Short thesis for the degree of doctor of philosophy (PhD)

Changes in abundance and diversity of Cladocera communities in the Oxbow Lake

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LIST OF ABBREVIATIONS

- **FS-1:** Fishing site-1
- **NS:** Natural site
- **FS-2:** Fishing site-2
- **KMT:** Kis-Morotva oxbow lake
- **SZA:** Szabolcs oxbow lake
- **TI:** Timár oxbow lake
- **LOI_{950}:** Loss of ignition at 950
- **LOI_{550}:** Loss of ignition at 550
- **KOH:** Potassium hydroxide
- **Chl_a:** Chlorophyll_a
- **Al^{3+}:** Aluminum
- **Cu^{2+}:** Copper
- **Ca^{2+}:** Calcium
- **SO_4^{2-}:** Sulfate
- **TDS:** Total dissolved solids
- **TSS:** Total suspended solids
- **Cl^-:** Chloride ions
- **Na^{2+}:** Sodium
- **K^+:** Potassium
- **NH^{4+}:** Ammonium-ions
- **Mg^{2+}:** Magnesium
- **Ba^{2+}:** Barium
- **Cr^{2+}:** Chromium
- **Pb^{2+}:** Lead
- **Sr^{2+}:** Strontium
- **ODO:** Optical dissolved oxygen
- **HCO_3:** Hydrogen carbonate
- **NO_{2-}:** Nitrite
- **PO_3^-:** Phosphate
- **ORP:** Oxidation reduction potential
- **BOD_5:** Biochemical oxygen demand

1. INTRODUCTION

The issue of inadequate environmental protection is a pressing concern. Ecology, a scientific field, studies the interactions between organisms and their environment, rooted in evolutionary concepts like natural selection, adaptation, and speciation (Kreb, 1985). It is crucial for understanding the distribution and abundance of organisms, as well as their connections with water and sediment.

Water availability is crucial for life on Earth, affecting all living things, including humans, plants, and animals. The quality of the water in rivers, lakes, and seas also has an impact on the health of aquatic ecosystems and the creatures that live there. So, the aquatic ecosystem is significantly impacted by anthropogenic pressures and pollution, including fish farming, urbanization, industrialization, and agricultural activities (Wetzel, 1992), which significantly impact biological communities and water quality (Alberti et al., 2007).

Sediments from lakes, including organic and inorganic remnants, provide valuable indicators for understanding their historical trajectory and paleoecological patterns (Alberti et al., 2007). These sediments, particularly those from deep lakes, accurately depict ecological interactions and fossils, indicating transformative processes that alter organic remnants.

The study uses branch tentacle crabs as indicator organisms, selecting various species of freshwater crustaceans from the Cladocera order, found in moist habitats and aquatic environments. Water fleas, known as Cladocera, are vital to the freshwater ecosystem, particularly in stagnant water bodies, where they significantly contribute to the food web (Forró et al., 2008). Cladocera are beneficial for paleolimnological studies due to their chitin-based exoskeletons, which are well-preserved in lake sediments (Korhola and Rautio, 2001). The extent of preservation varies among families due to chitin composition changes. After death or exoskeleton shedding, remains become part of the sediment record. Each species' remains include carapace, claw, mandible, headshield, postabdomen, and postabdominal. Cladocerans' remains can be categorized at the genus or species level (Korhola and Rautio, 2001). Additionally, Cladocera are aquatic microorganisms used to identify changes in lake physical, chemical, and biological features due to their sensitivity to environmental conditions. They infer water chemistry parameters like pH, dissolved organic carbon, salinity, nutrient status, and calcium concentration from cladoceran-based paleolimnological studies.

2. OBJECTIVE OF THE STUDY

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 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?

3. MATERIAL AND METHODS

3.1. Characteristic of the study area

3.1.1. The Nagy-Morotva oxbow lake

Nagy-Morotva oxbow lake is situated in North-East Hungary, between the cities of Tiszanagyfalu and Rakamaz. The Nagy-Morotva oxbow lake, located on the floodplain of the Tisza River, serves multiple purposes including irrigation, environmental conservation, fishing, and recreational activities. It covers a surface area of 100 hectares and is surrounded by large open water areas. The lake's water supply is primarily derived from flooded sections of the Tisza River, which form the oxbow lake. The lake's depth ranges from 80 to 150 cm depending on the water level (Tumurtogoo et al., 2022). 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 lake contains most of Hungary's natural fish species, including bream, common carp, crucian carp, grass carp, and pike perch. Aquatic vegetation covers a large part of the study area, contributing to organic matter generation and sedimentation. The natural site is covered with 80-90% vegetation during the entire planting period. The oxbow lake's shoreline is filled with lesser bulrushes, reed sweetgrasses, and common reeds.

The study collected samples from 21 sampling points across three sites at Nagy-Morotva's oxbow lake: Fishing site-1 (FS-1), Natural site (NS), and Fishing site-2 (FS-2). The first site, an open water zone, was used for fishing activities. The second site, a natural protected area, was characterized by microvegetation and water soldier vegetation. The third site, an open water zone, was used for angling. The sampling points were carefully chosen to accurately capture the diverse landscape and nature of Nagy-Morotva oxbow lake.

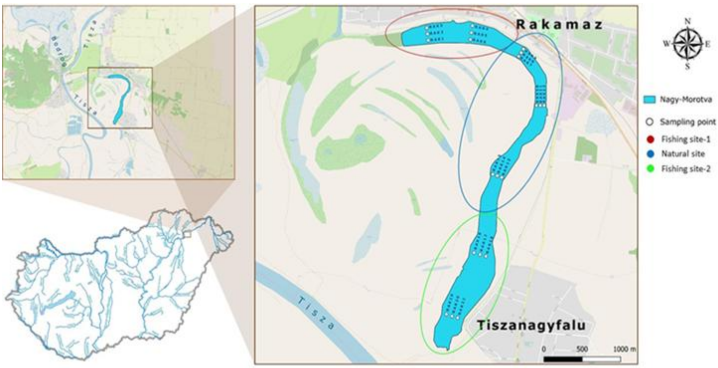

Figure 1. The map of the Nagy-Morotva oxbow lake displays the locations of the sampling points.

3.1.2. Kis-Morotva oxbow lake, Szabolcs oxbow lake and Timár Morotva oxbow

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 (Figure 2).

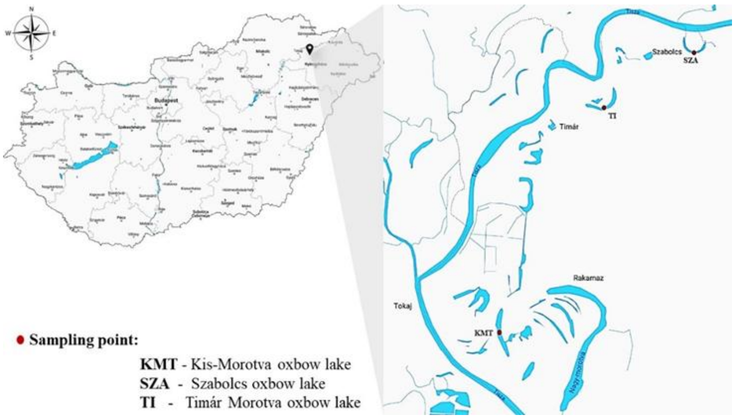

Figure 2. Showing the study areas and sampling points

Lakes can be replenished by the Tisza River, which has a catchment area of 157,186 km^2 and a Hungarian section of 597 km. The river's water regime is unpredictable, with significant floods occurring at any time of year due to rainstorms, snowmelt, or a combination of both. Inundations are more frequent during late winter and spring, with warm weather causing 35% of floods and cold weather causing 65%. Research on naturally produced, shallow, eutrophic lakes was conducted in KMT's intermittent oxbow lake and SZA and TI's permanent oxbow lakes.

The Oxbow Lake of Kis-Morotva, located between Tiszanagyfalu and Rakamaz cities, is a naturally formed, eutrophic lake with a maximum depth of 1.2 meters and a surface area of 14 hectares. It is protected under the Nature 2000 program and is classified as an intermittent water feature due to a drying out phenomenon in 2012. The Tisza River replenished the lake in 2013.

Szabolcs oxbow lake, located on the left bank of the Tisza River, spans 957 meters and covers 5.60 hectares. With an average depth of 1.3 meters and a maximum depth of 2.5 meters, it is a permanent water feature with a diverse array of fish species, including bream, carp, grass carp, pike, perch, and wels. The lake is surrounded by dense reed belts, cattails, bulrushes, and sedges.

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. Investigation process of the remains and composition of Cladocera in soft and short core sediments, and surface water from different utilization of oxbow lakes.

3.2.1. Field work

Soft and water samples were taken at 21 selected points at the Nagy-Morotva oxbow lake in October 2019. The three differently utilized parts of the oxbow lake were sampled in transects (from one side to the other side). We collected 6 samples from both fishing sites (1 and 2), while 9 samples were collected from the natural site. Data collection included field and laboratory methods for estimating the physical and chemical variables, and the Cladocera assemblages. 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.

A Single-core sediment samples were used as a gravity core to collect an 11cm 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.

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 sites of the Nagy-Morotva oxbow lake.

3.2.2. Laboratory work

3.2.2.1. Determination of the physical-chemical parameters

A laboratory chemical analysis was conducted on non-filtered water samples, using Hungarian Standard standards to determine TSS concentrations, chloride ions, total phosphorus, orthophosphate-ion, total hardness, ammonium-ions, Kjeldahl-nitrogen, nitrate-nitrogen, and nitrite-nitrogen. The study also estimated sulfate ion, biochemical oxygen demand, total alkalinity, chemical oxygen demand, hydrogen carbonate, and carbonate content. The study also measured humic acid content, chlorophyll_a content, and macro-elements using MP-AES (Microwave Plasma Atomic Emission Spectrometry).

The study analyzed sediment samples to estimate organic matter and calcium carbonate ($CaCO_3$) content and elemental composition. The sediment cores from KMT, SZA, and TI oxbow lakes were cut into slices at 1 cm intervals, and the soft sediments from Nagy-Morotva oxbow lake were processed for analysis in the laboratory, specifically for the subfossil Cladocera. We counted the subfossil cladoceran preserved in each sediment sample (54 samples in total) to examine the structure of the cladoceran community.

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.

Next step, the determination of the chemical parameters, the elemental composition was estimated in the dry sediment samples.

3.2.2.2. Microscopic identification and counting

Every sample (filtered, soft and core sediment samples) 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 samples. To identify the contemporary and subfossil 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/cm^3 based on our results.

3.3. Data analysis

This research utilized Paleontological Statistics (PAST) and R programs to perform statistical analyses on the distribution of cladoceran species and geochemical components in oxbow lakes. The physical-chemical variable patterns of variation were investigated using Bray-Curtis similarity in Principal Components Analysis (PCA), principal coordinates analysis (PCoA), and the Martinez function for pairwise comparisons. The distance-based redundancy (dbRDA) analysis was performed using the capscale() function in the vegan package. The cladoceran data underwent Hellinger transformation, while the geo-chemical variables were standardized using z-transformation. A PERMANOVA analysis was conducted to assess the similarity between the lakes in terms of their cladoceran communities and environmental factors. A sequence of redundancy analyses (RDA) was employed to determine the key environmental variables that influence the composition of the cladoceran community. Hill's numbers were used to estimate species diversity in subfossil cladoceran assemblages, which are determined by calculating 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.

4. RESULTS AND DISCUSSION

4.1. Composition and subfossil Cladocera in the Nagy-Morotva oxbow lake

This study analyzed filtered and sediment samples from Nagy-Morotva oxbow lake, identifying thirty-seven Cladocera species. 75% of these species were detected in both types. The prevailing taxa were Bosmina longirostris, Eubosmina coregoni, and Chydorus sphaericus. The highest concentration of B. longirostris was found in filtered samples (38-55%) and sediment samples (69%-73%).

The study found that the oxbow lake has a lower species variety and higher abundance of contemporary Cladoceran species in the filtered water sample. The study identified 29 taxa, with an individual count of 176,783 Ind. L-1. The species composition and abundance varied across different sites, with a decrease in species among the three sites (FS-1, NS, and FS-2). Fishing site-1 had 23 identified taxa, Natural site 19 identified taxa, and Fishing site-2 had 18 identified taxa. At fishing site-2, a high abundance of Cladocera was preserved, with 12 dominant species out of 29. Five species were exclusive at some sites, while eight species were not identified at some sites. The (PCoA) ordination revealed a significant variation in the Cladoceran species composition between the bottom and other sections of the oxbow lake However, the Cladoceran assemblages at FS-1 and NS of the oxbow lake were found to be strikingly similar. (Figure 3).

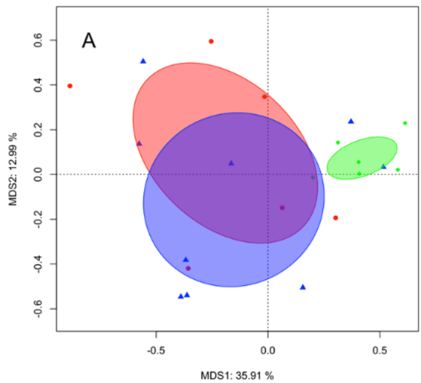

Figure 3. The findings from the Principal Coordinate Analysis (PCoA) conducted on the assemblages of contemporary Cladocera at the three sites of oxbow lake are presented. The sites' group centroids are graphically represented by colored ellipses. Notation: (Fishing site-1: Red, Natural site: Blue, Fishing site-2: Green).

The study identified 36 species of subfossil cladocera, with a total count of 131711 Ind. cm^{-3}. The sediment samples showed a higher species richness compared to filtered samples. The species richness increased when transitioning between FS-1 and FS-2, with FS-1 having a species richness of 29, NS having a species richness of 31, and FS-2 having the maximum species richness of 33. The study also found 25 of the 36 species in sediment samples, with 25 found in each site. Four species were not found at some sites, while four were found specifically in some sites. 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 4).

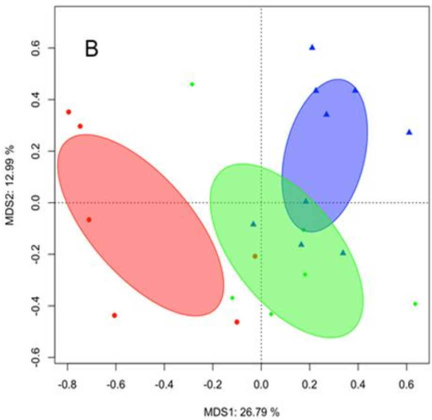

Figure 4. The findings from the Principal Coordinate Analysis (PCoA) conducted on the remains of Cladocera assemblages at the three sites of Nagy-Morotva oxbow lake are presented. The sites' group centroids are graphically represented by colored ellipses. Notation: (Fishing site-1: Red, Natural site: Blue, Fishing site-2: Green).

The study conducted principal component analysis on three sites using physical-chemical variables. The results showed significant differences in the filtered water samples, with FS-1, NS, and FS-2 locations showing significant differences. The natural site had a positive correlation with variables like Ca^{2+}, Chl_a, and DO.P. FS-2 showed the presence of SO_4^{2-}, TDS, Cl-, Na^{2+}, and NH_4^+. The primary factors observed at fishing site-1 were various cations, ODO, and HCO_3. The sediment samples showed similar characteristics, but distinct distinctions in FS-2. FS-1 had a strong association with conductivity, LOI_{550}, and NH_4^+, while NS had a strong association with conductivity, LOI_{550}, NO_2^-, NH_4^+, PO_3-, and ORP.

The study uses dbRDA to analyze the association between Cladoceran abundance and physic-chemical variables. The analysis reveals that FS-1 and the NS exhibit overlap in DO.P, Cu^{2+}, Chl_a, and BOD_5, which are significant in relation to the assemblage of contemporary Cladocera. Five species showed significant high abundance in both FS-1 and the NS, with DO.P. positively associated with M. dispar and A. intermedia species. There is an inverse relationship between BOD_5, Chl_a, and Cu^{2+} with DO.P. and the abundance of P. Globosus and C. sphaericus. FS-2 was isolated from the other two sites, but no significant relationships were found between Chl_a, BOD_5, DO.P, and Cu^{2+} in relation to FS-2 and Bosmina. sp. The study also found a strong correlation between PO_3^- and FS-2, with PO_3^- and LOI_{550} having no significant connection with fishing site-1.

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

The study found 38 cladoceran taxas from five families in sediment core samples from three oxbow lakes: Kis-Morotva (KMT), Szabolcs (SZA), and Timár Morotva (TI). Chydoridae had the most species, while Bosminidae, Daphniidae, Leptodoridae, and Sididae had fewer. The dominant species were Acroperus harpae, Alona gutta, Bosmina coregoni, Bosmina longirostris, Chydoridae sphericus, Coronatella rectangular, and Graptoleberis testudinaria. Alona rustica was only found in SZA oxbow lake.

The study found that the abundance of Cladocera species in the SZA oxbow lake ranged from 715 to 4418 individuals per cm^3, with an average of 2421 individuals per cm^3. The SZA oxbow lake had a large number of Cladocera communities, with 36 recognized taxa, while the TI oxbow lake had 31 taxa. The abundance of Cladocera species was significantly higher in the SZA and TI oxbow lakes compared to the KMT oxbow lake. The core sediment samples from the Kis-Morotva oxbow lake contained subfossils of 33 Cladoceran species, with the most common being A.gutta, Coronatella rectangula, B. coregoni, B. longirostris, C. sphearicus, and G. testudinaria.

The KMT oxbow lake's core sediment samples revealed 33 Cladoceran species, with Alona guttata, Coronatella rectangula, Bosmina coregoni, Bosmina longirostris, Chydorus sphaericus, and Graptoleberis testudinaria being the most dominant.

The Szabolcs oxbow lake exhibits greater taxonomic diversity than other oxbow lakes, with species observed across sediment layers. However, some species are absent in specific layers, such as Alonella exigua, Oxyurella tenuicaudis, and Alona intermedia. The presence of Camptocereus lilljeborgi species is restricted to sediment layers.

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.

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.

5. 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 some species of Cladocera density.
- We found that a mixed utiliation oxbow has higher diversity than natural or protected oxbows in case of the different other conditions.

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7. PUBLICATIONS

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Subject: PhD Publication List

Candidate: Uyanga Tumurtogoo
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., **Tumurtogoo, 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. **Tumurtogoo, 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.
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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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