³ based on our results.

Core sediment samples were analyzed in the laboratory to determine the contents of organic matter, calcium carbonate (CaCO₃), and the elemental composition. As a first part, the determination of the calcium carbonate (CaCO₃) and organic matter contents was carried out in accordance with Dean's (1974), completed by Heiri's et al., (2001). In the first step, from each sample, approximately 5 grams of sediment were weighed and placed in petri dishes, then weighted samples were dried at 105 °C in a drying oven. The dried samples are powdered in an agate mortar to obtain a sample of completely similar consistency. Then, each powdered sediment sample was measured out 1 gram into a known mass of ceramic cups. The samples were subjected to combustion at a temperature of 550 °C for a duration of four hours in an oven to ascertain their organic matter content. Using the weight loss of the samples, organic matter content per original weight was determined. The ceramic cups, which held the samples, were reintroduced into the annealing furnace and subjected to a heating duration of four hours, followed by a holding period of two hours at a temperature of 950 °C.

The initial weight was determined by evaluating the weight drop in relation to the calcium carbonate concentration.

As part of the determination of the chemical parameters, the elemental composition was estimated in the dry sediment samples. Initially, Precisa ES 225SM-DR of analytical balance was used to measure the dry sediment samples, and 0.2 grams were measured. In the chemical preparation of the samples, a solution consisting of 1.0 ml (H_2O_2 30%) (reagent grade, Merck) and 5.0 ml (HNO_3 65%) (reagent grade, Scharlau) was employed for the wet digestion method before elemental analysis. (Sajtos et al., 2019). Immediately after digestion, the results of digestion were diluted to a volume of 25.00 ml using water of ultrapure (Synergy UV Millipore) in plastic centrifuge containers equipped with volume calibration. For further elemental analysis, the solutions were stored at the ambient temperature after their production. After chemically preparing the sediment samples, we used MP-AES 4200, Agilent Technologies model of spectrometry of microwave plasma atomic emission to accurately measure the element content. While the measurements were taking place, nitrogen generators (Agilent Technologies 4107) continuously provided plasma gas. By using an automatic sampler, standard and sample solutions were applied, and each sample solution was washed with 0.1 ml HNO_3 solution made in water of ultrapure for 30 seconds between each sample. The sediment samples were analyzed for elemental concentration using the ICP-OES 5110 Vertical Dual View, Agilent Technologies model of spectrometry for inductively coupled plasma optical emission. We used the Agilent SPS4 model autosampler in conjunction with a Meinhard® type nebulizer and spray chamber of double pass. So, we carried

out the determination of geochemical elements (macro and micro) using a method of five-point calibration, specifically the ICP VI Merck. The determination of the macro elements including aluminum, iron, calcium, potassium, magnesium, and sodium was acquired by the use of a standard solution of mono-element spectroscopic with a concentration of 1000 mg L⁻¹ (Scharlau). While, the determination of the micro-elements including Ba, Cd, Co, Cr, Cu, Li, Mn, Ni, Pb, Sr, Zn was obtained by employing a standard solution of multi-element spectroscopic with a concentration of 1000 mg L⁻¹ (ICPIV, Merck). Calibration of a five-point process was used for all solutions; whereby standard solutions were diluted using 0.1 ml HNO₃ generated in water of ultrapure. Environmental variables in ordinations were determined based on the geochemical compositions of sediments.

3.2.3 Data analysis

To conduct the statistical analysis, a set of principal component analyses (PCA) were utilized to assess the distribution of Cladoceran species and geochemical components inside oxbows. Before doing PCA, the Cladoceran data underwent Hellinger transformation (square root of relative abundance) (Legendre and Gallagher, 2001), while the geo-chemical variables were standardized using z-transformation.

In order to assess the similarity between the lakes in terms of their Cladoceran communities and environmental factors, we conducted a PERMANOVA analysis utilizing the scores for the first two principal component analysis (PCA) components in each sediment core. The PERMANOVA analysis was conducted using Euclidean distance with 999 permutations. The analysis was performed in an R environment using the

Adonis2 function from the vegan package (Oksanen et al., 2017). We employed the betadisper function from the vegan package (Oksanen et al., 2017) to validate the mean distance between each point and the group median as a metric for multivariate dispersion. Following that, a sequence of redundancy analyses (RDA) was employed to determine the key environmental variables that influence the composition of the Cladoceran community. Initially, RDA studies were conducted without using conditional variables, which served as null models. A three RDA model was constructed, using conditional variables such as: a) kind (intermittent, permanent); b) lakes; c) depth. To identify the geochemical variables that best explain the largest variation in the species data, we used variance inflation factors (VIF) to identify strongly correlated geochemical variables. Variables having a variance inflation factor (VIF) over 20 were removed from the environmental dataset. So, the importance of each geochemical variable used in the RDA was tested using Monte Carlo permutation testing. Environmental variables that could not account for a substantial amount of species variation, as determined by Monte Carlo permutations ($p < 0.05$; 999 random permutations), were excluded from the RDA analysis. A sequential process of selection was conducted to identify the subset of environmental characteristics that were statistically significant. The estimation of species diversity in the subfossil Cladoceran assemblages was conducted using Hill's numbers (Hill, 1973) based on densities. In this context, N0 represents species richness (the number of taxa), N1 represents Shannon-Wiener diversity, and N2 represents inverse Simpson diversity, which is the reciprocal of Simpson's diversity index (Hill, 1973; Jost, 2006; Telford and Birks, 2011). The

Shannon-Wiener index is responsive to infrequent taxa, whereas the Simpson index is responsive to prevalent ones (Jost, 2006). The Hill's numbers were computed using the `renyi` function from the `vegan` package. To determine the diversity ranking, we calculated the average genuine diversity values based on lakes.

Beta-diversity was estimated independently for all lakes, considering the entire variation of species compositional data. Beta-diversity is partitioned into three components: replacement, richness difference, and similarity, using the `be-ta.div.comp` function of the `adespatial` R-package. Replacement refers to the act of substituting one species for another within sediment layers, whereas richness difference quantifies the extent to which communities vary in the number of species they contain (Legendre, 2014). In order to compute this, we employed the SDR-simplex methodology, which relies on the Jaccard index (Legendre, 2014; Podani and Schmera, 2011). The pairwise values can be displayed on ternary plots, often known as simplices, where the sum of Replacement, Richness Difference, and Similarity equals 1. By examining the pairwise sums of the additive components, one may assess the relative contributions of beta diversity (which includes Replacement and Richness difference) and nestedness (which includes Richness difference and Similarity) to gamma diversity. The beta diversity of sediment layers in the lakes was determined using the `beta.div` function from the `adespatial` R package. This analysis also included the local contribution to the beta diversity (LCBD). The studies were conducted using the R statistical environment (Michael and Sharma, 1988; R core Team, 2018).

4. RESULTS

4.1 Cladocera composition in the Nagy-Morotva oxbow lake

4.1.1 Applicability of Cladocera found in filtered water and sediments to verify recent conditions

The filtered and sediment samples indicated above were included in this study. A record of 37 species of Cladocera was established, encompassing both sediment and surface water, in the Nagy-Morotva oxbow lake. 75% of the aforementioned species were detected in both type of samples. The prevailing taxa in Cladoceran communities consisted of *Bosmina longirostris*, *Eubosmina coregoni*, and *Chydorus sphaericus*. The samples collected from three sites, namely FS-1, NS, and FS-2, exhibited the highest levels of *B. longirostris* concentration in both the filtered samples (ranging from 38% to 55%) and sediment samples (ranging from 69% to 73%).

4.1.2 Verifying the recent state of oxbow lake using contemporary Cladoceran species

The findings of our study revealed that the oxbow lake exhibits a lower level of species variety and a higher level of abundance of contemporary Cladoceran species in the filtered water sample. Specifically, we identified a total of 29 taxa, with an individual count of 176,783 Ind. L⁻¹. The species composition and abundance of Cladocera exhibited significant differences across different sites. The observed data indicates a decrease in number of different species of contemporary Cladocerans among the three sites (FS-1, NS, and FS-2). Specifically, the species richness values were recorded as follows: Fishing site-1 with 23 identified taxa, Natural site with 19 identified

taxa and lastly, Fishing site-2 with 18 identified taxa. The high species number (RAK1: taxa-16) preserved in the FS-1.

At fishing site-2, a high abundance of the Cladocera was preserved in the filtered samples. There was dominant 12 species out of 29 that occurred in each site. There are *Acroperus harpae*, *Alona guttata*, *Alona intermedia*, *Alona quadrangularis*, *Alonella exigua*, *Bosmina longirostris*, *Chydorus sphaericus*, *Eubosmina coregoni*, *Eubosmina longispina*, *Graptoleberis testudinaria*, *Pleuroxus laevis*, *Pseudochydorus globosus*. 5 species were identified that exhibited exclusive presence at some sites. These are *Oxyurella tenuicaudis*, *Pleuroxus uncinatus*, *Polyphemidae sp* (in FS-1), *Camptocercus fennicus* (in FS-2) and *Disparalona rostrat* (in NS). 8 species were not identified at some sites. These are *Alonella excise* (FS-1), *Alona costata*, *Alona rectangular*, *Paralona pigra* (NS), *Alona affinis*, *Leydigia leydigii*, *Pleuroxus trigonellus*, and *Pleuroxus truncates* (FS-2).

The species composition of contemporary Cladocera underwent Principal Coordinate Analysis (PCoA) based on Jaccard dissimilarity. The (PCoA) ordination revealed a significant variation in the Cladoceran species composition between the bottom and other sections of the oxbow lake ($R^2=0.142$, $p<0.05$ for adonis). However, the Cladoceran assemblages at FS-1 and NS of the oxbow lake were found to be strikingly similar (Table 1, Figure 7).

TABLE 1. The adonis analysis was used to compare the contemporary Cladoceran assemblages in the three sites of the oxbow lake using pairwise multilevel comparison.

Pairs	F.Model	R ²	p-value	p _{adjusted}	sig
FS-1 vs NS	0.7835624	0.0568476	0.607	0.6070	n.s.
FS-1 vs FS-2	3.6415464	0.2669453	0.007	0.0105	.
NS vs FS-2	3.7957823	0.2259962	0.007	0.0105	.

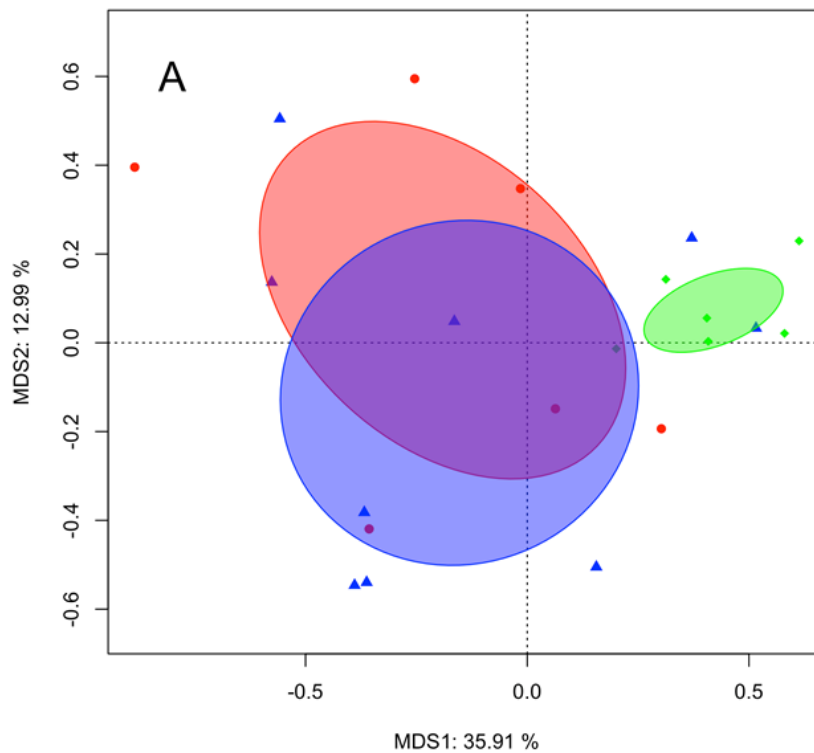


Figure 7. The findings from the Principal Coordinate Analysis (PCoA) conducted on the assemblages of contemporary Cladocera at the three sites of oxbow lake are presented. The sites' group centroids are graphically represented by coloured ellipses. Notation: (Fishing site-1: Red, Natural site: Blue, Fishing site-2: Green).

4.1.3 Verifying the recent state of oxbow lake using remains of Cladocera

In the case of the subfossil Cladocera, a total of 36 species identified with an individual count of 131711 Ind. cm⁻³. The sediment samples exhibited a greater degree of species richness compared to the filtered samples. Based on our analysis, the data suggests a rise in the species richness of the Cladocerans when we transitioned among FS-1 to FS-2. In particular, FS-1 exhibited a species richness of 29, whereas the NS showed a species richness of 31, and FS-2 had the maximum species richness of 33. The high species number (RAK18: taxa-27) preserved in the FS-2. High abundance of the contemporary Cladocera preserved in the NS.

25 of the 36 species found in sediment samples. Species were found in each site. These were *Alona guttata*, *Alona affinis*, *Alona quadrangularis*, *Alonella excise*, *Alona rectangular*, *Alona intermedia*, *Alonopsis elongate*, *Alonella exigua*, *Bosmina longirostris*, *Chydorus gibbus*, *Camptocercus rectirostris*, *Chydorus sphaericus*, *Daphnia pulex*, *Disparalona rostrata*, *Eubosmina coregoni*, *Eubosmina longispina*, *Graptoleberis testudinaria*, *Leydigia acanthocercoides*, *Monospilus dispar*, *Paralona pigra*, *Pleuroxus laevis*, *Pleuroxus trigonellus*, *Pleuroxus truncates*, *Pleuroxus uncinatus*, *Pseudochydorus globosus*. We defined four species which did not occur at some sites. These are *Acroperus harpae*, *Daphnia longispina*, *Sida crystallina* (in Fishing sites) and *Camptocercus fennicus* (in Natural site). Four species were found that were specifically found only in some sites. These are *Kurzia lattissima* (FS-1), *Leydigia leydigii* (NS), *Camptocercus lilljeborgi* and *Oxyurella tenuicaudis* (FS-2).

The principal co-ordinates analysis (PCoA) conducted revealed that the sites exhibited distinct remain of Cladocera assemblages (Adonis: R²=0.201, p<0.05) (Table 2). Nevertheless, the remains of Cladocera assemblages at the two fishing sites showed a greater resemblance to each other, while the natural site had a noticeably distinct assemblage (Figure 8).

TABLE 2. The adonis analysis was used to conduct a pairwise multilevel assessment of subfossil Cladoceran assemblages in the oxbow lake.

Pairs	F.Model	R²	p-value	p_{adjusted}	sig
FS-1 vs NS	4.671560	0.2643547	0.003	0.009	*
FS-1 vs FS-2	2.978583	0.2294999	0.012	0.015	.
NS vs FS-2	1.750745	0.1186886	0.015	0.015	.

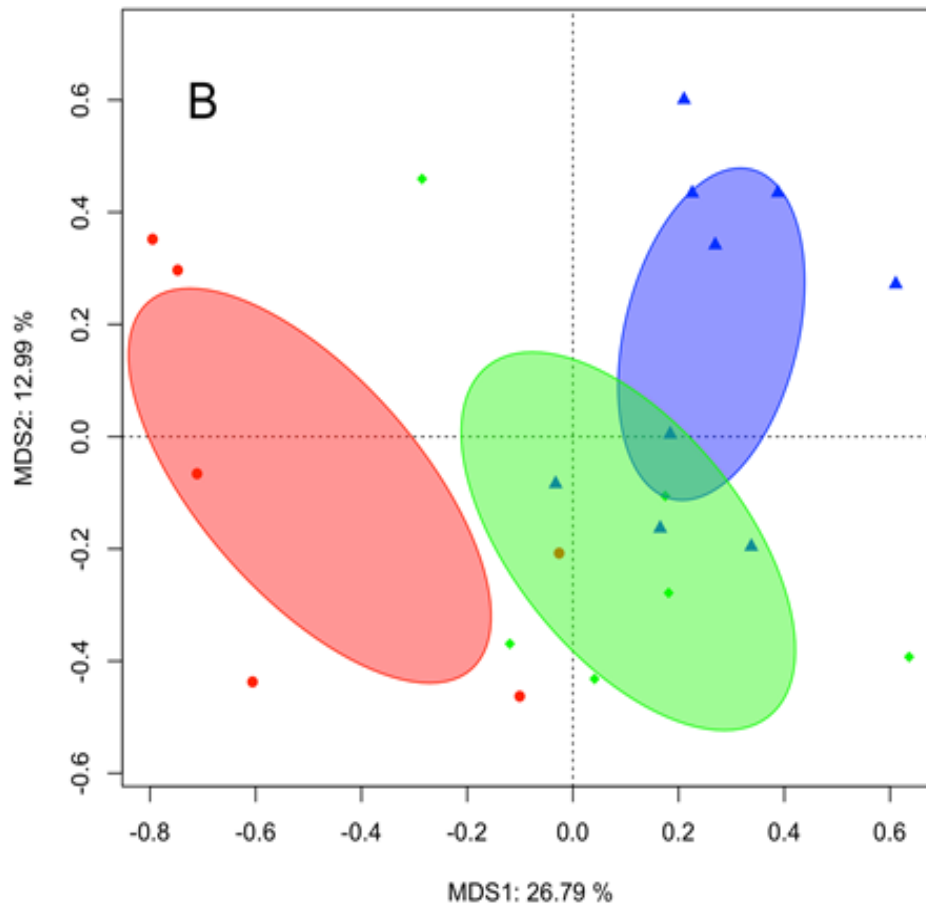


Figure 8. The findings from the Principal Coordinate Analysis (PCoA) conducted on the remains of Cladocera assemblages at the three sites of Nagy-Morotva oxbow lake are presented. The sites' group centroids are graphically represented by coloured ellipses. Notation: (Fishing site-1: Red, Natural site: Blue, Fishing site-2: Green).

4.1.4 Physical-chemical parameters of oxbow lake

Utilizing physical-chemical variables, principal component analysis was performed on three sites (Figure 9). In the case of the filtered water samples, the physical-chemical variables underwent between-group principal

component analysis, which indicated that the FS-1, NS, and FS-2 locations exhibited significant differences (Figure 9A). The sum of the contributions from the initial PC1 and the subsequent PC2 was 31.15 and 18.17 percent, respectively, of the total variance. There was a positive correlation between the natural site and the variables Ca^{2+} , Chl_a , and DO.P . FS-2 exhibited the presence of SO_4^{2-} , TDS, Cl^- , Na^{2+} , and NH_4^+ . The primary factors observed at fishing site-1 were the presence of various cations (K^+ , Mg^{2+} , Al^{3+} , Ba^{2+} , Cr^{2+} , Pb^{2+} , Sr^{2+}), as well as ODO and HCO_3^- .

Regarding the sediment samples, analysis of principal component was conducted using physical-chemical variables (Figure 9B). The results of this study revealed that the FS-1 and NS locations had similar characteristics, however, the FS-2 locations displayed distinct features. The fishing site designated as FS-1 experienced a strong association with conductivity, LOI_{550} and NH_4^+ . The NS had a strong association with conductivity, LOI_{550} , NO_2^- , NH_4^+ , PO_3^- , and ORP, while displaying a negative correlation with LOI_{950} , and pH. The FS-2 had a strong positive association with the presence of NO_2^- and PO_3^- .

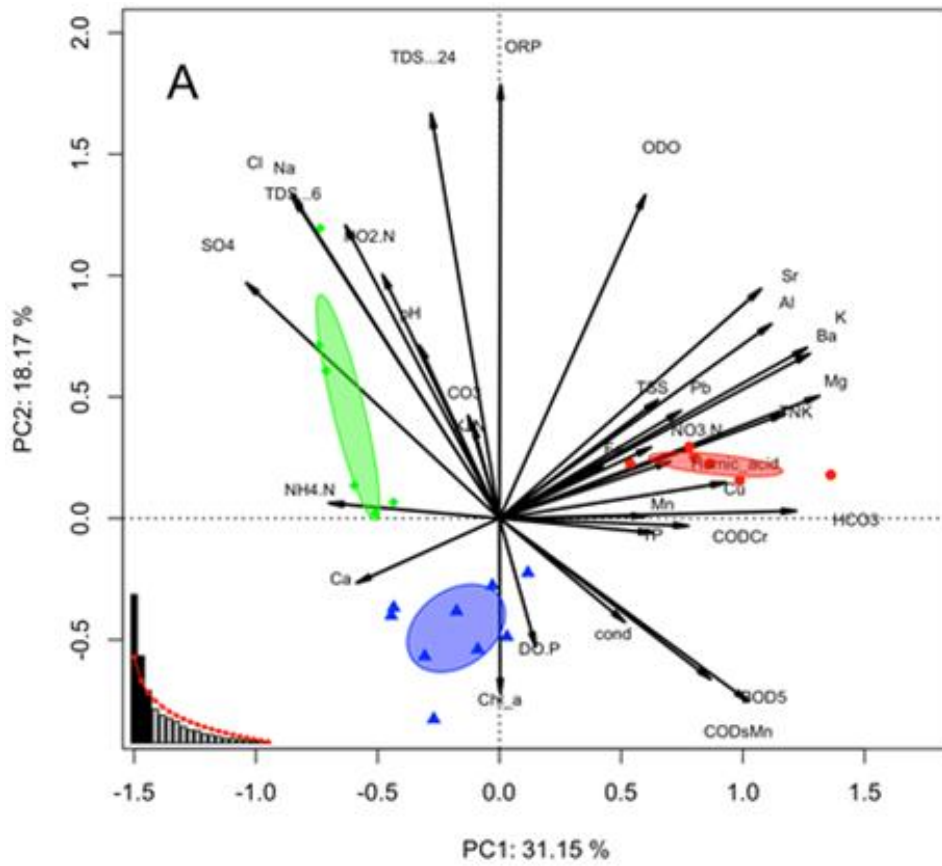


Figure 9. The principal components analysis (PCA) was conducted on the whole set of physical-chemical variables recorded in both the water (A) and surface sediment (B) samples collected from the oxbow lake. The locations depicted in the diagram are labeled as follows: The red area represents Fishing Site-1, the blue area represents a Natural Site, and the green area represents Fishing Site-2.

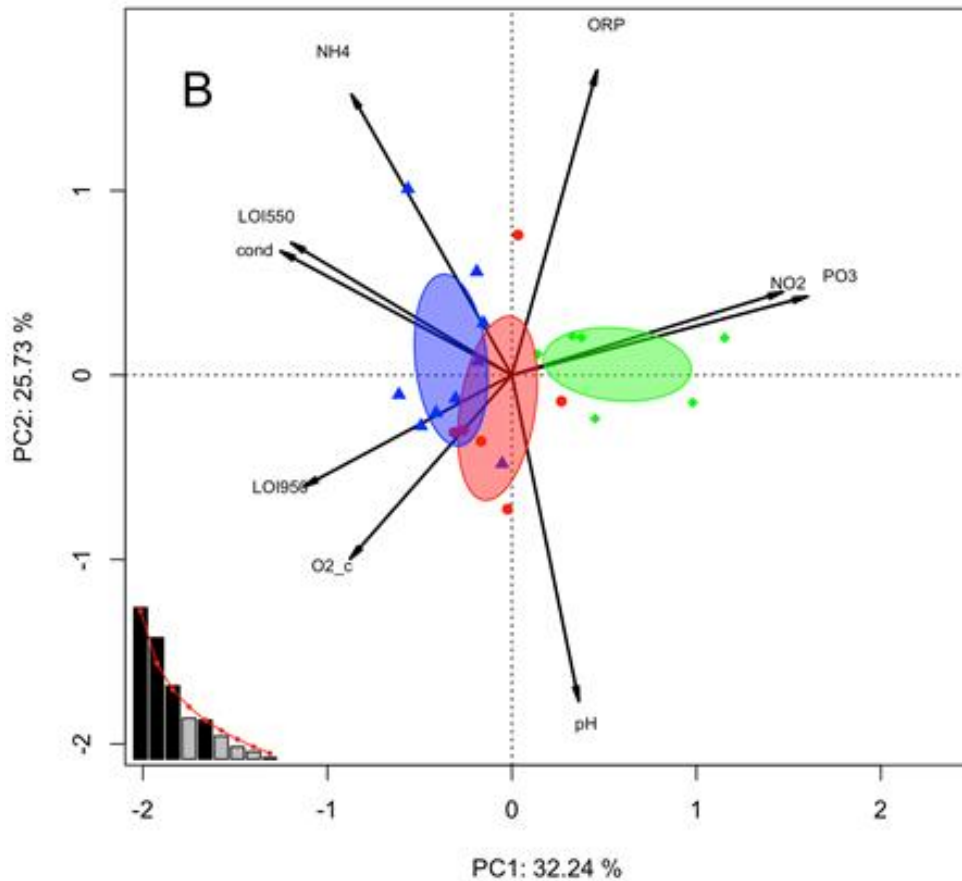


Figure 9. The principal components analysis (PCA) was conducted on the whole set of physical-chemical variables recorded in both the water (A) and surface sediment (B) samples collected from the oxbow lake. The locations depicted in the diagram are labeled as follows: The red area represents Fishing Site-1, the blue area represents a Natural Site, and the green area represents Fishing Site-2.

The present study employs dbRDA and investigates the association between Cladoceran abundance and physic-chemical variables. With this analysis, it was our intention to define those possible species of Cladocera and physical-chemical variables that can act as indicators of the three sites (Figure 10).

In case of the filtered samples, the dbRDA1 expressed 36.42% and dbRDA2 was 6.96% of the total variance (Figure 10A). The result of the analysis showed that it was observed that FS-1 and the NS exhibited overlap in terms of DO.P, Cu²⁺, Chl_a, and BOD₅. These variables were shown to have a high level of significance in relation to the assemblage of contemporary Cladocera. In both FS-1 and the NS, five species showed significant high abundance. These are *Bosmina. sp.*, *C. sphaericus*, *Alona intermedia*, *Pseudochydorus globosus* and *Monospilus dispar*. DO.P. was significantly and positively associated with *M. dispar* and *A. intermedia* species. There exists a noteworthy inverse relationship between BOD₅, Chl_a, and Cu²⁺ with DO.P. There was a notable inverse relationship seen between the BOD₅, Chl_a, and Cu²⁺ variables and the abundance of *P. Globosus* and *C. sphaericus*. FS-2 was isolated from the other two sites. It was determined that there were no significant relationships between Chl_a, BOD₅, DO.P, and Cu²⁺ in relation to FS-2 and *Bosmina. sp.*

The findings indicated that the three sites were delineated on the dbRDA with respect to the sediment samples (Figure 10B). The first dbRDA component accounted for 17.64% of the overall variation, whereas the second dbRDA component accounted for 4.75%. The correlation of PO₃⁻ showed a strongly association with FS-2, whereas there was a notable inverse correlation between the LOI₅₅₀ and the NS. Moreover, the variables PO₃⁻ and LOI₅₅₀ had no significant connection with fishing site-1. Generally, the species *A. intermed*, *Bosmina sp*, *Coronatella rectangula*, *P. globosus*, and *C. Sphaericus* exhibited significant levels of abundance throughout the three sites. In both the NS and FS-2, the species *Alona gutatta*, *Pleuroxus*

trigonellus Graptoleberis testudinaria, and *Acroperus harpae*, exhibited a significantly strong density.

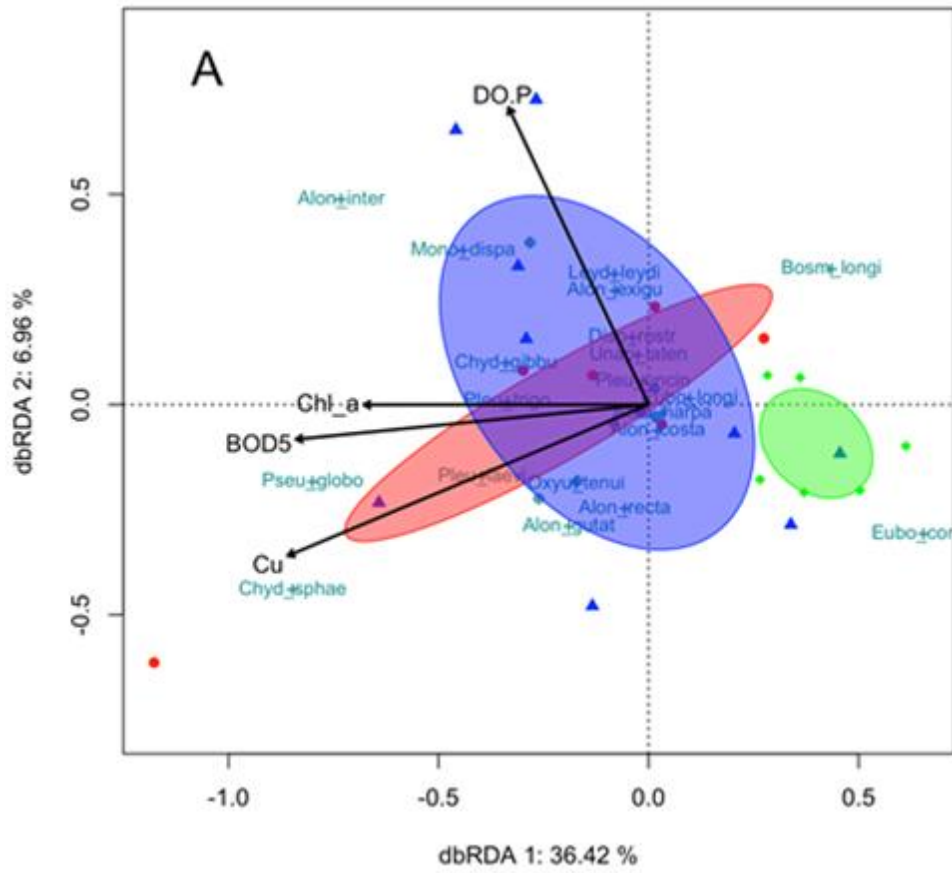


Figure 100. An ordination diagram based on distance-based redundancy analysis (dbRDA) illustrating (A) present-day and (B) subfossil Cladocera assemblages across three sites in relation to forward-measured physical-chemical variables. The sites' colors denoted samples collected at three distinct locations. (Fishing site-1: Red, Natural site: Blue, and Fishing site-2: Green).

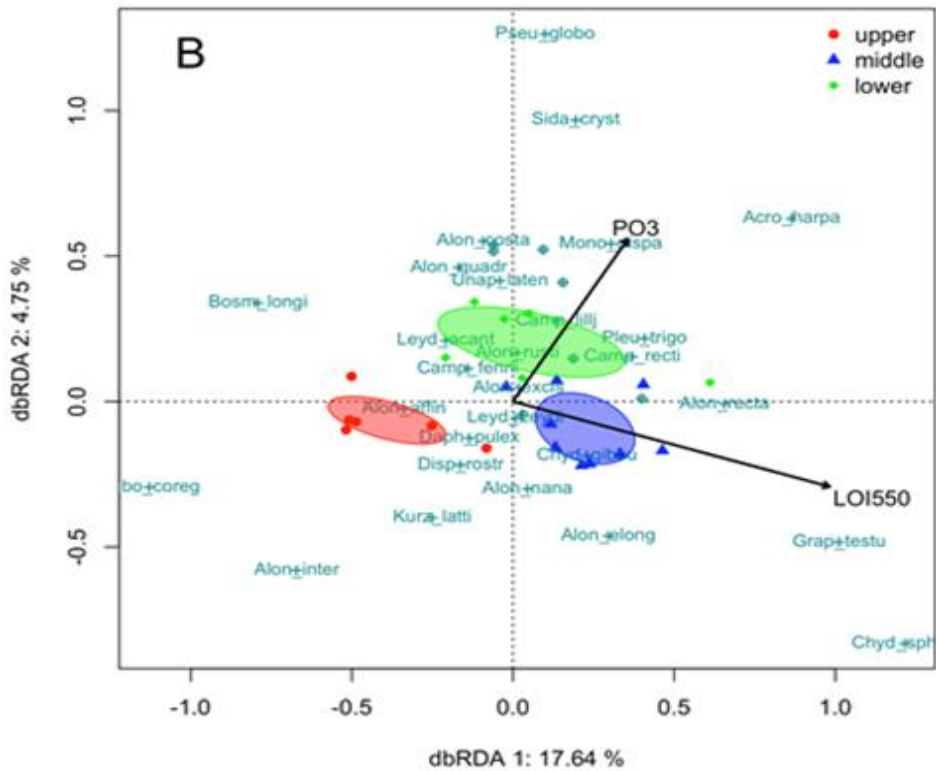


Figure 110. An ordination diagram based on distance-based redundancy analysis (dbRDA) illustrating (A) present-day and (B) subfossil Cladocera assemblages across three sites in relation to forward-measured physical-chemical variables. The sites' colors denote samples collected at three distinct locations. (Fishing site-1: Red, Natural site: Blue, and Fishing site-2: Green).

4.1.5 Examining the pattern of Beta-diversity with Cladocera assemblage

In the contemporary assemblages, the Shannon index values varied across different sites. Specifically, the fishing site-1 exhibited a range of 0.89 to 2.07, the natural site ranged from 0.63 to 1.45, and the fishing site-2 ranged from 0.74 to 0.83. However, the Shannon index values of the subfossil assemblages exhibited greater values (fishing site-1: 0.67-2.13; natural site:

1.75-2.27; fishing site-2: 1.71-2.33) compared to the contemporary assemblages.

The oxbow lake exhibited a notable resemblance between the contemporaneous and subfossil assemblages throughout all three sites. Approximately 43% and 51.5% of the total species stock exhibit standard characteristics. In contemporary assemblage, there has been an observed rise in diversity and beta-diversity, which collectively account for 56.8% of the observed variance (Figure 11). The natural site had the highest beta diversity, indicating the lowest level of similarities. Approximately 30% of the species exhibited a distinct association with a single habitat. During observations conducted at fishing site-1 and fishing site-2, it was determined that the proportion of individual species exclusively occurring in a specific location ranged from 15% to 20%.

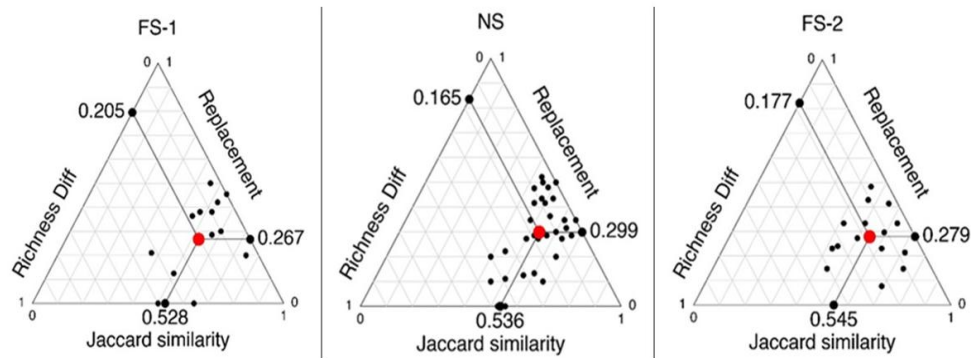


Figure 11. Simplex plots prepared for the species richness (RichDiff), species replacement and similarity (Jaccard similarity) values of the contemporary Cladocera assemblages of the three sites of the Nagy-Morotvo oxbow lake. Three sites: Fishing site-1 (FS-1), Natural site (N.S), and Fishing site-2 (FS-2).

The subfossil Cladocera assemblage observed in the oxbow lake exhibits a higher degree of resemblance to the contemporary assemblage. The beta diversity of the subject in question exhibits a lower value of 48.5%. The species composition of the three areas exhibited a strikingly similar pattern (Figure 12). The fishing site-1 exhibited the highest beta diversity (47.2%), while the other two sites displayed progressively decreasing values (NS: 46.4% and FS-2: 45.5%). In the fishing site-1, it was observed that 20% of the species were exclusively present in a single location. While the natural site exhibited the highest diversity in the Cladocera assemblage, with approximately 30% of the species accounting for the observed variety.

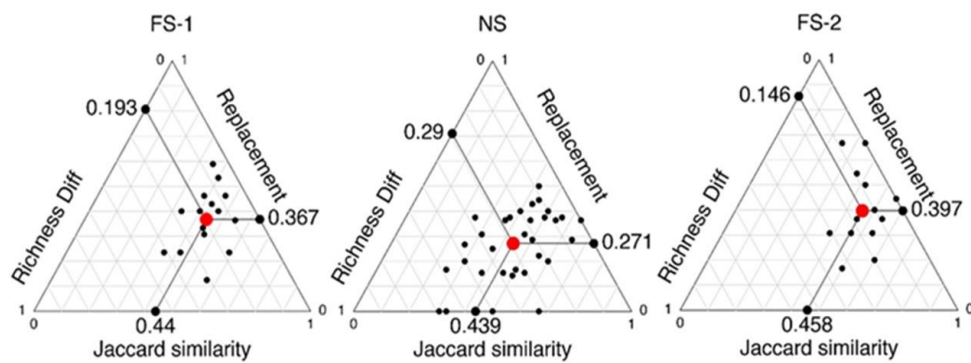


Figure 12. Simplex plots prepared for the species richness (RichDiff), species replacement and similarity (Jaccard similarity) values of the subfossil Cladocera assemblages of the three sites of the Nagy-Morotvo oxbow lake. Three sites: Fishing site-1 (FS-1), Natural site (N.S), and Fishing site-2 (FS-2).

4.2 Clarify the persistence of Cladoceran assemblages in sediment layer sequences.

4.2.1 Describe the deposition of Cladocera remains through the analysis of sediment core samples from oxbow lakes

38 Cladoceran taxa from five families including Bosminidae, Chydoridae, Daphniidae, Leptodoridae, and Sididae were found in sediment core samples from three oxbow lakes: Kis-Morotva (KMT), Szabolcs (SZA), and Timár Morotva (TI). The family of Chydoridae had the most species, while Bosminidae, Daphniidae, Leptodoridae, and Sididae had fewer species. Consisting of 72% of the total species composition, each core sediment sample contained all 28 identified species. Most frequently observed were the following dominant species in oxbow lakes: *Acroperus harpae*, *Alona gutta*, *Bosmina coregoni*, *Bosmina longirostris*, *Chydoridae sphericus*, *Coronatella rectangular*, and *Graptoleberis testudinaria*. SZA oxbow lake was the sole location where *Alona rustica* was identified. Sedimentary layers were observed in the oxbow lakes of KMT, SZA, and TI under the *Disparalona rostrata*. *Alona rustica* was exclusively observed within SZA oxbow lake. The *Disparalona rostrata* was found to exhibit sedimentary layers in the oxbow lakes of KMT, SZA, and TI.

The Cladocera species' abundance varied from 715 to 4418 individuals per cm³, with an average of 2421 individuals per cm³. In the SZA oxbow lake, the research discovered a large number of Cladocera communities, with a total of 36 recognized taxa. On the other hand, the quantity of Cladocera communities observed in TI oxbow lake was relatively low, comprising a mere 31 taxa. When compared to the KMT oxbow lake, the

abundance of Cladocera species was significantly higher in the SZA and TI oxbow lakes. The core sediment samples from the Kis-Morotva oxbow lake contained subfossils of 33 taxa of Cladocerans, with the most common species being *A. gutta*, *Coronatella rectangula*, *B. coregoni*, *B. longirostris*, *C. sphaericus*, and *G. testudinaria*.

The documentation of species detection in sediment layers revealed the following: *Alonella nana* was observed in layers 9-10 of the core sediment, while *Monospilus dispar* was identified in layers 2-3, *Paralona pigra* was found in layers 4-5, and *Chydorus gibbus* was detected in layers 5-6. In addition, certain layers in the core sediment did not contain preserved remains of *A. exigua* in layer 0-1 and *Acroperus harpae* in layer 8-9. The entire amount of species individuals in the first second layers were smaller count than in the following layers.

The core sediment samples from the KMT oxbow lake contained thirty-three Cladoceran species, with *Alona guttata*, *Coronatella rectangula*, *Bosmina coregoni*, *Bosmina longirostris*, *Chydorus sphaericus*, and *Graptoleberis testudinaria* being the most dominant. Furthermore, the some species that were found in the sediments were nearly nonexistent, however remains of *Alonella nana* (layers 9–10), *Chydorus gibbus* (layers 5–6), *Monospilus dispar* (layers 2-3) and *Paralona pigra* (layers 4-5) could be found in several core sediment layers.

Taxonomic diversity was greater in the Szabolcs oxbow lake (tax 37) than in other oxbow lakes. The observed species over every sediment layers are *A. harpae*, *A. gutta*, *A. excisa*, *B. coregoni*, *B. longirostris*, *C. rectangular*,

C. sphaericus, *G. testudinaria*, *P. trigonellus*, and *S. crystalian*. Some sediment-dwelling organisms were absent in specific sediment layers.

Several species were missing from certain sediment layers, such as *Alonella exigua* in layers 3-4, *Oxyurella tenuicaudis* in layers 4-5, and *Alona intermedia* in layers 10-11. The presence of the *Alona rustica* species was solely documented in sediment layers 7-8. Additionally, it was noted that the presence of *Camptocereus lilljeborgi* species was considerably restricted to the sediment layer, as detection was restricted to layers 2-3 and 9-10.

The Timár Morotva (TI) oxbow lake exhibited the smallest number of taxa, with 31 being the lowest count. 10 taxa were prevalent in this oxbow lake, while 8 taxa were prominent in the SZA oxbow lake. Furthermore, *Alona intermedia* and *Picripleuroxus laevis* were present in every layers.

4.2.2 Examining the pattern of Beta-diversity in the Cladocera remain with geochemical elements

Distinguishing characteristics of the three oxbow lakes were uncovered by the PCA analysis of the Cladoceran data and the environmental factors (geochemical element composition). The distribution of both environmental factors and Cladoceran was homogenous, while the communities of Cladoceran and geochemical element composition of the oxbow lakes varied (Table 3).

TABLE 3. PERMANOVA F and p values based Euclidean distance for PCA scores and statistic parameters of the Permutation test for homogeneity of multivariate dispersions (PERMDISP) based on PERMANOVA for functional composition.

Data set		R	F	p
Cladocerans	PERMDISP		1.4	0.268
	PERMANOVA	0.7145	37.529	0.001
Environmental variables	PERMDISP		0.225	0.809
	PERMANOVA	0.591	21.639	0.001

The results of the RDA analyses indicated that the communities of Cladocera of each oxbow lakes varied (Figures 13-16). Within the null model, significant environmental factors (geochemical elements: Cu, Zn, Ni; LOI₉₅₀ from the Tisza,) accounted for 43% of the variation in the communities of Cladocera. As a conditional variable, the depth of the layers accounted for a mere 3.3% of the variance; the combined effect of the conditional variables including Ba and LOI₉₅₀ reduced the variance to 18%.

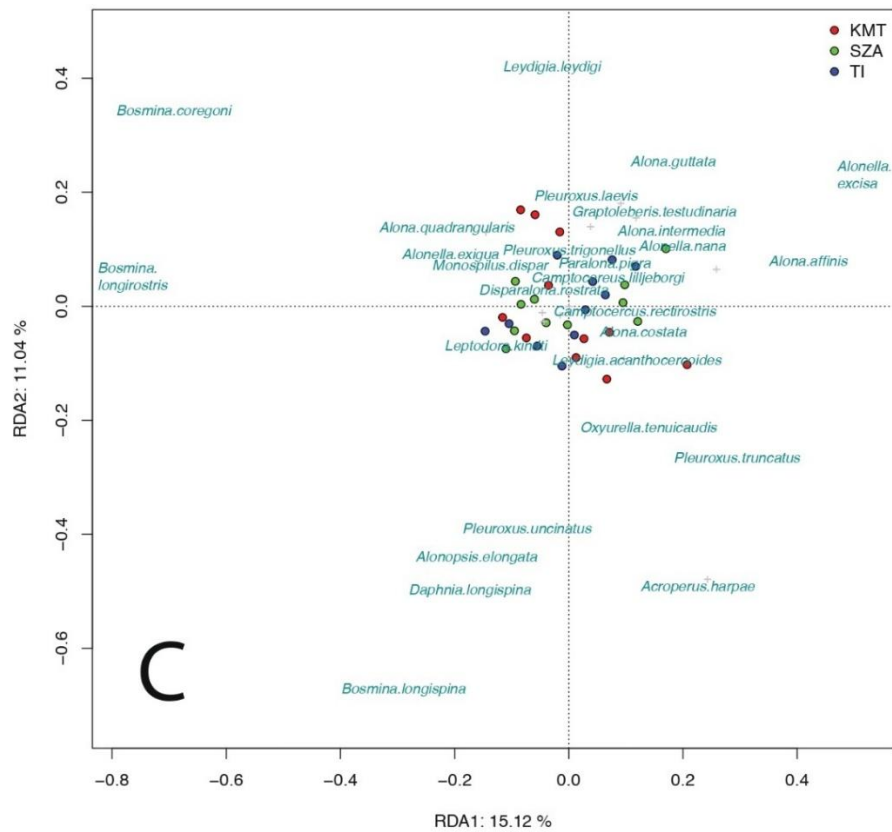


Figure 123. Biplot of redundancy analyses. (Arrows represent significant environmental variables. A: null model; B: depth conditioned model, C: site conditioned model).

Upon their introduction as conditional variables in the RDA, sites accounted for 29% of the overall variation and no variance remained constrained. The variance partitioning analysis validated the findings of the principal component analysis, indicating that the species pools in these oxbows are distinct from one another (Table 4).

TABLE 4. Results of redundancy analyses

	Null model		Depth conditioned		Site conditioned	
	Inertia	Proportion	Inertia	Proportion	Inertia	Proportion
Total	0.1697	1	0.1697	1	0.1697	1
Conditional			0.0056	0.0329	0.0487	0.2872
Constrained	0.0728	0.4288	0.0299	0.1760		
Unconstrained	0.0969	0.5713	0.1342	0.7911	0.1209	0.7128
F	4.053		3.2261		0	
<i>p</i>	0.001		0.001		0	

In the KMT oxbow lake, the species diversity of Cladocerans ranged from 16 to 22. The N1 diversity in the KMT oxbow varied from 7 to 15, in the SZA from 13 to 17, and in the TI from 9 to 13. The KMT, SZA, and TI exhibited N2 diversity ranging from 4 to 11, 9 to 13, and 5 to 10, respectively (Figure 15). How environmental changes can affect Cladoceran communities is illustrated by the sediment layer impact on the beta diversity of the oxbow lakes. Variations in environmental factors could enhance the the variations of the Cladoceran communities, i.e., beta diversity. Therefore, local distribution to beta diversity (LCBD) will be modified. Minor modifications were noticed in the LCBD along the depth in the oxbow lakes. The most significant alterations occurred in the top layer of the KMT oxbow lake and section from 3 to 8 cm and the bottom most layers in the SZA oxbow lake. The variations in the LCBD in Timár oxbow lake were rather consistent throughout the depth levels, as shown in Figure 14.

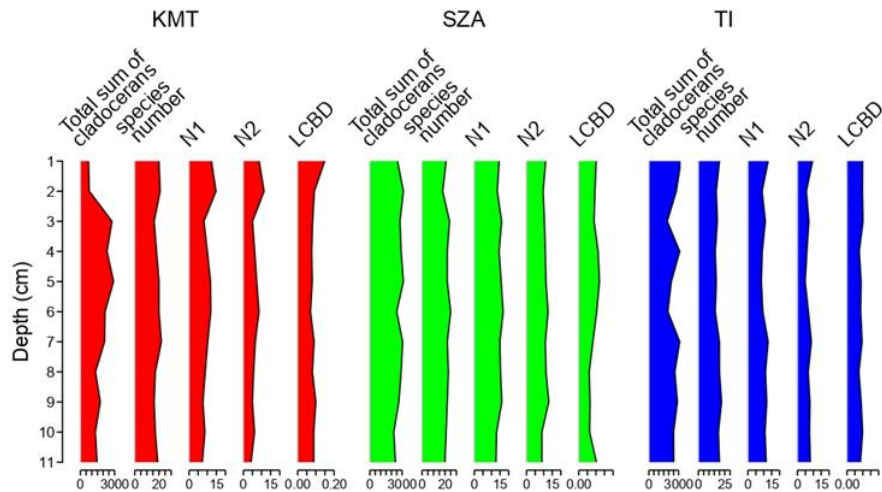


Figure 134. Stratigraphy plots of Cladocera abundances and diversities (number of species, Hill's N1, Hill's N2), and local contribution to beta-diversity (LCBD) of the Cladoceran communities in the oxbows. (KMT: Kis-Morotva oxbow, SZA: Szabolcs oxbow, TI: Timár Morotva oxbow).

The SZA oxbow demonstrated the greatest diversity, while the TI had a modest advantage in a number of species and the KMT had a marginal advantage in rare taxa (Figure 15).

The analysis of beta-diversity in oxbows showed that common Cladoceran species play a significant role in determining the species composition of sediment cores. The similarity among layers was notably high, with values of 58% in the KMT, 61% in the SZA, and 64% in the TI (Figure 15). The replacement components, which suggest that these species are the cause of the differences in the sediment layers, were notably high at 32%, 31%, and 28% in the KMT, SZA, and TI, respectively. The Richness Diff is calculated as the absolute difference in the numbers of species found at the locations (10%, 8%, 10% in the KMT, SZA, and TI, respectively). The beta-

diversity components were nearly identical across all the oxbow lakes, as seen in Figure 16.

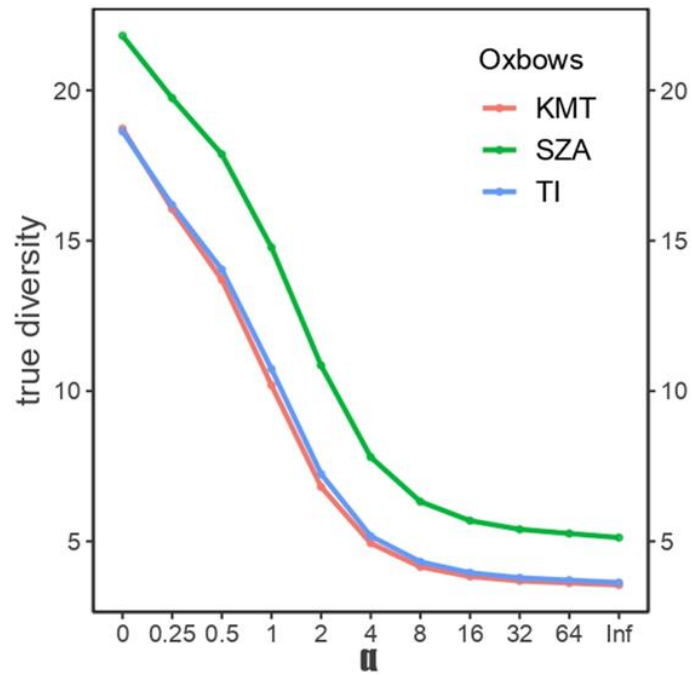


Figure 145. Diversity ordering of the oxbows

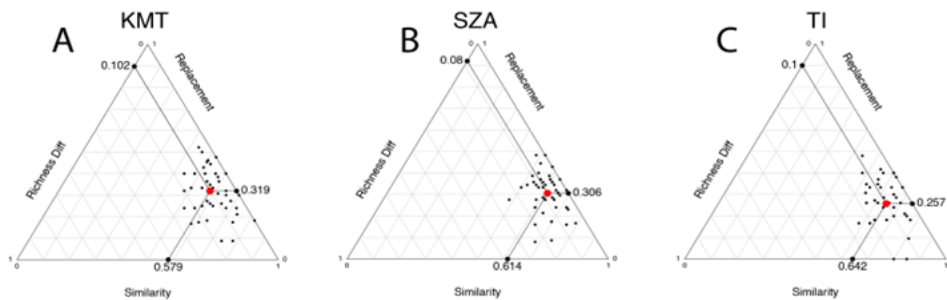


Figure 156. Triangular plots of beta diversity based on similarity, abundance Diff, and replacement for all comparisons of Cladocera communities among all sediment layers of three oxbow lakes, showing mean relative values for similarity, replacement, and abundance Diff (abundance difference). Notations: (A) KMT: Kis-Morotva oxbow lake, (B) SZA: Szabolcs oxbow lake, (C) TI-Timar oxbow lake

5. DISCUSSION

5.1 Is it necessary to simultaneously investigate the Cladocera community of filtered water samples and recent sediment samples in order to determine the impact of different sites within Nagy-Morotva oxbow lake?

Different assemblages of Cladocera can be discovered in samples of filtered water and surface sediment (Amoros and Jacquet, 1987; Frey, 1960). The examination of subfossil Cladocera assemblages is a crucial method for obtaining fundamental insights into the ecology of benthic and littoral environments. Therefore, we conducted an investigation on the assemblages of both contemporary and subfossil Cladocera in an oxbow lake known as Nagy-Morotva. The oxbow lake exhibited a lower diversity of species in the filtered samples, but a higher density of subfossil Cladoceran species. Specifically, there were 29 taxa and 176,783 Ind. L⁻¹ in the filtered samples, whereas the sediment samples contained 36 taxa and 131,711 Ind. cm⁻³. Previous researchers (Davidson et al., 2007; Frey, 1960) have indicated that there are discrepancies in the findings when comparing filtered and sediment samples. The diversity and density of a subfossil assemblage are derived from the accumulation of several years' worth of sediment on the surface, as well as its correlation with various environmental factors (Brodersen et al., 1998; Brooks and Dodson, 1965). In a study conducted by Korponai et al., (2019), identified 27 current Cladocera species and 18 subfossil Cladocera species in the same region.

It was observed that a total of 27 taxa for contemporary Cladocera species and 18 taxa for subfossil Cladocera species were identified within the

same region of the country. The observed disparities can likely be attributed to variations in the sampling locations. In contrast to Korponai et al., (2019) who used only one sampling point per oxbow lake, our analysis was more comprehensive, gathering samples from 21 different points. Similarities were noted in the high density of *E. longirostris* and *C. sphaericus* in both types of investigation. When studying a shallow oxbow lake, analysing subfossil Cladocera assemblages based on a single sample from the deepest point is inadequate. When studying a shallow oxbow lake, analysing subfossil Cladocera assemblages based on a single sample from the deepest point is inadequate.

Davidson et al., (2007) noted that the population of zooplankton communities in shallow oxbow lakes is affected by the density of size-selective predators and macrophytes. Furthermore, research has shown that the existence of fish puts pressure on larger Cladocera species, leading to increased predation. This phenomenon subsequently leads to a reduction in species diversity, with smaller Cladocera species potentially becoming more prevalent within the aquatic ecosystem (Berta et al., 2019; Confer and Applegate, 1979). The results showed that fishing site-1 (filtered sample) and fishing site-2 (sediment sample) had a significant number of Cladocera species, with some similarities observed. Furthermore, the fishing locations showed a significant presence of *Bomina sp.* The density of contemporary and subfossil *B. longirostris* was comparatively higher in fishing sites 1 and 2 when compared to the natural site. Nevertheless, the current study found that the contemporary and remain of *C. sphaericus* exhibited a substantial presence in the natural site. Under conditions of intense fish predation, these

two species emerged as the prevailing members of the Cladocera community (Berta et al., 2019). Furthermore, prior research has shown that the remnants of *A. guttata* were discovered in a large deposit of organic material (Sayer et al., 2010). Our analysis discovered a substantial amount of well-preserved remains of *A. guttata* at fishing site-1. Nevertheless, several studies have indicated (Davidson et al., 2010; Gannon and Stemberger, 1978; Jeppesen et al., 1997; Kattel et al., 2007; Sayer et al., 2010; Scheffer, 2001) that an more microvegetation in a shallow lake reduces fish population, leading to lower predation pressure.

Several species, including *A. rustica*, *A. nana*, *A. elongata*, *C. fennicus*, *C. lilljeborgi*, *D. longispina*, and *D. crystalline*, were found in the sediment samples. However, these species were not observed in the filtered water samples, which aligns with findings from a separate study (Nevalainen, 2010). The researchers have documented (Brooks and Dodson, 1965; Çakıroğlu et al., 2014) that the Polyphemidae sp. family possesses a chitinous body part with a soft shell, which is likely to be found exclusively in the contemporary assemblage examined in this study. The analysis of sedimentary remains reveals a notable change in the diversity of Cladocera, a group of small crustaceans, as documented in previous studies conducted in shallow lakes (Brooks and Dodson, 1965; Jeppesen et al., 2000).

The results of the beta-diversity analysis, which compared contemporary and subfossil Cladocera communities, did not identify any statistically significant differences. The phenomenon of intersite species replacement was observed to have a relatively low occurrence, and there was also a limited variation in species richness among the sampled sites in both

assemblages. Consequently, we have observed contrasting Shannon values for the Cladocera assemblage between the natural site (contemporary) and fishing site-1 (subfossil). Specifically, the natural site exhibited lower Shannon values, while fishing site-1 displayed higher values. The density of contemporary Cladocera assemblages was found to be lower at fishing sites compared to natural sites. Berta et al. (Berta et al., 2019) have previously provided evidence regarding the influence of fish introduction.

5.2 Did the Cladocera assemblages and the physical-chemical variables exhibit variation across different sites within the Nagy-Morotva oxbow lake?

Principal Component Analysis (PCA) and distance-based Redundancy Analysis (dbRDA) were employed to investigate the potential impact of variations in physical-chemical variables on the densities of Cladoceran organisms in the oxbow lake. In our study, we identified six measured variables (DO.P, Cu^{2+} , BOD₅, Chl_a, PO₃, and LOI₅₅₀) that exhibited the potential to elucidate the substantial variability observed in the density of Cladoceran assemblages across the three sites within the oxbow lake. The four variables under consideration, namely DO.P, Cu^{2+} , BOD₅, and Chl_a, exhibit a significant correlation with fishing site-1 and the natural site. In the other published studies, the distribution of contemporary Cladoceran assemblages was found to be significantly influenced by the measured variables of phosphorus and chlorophyll_a (Brodersen et al., 1998; Kattel et al., 2007; Tavşanoğlu et al., 2017). The findings of these studies indicate that nutrient enrichment has an impact on the habitat conditions of Cladocera, encompassing factors such as the availability and quality of food, the intensity

of predation, and the presence of macroinvertebrates. Tavşanoğlu et al. (Tavşanoğlu et al., 2017) emphasized that the augmentation of phosphorous content could potentially be associated with heightened fish predation in Cladocerans of substantial size. A decline in the number of Cladoceran species was observed as we moved from fishing site-1 to fishing site-2. Conversely, an increase in phosphorous levels was observed from fishing site-2 to fishing site-1. Contrarily, Jeppesen et al. (Jeppesen et al., 2000) observed an inverse correlation between phosphorous levels and species richness, indicating a decrease in species diversity as phosphorous concentrations increase. In the contemporary dataset, the correlation between Cu^{2+} and *C. sphaericus* in fishing site-1 was found to be significant. The study conducted by Sadeq et al. (Sadeq and Beckerman, 2019) revealed that the presence of Cu^{2+} has a significant impact on various aspects of Cladocera species, including their survival, density, size, and growth rate.

5.3 Can we use subfossil Cladocera to characterize the past condition of a shallow oxbow lake?

An analysis was conducted on 38 species, which belonged to five families (Bosminidae, Chydoridae, Daphniidae, Leptodoridae, and Sididae), collected from oxbow lakes (KMT, SZA, TI) situated in the Rakamaz region of Hungary. The family Chydoridae has the highest number of species, which is comparable to other climatic regions (Lansac-Tôha et al., 2009; Shah et al., 2013). The families Bosminidae, Daphniidae, Leptodoridae, and Sididae were less prevalent.

The Chydoridae family is predominantly composed of *Chydorus sphaericus* in the oxbow lakes that were examined. This species was also

highly abundant in our core sediment samples, indicating that it has adapted to a variety of pelagic habitats and detrital food sources such as detritus and attached microbes under eutrophic conditions (Bernardi et al., 1990, 1987; Vijverberg and Boersma, 1997). *Bosmina longirostris*, a member of the Bosminidae family, was the second most abundant species in the oxbow lakes. Additionally, this species has been observed in numerous reservoirs and lakes in the central, northern, and eastern regions of Europe. Also, the main species in the oxbow lakes were a mix of littoral (including *Acroperus harpae*, *Alona guttata*, *Chydorus sphaericus*, *Coronatella rectangula*, and *Graptoleberis testudinaria*) and planktonic species (including *Bosmina longirostris* and *Bosmina coregoni*) (Korhola and Rautio, 2001b).

The beta diversities (Richness Difference and replacement components) of the cores were lower in the KMT (42%), SZA (31%), and TI (36%) compared to the nestedness (Richness Difference and similarity) in the KMT (68%), SZA (62%), and TI (74%). Based on this outcome, it can be deduced that the oxbow lakes themselves provided almost identical habitats for Cladoceran and that the alterations experienced by their communities were also comparable. Site-conditioned RDA also confirmed this, since the site effect explained almost 30% of the total variance, while depth explained only 3%, i.e., the variances between oxbows were much larger than those within the oxbows.

Oxbow lakes are shallow bodies of water with high nutrient levels that are significantly impacted by floods (Babka et al., 2018; Borics et al., 2016; Korponai et al., 2016). The oxbow lakes of SZA and TI are situated near the River Tisza; hence, they regularly experience water influx from minor floods.

Whereas the KMT oxbow lake is located a considerable distance from the river, thus it is only flooded during the most extreme floods. Hydrological changes impact on the community structure of aquatic invertebrates in floodplains (Dias et al., 2016). Cladocerans are displaced during floods and subsequently covered by fresh silt, affecting all habitats. Floods from other habitats have the potential to introduce new populations (Korponai et al., 2016). Although species composition does not differ between lotic and lentic states, quantity can differentiate the two (Korponai et al., 2016). The abundance of Cladoceran in the KMT oxbow lake exhibited an upward trend from the bottom to a depth of 3 cm, implying stable lentic phases. However, a decrease in abundance was observed near the surface, possibly as a result of drought. Minor fluctuations were observed in the abundance of Cladocera due to regular filling, whereas variations in Cladoceran abundance in the TI oxbow might be linked to flooding. Very dense macrophyte deposits were present in the TI and KMT oxbow lakes, creating an environment where hypoxia could develop near the sediment surface. This prevented mud dwelling Cladocera (including *Leydigia* and *Monospilus dipar*) from establishing habitation. Consequently, these species were most abundant in the SZA oxbow lake, with 10 times as many detected in this oxbow lake compared to the KMT and TI oxbow lakes.

The Cladoceran communities in oxbow lakes showed considerable differences, particularly in the SZA. The low beta diversity observed in the SZA oxbow lake, which is a fishing lake for anglers, this suggests a more homogeneous habitat structure within the lake and highlights the significant predation pressure exerted by fish on Cladoceran within this environment.

Certain sediment layers exhibited greater impacts on beta diversity, perhaps indicating alterations in the oxbow's management.

The community of Cladoceran residing in the intermittent oxbow lake (KMT) experienced a progressive rise in complexity subsequent to their natural re-entry via groundwater impacted by the River Tisza's high-water level. The oxbow lake demonstrated the most diversity in the Cladoceran community (beta diversity) as a result of the changing hydrological circumstances. The increased diversity of the substance and the greater contribution of the uppermost layer to the beta diversity indicate that the hydrological condition has stabilized. The Cladocera composition in the TI oxbow lake appears to be quite consistent, as seen by the high levels of similarity and nestedness in beta diversity. The consistent LCBD values of its sediment layers indicate that there have been no substantial changes in hydrological conditions and fish pressure.

6. CONCLUSION

In the research, we showed differences in Cladoceran assemblages from the water and the surface sediment of three different oxbow lake sites, also comparing the use of different sampling methods (i.e., filtered water samples and sediments). The subfossil Cladocera assemblage presented a high number of species, and density differed from contemporary assemblages in the three sites (fishing site-1, natural site, and fishing site-2). It showed that the fishing sites of oxbow lake could increase the density of some species. Also, our research showed that analysis of contemporary Cladocera only proved informative about species diversity and density at the sampling time. However, the subfossil Cladocera community can provide information about the Cladocera for over a year and determine changes in environmental variables (fish, large plants, and environmental conditions). Research pointed out that comparing subfossil and contemporary Cladocera assemblages is particularly useful in characterizing water body conditions.

Additionally, an examination of the preserved remnants of cladocerans has the potential to unveil alterations in their surroundings, such as hydrological conditions and lake management practices. The habitat preferences of the taxa may be used to recreate floods and the formation of macrophyte cover. Our findings validate the importance of subfossil Cladocera remnants in reconstructing environmental changes in both shallow and deep lakes.

7. NEW SCIENTIFIC FINDINGS

- We verified the contemporary Cladocera (filtered samples) only proved information about species diversity and density at the sampling time. While the subfossil Cladocera community (sediment samples) can provide information about the Cladocera for over a year and determine changes in environmental variables.
- Our study pointed out that comparing subfossil and contemporary Cladocera assemblages is particularly useful in characterizing water body conditions.
- Our study indicated that the fishes have significant effect on the some species of Cladocera density.
- We found that a mixed utilization oxbow has higher diversity than natural or protected oxbows in case of the different other conditions

8. SUMMARY

The aim of this research is to examine the utilization and environmental condition on physical-chemical variables and Cladocera community in the shallow oxbow lakes. These oxbow lakes were investigated during the study, oxbow lakes of Nagy-Morotva, Kis-Morotva, Szabolcs and Timár within Hungary.

In the Nagy-Morotva oxbow shallow lake, it serves multiple purposes, including irrigation, environmental conservation, fishing, and recreational activities. This oxbow lake consists of two different utilization including fishing (angling), and natural protected. Samples were collected from 21 sampling points across three sites (FS-1, NS, and FS-2) at Nagy-Morotva's oxbow lake, ensuring accurate capture of the diverse landscape and nature, using cross-sections and moving from one side to another. The research analysed Cladoceran assemblages in three sites of oxbow lake using filtered water samples and sediments. The subfossil Cladocera assemblage had a higher number of species and density compared to contemporary assemblages. Fishing sites in the lake could increase species density. Contemporary Cladocera analysis only provided information about species diversity and density at the sampling time. Comparing subfossil and contemporary Cladocera assemblages is useful in characterizing water body conditions.

The oxbow lakes studied were in the Tisza River catchment, near Rakamaz, Kis-Morotva oxbow lake (KMT), Szabolcs oxbow lake (SZA), and Timár oxbow lake (TI). Oxbow lakes have the potential to receive replenishment from the Tisza River through direct inflows from floods and

inland water sources. The Tisza River's water regime is extremely unpredictable, with significant floods occurring at any point during the year. The oxbow lakes are naturally produced and eutrophic, with a shallow depth. The research was conducted on two different types of lakes: the oxbow lake of KMT, which is considered intermittent, and the SZA and TI oxbow lakes, which are marked by permanent.

KMT oxbow lake is an intermittent water feature due to the phenomenon of drying out in 2012. SZA oxbow lake is a permanent water feature due to its lack of natural conservation protection and intensive fishing activity. TI is an unutilized natural lake protected under the Natura 2000 program, with over half of its surface occupied by emergent, submergent, and floating leaf macrophytes. The study involved collecting an 11cm short core from each oxbow lake of Kis-Morotva, Szabolcs, and Timár, and processing it into slices for analysis in the laboratory.

The study reveals that studying preserved Cladoceran remnants can reveal hydrological changes and lake management practices, allowing for the reconstruction of floods and macrophyte cover, thereby confirming the significance of subfossil Cladocera in both shallow and deep lakes.

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11. APPENDIX

Appendix 1: Table showing species list from surface water and sediment analyzed in three different sites of Nagy-Morotva oxbow lake. x is present and 0 is absent.

№	Species name	Fishing site-1		Natural site		Fishing site-2	
		Sediment Ind/cm ³	Filtered Ind/l	Sediment Ind/cm ³	Filtered Ind/l	Sediment Ind/cm ³	Filtered Ind/l
1	<i>Acroperus harpae</i> (Baird, 1834)	0	0	x	0	x	x
2	<i>Alona affinis</i> (Leydig, 1860)	x	x	x	x	x	0
3	<i>Alona costata</i> (Sars, 1862)	x	x	x	0	x	x
4	<i>Alona guttata</i> (Sars, 1862)	x	x	x	x	x	x
5	<i>Alona intermedia</i> (Sars, 1862)	x	x	x	x	x	x
6	<i>Alona quadrangularis</i> (O. F. Müller, 1776)	x	x	x	x	x	x
7	<i>Alona rectangular</i> (Sars, 1862)	x	x	x	0	x	x
8	<i>Alona rustica</i> (Scott, 1895)	0	0	0	0	x	0
9	<i>Alonella excisa</i> (Fischer, 1854)	x	0	x	x	x	x
10	<i>Alonella exigua</i> (Lilljeborg, 1853)	x	x	x	x	x	x
11	<i>Alonella nana</i> (Baird, 1850)	x	0	x	0	0	0
12	<i>Alonopsis elongate</i> (Sars, 1862)	x	0	x	0	x	0
13	<i>Bosmina longirostris</i> (O. F. Müller, 1785)	x	x	x	x	x	x
14	<i>Camptocercus fennicus</i> (Stenroos, 1898)	x	0	0	0	x	x
15	<i>Camptocercus rectirostris</i> (Schoedler, 1862)	x	0	x	0	x	0
16	<i>Camptocercus lilljeborgi</i> (Schoedler, 1862)	0	0	0	0	x	0
17	<i>Chydorus gibbus</i> (Sars, 1891)	x	x	x	x	x	0
18	<i>Chydorus sphaericus</i> (O.F. Müller, 1776)	x	x	x	x	x	x
19	<i>Daphnia longispina</i> (O. F. Müller, 1776)	0	0	x	0	x	0
20	<i>Daphnia pulex</i> (Leydig, 1860)	x	0	x	0	x	0
21	<i>Disparalona rostrata</i> (Koch, 1841)	x	0	x	x	x	0

22	<i>Eubosmina coregoni</i> (Baird, 1857)	x	x	x	x	x	x
23	<i>Eubosmina longispina</i> (Leydig, 1860)	x	x	x	x	x	x
24	<i>Graptoleberis testudinaria</i> (Fischer, 1848)	x	x	x	x	x	x
25	<i>Kurzia lattissima</i> (Kurz, 1874)	x	0	0	0	0	0
26	<i>Leydigia leydigii</i> (Schoedler, 1863)	0	x	x	x	0	0
27	<i>Leydigia acanthocercoides</i> (Fischer, 1854)	x	0	x	0	x	0
28	<i>Monospilus dispar</i> (Sars, 1862)	x	0	x	0	x	0
29	<i>Oxyurella tenuicaudis</i> (Sars, 1862)	0	x	0	0	x	0
30	<i>Paralona pigra</i> (Sars, 1862)	x	x	x	0	x	x
31	<i>Pleuroxus laevis</i> (Sars, 1862)	x	x	x	x	x	x
32	<i>Pleuroxus trigonellus</i> (O. F. Müller, 1776)	x	x	x	x	x	0
33	<i>Pleuroxus truncates</i> (O. F. Müller, 1785)	x	x	x	x	x	0
34	<i>Pleuroxus uncinatus</i> (Baird, 1850)	x	x	x	0	x	0
35	<i>Polyphemidae sp.</i> (Baird, 1845)	0	x	0	0	0	0
36	<i>Pseudochydorus globosus</i> (Baird, 1843)	x	x	x	x	x	x
37	<i>Sida crystallina</i> (O. F. Müller, 1776)	0	0	x	0	x	0

Appendix 2: Table showing diversity indices of contemporary Cladoceran assemblages in the oxbow lake. Notation: (C: contemporary assemblage).

Sites	Sampling points	Taxa	Individuals (Ind. L ⁻¹)	Dominance	Shannon
Fishing site-1	C_RAK1	16	610	0.1973	2.07
	C_RAK2	11	2975	0.4691	1.22
	C_RAK3	8	2825	0.5990	0.89
	C_RAK4	12	2950	0.5402	1.09
	C_RAK5	9	6201	0.6578	0.67
	C_RAK6	10	4800	0.5352	1.02
Natural site	C_RAK7	12	2525	0.4061	1.41
	C_RAK8	7	3450	0.5806	0.86
	C_RAK9	6	3400	0.6620	0.63
	C_RAK10	11	3125	0.5668	1.05
	C_RAK11	13	3500	0.4184	1.45
	C_RAK12	9	3000	0.4678	1.23
	C_RAK13	9	2450	0.4511	1.27
	C_RAK14	8	1125	0.4084	1.29
	C_RAK15	4	1300	0.5806	0.76
Fishing site-2	C_RAK16	8	8800	0.6408	0.74
	C_RAK17	7	15450	0.5411	0.75
	C_RAK18	11	14950	0.5566	0.83
	C_RAK19	9	21500	0.5512	0.74
	C_RAK20	8	11950	0.5407	0.80
	C_RAK21	8	14900	0.5607	0.78

Appendix 3: Table showing diversity indices of subfossil and contemporary Cladoceran assemblages in the oxbow lake. Notation: (S: subfossil assemblage).

Sites	Sampling points	Taxa	Individuals (Ind. cm ⁻³)	Dominance	Shannon
Fishing site-1	S_RAK1	19	8417	0.2077	2.13
	S_RAK2	18	11000	0.3627	1.63
	S_RAK3	10	13500	0.4489	1.22
	S_RAK4	15	8333	0.3498	1.57
	S_RAK5	16	19750	0.3878	1.46
	S_RAK6	19	10833	0.2419	2.05
Natural site	S_RAK7	20	15375	0.1866	2.22
	S_RAK8	11	4950	0.2374	1.75
	S_RAK9	20	9750	0.1936	2.14
	S_RAK10	19	4950	0.1709	2.27
	S_RAK11	20	8700	0.1711	2.25
	S_RAK12	17	7275	0.1923	2.07
	S_RAK13	14	5200	0.1916	1.98
	S_RAK14	20	8475	0.3039	1.85
	S_RAK15	16	4850	0.2186	2.00
Fishing site-2	S_RAK16	24	6750	0.1101	2.63
	S_RAK17	16	4500	0.3277	1.71
	S_RAK18	27	6250	0.2026	2.33
	S_RAK19	22	4750	0.1745	2.30
	S_RAK20	18	5750	0.2599	1.99
	S_RAK21	23	7425	0.2456	2.19

Appendix 4: Table showing diversity indices of Cladoceran community in the oxbow lakes. Notation: (KMT: Kis-Morotva oxbow lake, SZA: Szabolcs oxbow lake, TI: Timár oxbow lake)

Oxbow lake	Core sediment layer	Taxa_S	Dominance_D	Shannon_H
KMT	0-1	19	0.1174	2.480
	1-2	21	0.0876	2.696
	2-3	16	0.1986	2.105
	3-4	18	0.1603	2.308
	4-5	20	0.1358	2.471
	5-6	19	0.1185	2.454
	6-7	22	0.1522	2.328
	7-8	17	0.1769	2.189
	8-9	16	0.2011	2.035
	9-10	17	0.1620	2.166
	10-11	18	0.2405	1.960
SZA	0-1	21	0.0896	2.674
	1-2	18	0.1034	2.594
	2-3	24	0.0958	2.768
	3-4	21	0.0943	2.628
	4-5	22	0.0884	2.750
	5-6	24	0.0827	2.781
	6-7	22	0.0911	2.702
	7-8	23	0.0881	2.727
	8-9	21	0.0785	2.746
	9-10	21	0.1117	2.565
	10-11	19	0.1149	2.488
TI	0-1	19	0.1066	2.521
	1-2	17	0.1764	2.194
	2-3	18	0.1381	2.400
	3-4	16	0.1670	2.207
	4-5	17	0.2042	2.141
	5-6	16	0.1444	2.244
	6-7	20	0.1132	2.550
	7-8	20	0.1468	2.409
	8-9	22	0.1265	2.478
	9-10	18	0.1334	2.349
	10-11	19	0.1242	2.419

12. PUBLICATION ON THE TOPIC OF DISSERTATION



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Registry number: DEENK/290/2024.PL
Subject: PhD Publication List

Candidate: Uyanga Tumurtoogo
Doctoral School: Pál Juhász-Nagy Doctoral School of Biology and Environmental Sciences

List of publications related to the dissertation

Foreign language scientific articles in international journals (2)

1. Gyulai, I., Korponai, J., Wamugi, S. M. A., Jakab, J., Kawu, U. A., Soltész, A., Karches, T.,
Tumurtoogo, U.: Cladocera and Geochemical Variables from Core Sediments Show
Different Conditions of Hungarian Lakes.
Water. 16 (9), 1-12, 2024. EISSN: 2073-4441.
DOI: <http://dx.doi.org/10.3390/w16091310>
IF: 3.4 (2022)
2. **Tumurtoogo, U.,** Figler, A., Korponai, J., Sajtos, Z., Grigorszky, I., Berta, C., Gyulai, I.: Density
and Diversity Differences of Contemporary and Subfossil Cladocera Assemblages: A Case
Study in an Oxbow Lake.
Water. 14 (14), 1-14, 2022. EISSN: 2073-4441.
DOI: <http://dx.doi.org/10.3390/w14142149>
IF: 3.4





List of other publications

Foreign language scientific articles in international journals (1)

3. Grigorszky, I., Kiss, K. T., Szabó, L. J., Dévai, G., Nagy, S. A., Somlyai, I., Berta, C., Gligora-Udovič, M., Borics, G., Pór, G., Yaqoob, M. M., Hajredini, A., **Tumurtogoo, U.**, Ács, É.: Drivers of the Ceratium hirundinella and Microcystis aeruginosa coexistence in a drinking water reservoir.

Limnetica. 38 (1), 41-53, 2019. ISSN: 0213-8409.

DOI: <http://dx.doi.org/10.23818/limn.38.11>

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The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

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