MASTERARBEIT | MASTER'S THESIS

Titel | Title

Factors shaping Cladocera Communities in Waldviertel Fish Ponds (Lower Austria), with special reference to *Leptodora kindtii* (Focke 1844).

verfasst von | submitted by

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angestrebter akademischer Grad | in partial fulfilment of the requirements for the degree of

Master of Science (MSc)

Wien | Vienna, 2026

Studienkennzahl lt. Studienblatt | Degree programme code as it appears on the student record sheet:	UA 066 833
Studienrichtung lt. Studienblatt | Degree programme as it appears on the student record sheet:	Masterstudium Ecology and Ecosystems
Betreut von | Supervisor:	ao. Univ.-Prof. i.R. Dr. Johann Waringer

Danksagung

Diese Arbeit wäre ohne die Hilfe einiger Personen, die ich eingangs gerne erwähnen möchte, nicht zustande gekommen. Zuallererst möchte ich mich bei Chun-Chieh Yen, Johann Waringer und Michael Schagerl bedanken. Ohne den Vorschlag, Zooplankton und Phytoplankton in parallelen Arbeiten zu untersuchen, hätte meine Reise nie ins schöne Waldviertel geführt.

Im Kontext der Probennahme bedanke ich mich herzlich bei Christian Bauer und Günther Gratzl vom Bundesamt für Wasserwirtschaft, die uns die Zufahrt zu den Teichen ermöglicht, den Kontakt zu den Teichbesitzern gehalten und wichtige Informationen zu den Teichen eingeholt haben. Außerdem bedanke ich mich bei Andreas Fischer-Ankern für die Erlaubnis zur Probennahme sowie Zufahrt zu den Pürbacher Teichen. Vielen Dank an Hubert Kraill für die Unterstützung und Durchführung der Laborarbeiten und der chemischen Analytik, und an Santiago Gaviria-Melo für die freundliche Hilfe und Unterstützung bei der Bestimmung der Arten.

Ein großes Dankeschön nochmal an Chun für die großartige Zusammenarbeit während der Freilandarbeit und im Labor, und für den regen und stets interessanten Austausch, und an Florian Prinz für die Unterstützung und die gute Gesellschaft bei der Probennahme. Vielen Dank an Michael Schagerl für die Organisation der Feldarbeit (inkl. der zusätzlichen Fahrt, um eine fehlende Probe zu holen), die Hilfe bei der Laborarbeit und der statistischen Auswertung sowie die immer schnelle, lösungsorientierte Hilfe bei zahlreichen anderen Fragen. Zuletzt möchte ich mich von Herzen bei Johann Waringer für die hervorragende Betreuung bedanken. Danke für deine unendliche Geduld und Unterstützung. Ohne die ausführlichen, konstruktiven und wegweisenden Rückmeldungen wäre diese Arbeit nicht möglich gewesen.

Ja se kanim srdačno zahvalit mojim starjim, vi ste me uvik bezuvjetno podupirali i mi dali slobodu da najdem svoj put. Pipo i Lukas, ja sam jako zahvalan za vaše tovaruštvo, vi ste me svagdar motivirali i ohrabrili na cijelom putu. Vera i Alex, kod našega coworkinga sam već napredovao neg bi si mislio. A na koncu najveća hvala tebi, Katharina, za tvoje beskrajno strpljenje, podršku u svakoj situaciji i pomoć kod svakoga (maloga) problema. Hvala za duge diskusije i razgovore, za poslušanje i povjerenje, za inspiraciju i kritiku pak za sve ča sam se od tebe naučio.

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1. Abstract

The aim of the present study was to identify abiotic and biotic key factors shaping the observed Cladocera assemblages in a wide range of carp ponds in the Austrian Waldviertel. Particular focus was given to the predatory Cladoceran *Leptodora kindtii*. To this end, 15 ponds were sampled in April, July and September 2021, with a total of 28 hydromorphological, chemical and physical descriptors recorded. Zooplankton was collected using nets with a mesh size of 100µm, identified and evaluated both qualitatively and quantitatively. The analyses revealed that the chemical fingerprints varied stronger between individual ponds than between months. Six key factors (Secchi-depth, alkalinity, magnesium, chloride, nitrate and NPOC) were identified grouping the ponds into seven clusters. The biotic data revealed a total of 24 Cladoceran species. A significant compositional shift from spring to summer was observed. Temperature, fish stocking and silicate concentration had the strongest effects on species communities and were able to significantly explain the observed spatial patterns with respect to unique pond-specific species sets. *L. kindtii* occurred exclusively during the summer months, with higher densities at lower fish stocking densities. A significant correlation between sympatry and abundances of *L. kindtii* and *Diaphanosoma brachyurum*, as well as *Daphnia cucullata*, was detected. The differences in the abiotic signatures of the ponds suggest a strong influence of the immediate environment and the management of the ponds, both of which have a direct impact on the Cladoceran communities. Fish stocking and riparian vegetation proved to be the dominant factors influencing the abundance of *L. kindtii*. No negative effect of *L. kindtii* on preferred prey species nor any influence on species composition were detected, suggesting that due to fish predation, *L. kindtii* did not reach threshold population densities to act as a top-down agent regulating the abundance of its preferred prey species.

2. Introduction

2.1 Background and history of the research area

The Austrian Waldviertel, situated in the north-west of Lower Austria, is famous for its fish ponds and the farming of carp. First records of pond farming in Lower Austria date back to the thirteenth century (Bauer, 2014; Dvorak et al., 1994). Landowners, including the church and feudal lords, invested into pond-farming and fish breeding, finding profitable use for non-fertile soils (Kirchmaier et al., 2020; Knittler, 2005). Over the centuries, the knowledge of pond farming and fish breeding was passed on mainly through monasteries (Füllner et al., 2007; Matzinger, 2014). The name of the outlet structure, "Mönch" (German for monk), still reminds of their significant role.

The construction of large ponds in South Bohemia in the sixteenth century generated strong competition and led to a declined construction of new ponds in northern Austria. (Knittler, 2005). While the ponds in the neighbouring Weinviertel were given up for more lucrative meadows and pastures, ponds in Waldviertel still exist today (Bauer, 2014; Matzinger, 2014). Austrian fisheries became of greater importance again after the Second World War. With meat in very short supply, fish became a viable alternative source of protein that could be produced locally (Matzinger, 2014). Today there are 1800 ponds with a total area of 1650 ha in the Waldviertel (out of 2700 ha in Austria), the largest being the Gebhartsteich with 57 ha (Bauer, 2014; Niederösterreichischer Teichwirteverband, 2024). Around 400 businesses use the ponds to breed and produce fish in the area, thus being economically important for the entire region (Matzinger, 2014). For commercial and marketing purposes, the trademark "Waldviertler Karpfen" was established in 1999 (Sommer et al., 2023). Since 2011, the network of ponds in the Waldviertel is classified as part of the Natura 2000 European nature reserve "Waldviertler Teich-, Heide- und Moorlandschaft" according to the Habitats Directive.

2.2 Pond ecology

Ponds are defined as shallow artificial water bodies. They can be distinguished from other artificial waters such as reservoirs by the absence of an aphotic layer, with the maximum depth of ponds usually around three meters. The shallow nature of the water body causes a homogenous distribution of nutrients along the water column and mostly inhibits the emergence of a temperature gradient (Böhmer et al., 1989; Füllner et al., 2007). A further defining characteristic of (fish) ponds is the possibility to drain and refill the ponds. Ponds

are traditionally classified by their source of water (Böhmer et al., 1989): Sky ponds ("Himmelsteiche") are only fed by rain water from the catchment of the pond. Water supply exclusively depends on precipitation and can only be managed to a certain extent. The second type are brook ponds ("Bachteiche") which get their water supply from brooks, streams, or rivers. Finally, spring ponds ("Quellteiche") are ponds fed directly from a spring (Böhmer et al., 1989; Füllner et al., 2007; Matzinger, 2014).

Many of the ponds in the Waldviertel are part of a chain of brook ponds. These ponds are created by damming up a stream or small river several times. In these ponds water levels can easily be regulated both ways, emptied to lie dry as well as refilled at any chosen time. Sky ponds on the other hand need to be refilled right after drainage to ensure that they hold enough water in spring when the ponds are restocked with fish. However, most ponds are drained in autumn for fish yield and refilled immediately. Sometimes they are left dry for the winter or longer periods, which helps with mineralisation and hygiene, as fish parasites do not cope well with draughts (Bauer, 2014; Matzinger, 2014). Ponds can be further classified by their economic usage as well as the stock fish species. Fisheries use breeding ponds ("Laichteiche") where the fish breed, growing ponds ("Vorstreck"- und "Streckteiche") where the fish larvae can grow safely, and yielding ponds ("Abwachsteiche") for mature fish from the age of two years until being harvested. Furthermore, specialized wintering ponds ("Winterteiche") are used for overwintering of the stock fish. As the most used fish species in the Waldviertel, common carp are active over winter months and react sensitively to changes in their environment, such as oxygen depletion (Bauer & Schlott, 2004, 2006). In contrast to trout ponds, which need oxygen rich cold water, carp ponds are usually warmer (average summer temperatures above 20°C) and do not need strong water flow for oxygen supply (Füllner et al., 2007). As the relatively cold climate of the region results in slower fish growth, the carp usually need three to four years to grow to their target weight of around two kilograms (Bauer, 2014; Matzinger, 2014).

In general, fish ponds are eutrophic water bodies with high nutrient load (Böhmer et al., 1989; Pechar, 2000). The eutrophication of the system is primarily caused by anthropogenic nutrient input, most importantly fish feed. Overstocking of fish and excessive feeding can lead to hypertrophic states. Strong nutrient overload results in cyanobacteria blooms (and corresponding cyanotoxin production), high pH and strong oxygen fluctuations (Pechar, 1995, 2000). These conditions can be detrimental to fish: Anoxic conditions can lead to fish

kills and internal loading of phosphorus from the sediment (Søndergaard et al., 2003), high pH can cause elevated toxic ammonia concentrations (Durborow et al., 1997; Emerson et al., 1975) and cyanotoxins can have negative effects on fish and even on human health through accumulation in the food chain (Drobac et al., 2016; Ferrão-Filho et al., 2002). Benthivorous fish, such as carp, further increase turbidity and cause additional phosphorus mobilization from the benthic zone through their behaviour (Bauer, 2014; Driver et al., 2005).

Due to changes in farming practices in the past decades, problems with hypertrophy were reduced in the Waldviertel's ponds. Pond farming became predominantly extensive with stocking densities between 300 and 600 carp per hectare and mineral fertilization was stopped in the 1980ies (Bauer, 2014). In recent years, organic fish breeding and farming became more common in the region, with more than 25% of the total production in 2014 (Matzinger, 2014). A further reduction in nutrient input was achieved by providing fish feed on demand while considering the quantity of natural food sources, i.e. zooplankton biomass (Bauer, 2014; Schlott et al., 2011). As a result of these changes, three-year mean concentrations of total phosphorus decreased from 0.3 mg/l in 1983-1985 to 0.19 in 2010-2012 (Bauer, 2014).

2.3 Cladocera in fish ponds

Small water bodies such as lakes or ponds offer great opportunities to study species diversity dynamics in both time and space as they constitute defined communities connected by the exchange of individuals. Lakes and ponds can be seen as confined "aquatic islands" with clear borders in an uninhabitable terrestrial landscape (Hessen et al., 2019). Within this study system, zooplankton is frequently used to study community dynamics (Bozelli et al., 2015; Lopes et al., 2014). Their high reproduction rates, coupled with efficient dispersal through resting eggs (ephippia) makes them very suitable for studies on the impact of environmental factors on communities (niche filtering) as well as the role of dispersal (Brown et al., 2018; Gray & Arnott, 2011; Heino et al., 2015; Hessen et al., 2019). Large zooplankton, such as daphniids, take on keystone positions in food webs in aquatic ecosystems (Gianuca et al., 2016; McQueen et al., 1986, 1989; Ogorelec et al., 2021). Keystone species, especially large daphnids, represent a link between primary producers and fish and changes in their abundance can cause trophic cascading effects

(Carney, 1990; Carpenter et al., 1985; Cottee-Jones & Whittaker, 2012; Pagnucco et al., 2016; Zöllner et al., 2003).

The high densities of fish in fish farming ponds, especially planktivorous fish such as (young) carp, result in a reduction of keystone zooplankton species, changing the ecology and trophic state of the ponds (Brooks & Dodson, 1965; Williams & Moss, 2003) and shifting the species community towards smaller biota (Sommer et al., 2012). For example, daphniid abundance depends on fish stocking density and overstocking leads to high grazing pressure on large zooplankton (Ogorelec et al., 2021; Schlott-Idl, 1991). The latter, combined with high turbidity, high phosphorus supply and elevated temperature enable long-lasting algae and cyanobacteria blooms (Schlott, 2007) and macrophyte-poor states that can significantly reduce diversity (Scheffer, 1990; Weber & Brown, 2009). These blooms are characterized by very low diversity and effect herbivorous Cladocera in several ways, e.g., clogging of the filtration apparatus (DeMott et al., 2001; Webster & Peters, 1978) and deficient or toxic food source (Brett & Müller-Navarra, 1997; DeMott, 1999; Rohrlack et al., 2005).

Besides their primarily zoobenthic feeding mode, common carp feed on large zooplankton as their preferred natural food source (Füllner et al., 2007; Schlott, 2007). Therefore, large zooplankton, such as Cladocera, play a significant role in fish farming and aquaculture. Since pond farmers in the Waldviertel add fish feed based on occurring zooplankton biomass densities, naturally occurring food sources make up a substantial proportion of the carp's diet. Optimal stocking densities will result in sufficient natural food (i.e. large daphniids), as relatively low fish densities allow for higher zooplankton densities (Schlott, 2007; Schlott et al., 2011).

2.4 Autecology of *Leptodora kindtii*

Leptodora kindtii (Focke, 1844) is a large, hyaline predatory daphniid (order Haplopoda, family Leptodoridae) with a Holarctic distribution. In Austria the species has been recorded in the lowlands of Burgenland, Lower Austria and Vienna, as well as in the colline region of Carinthia, Lower and Upper Austria, Styria, Salzburg, Vorarlberg, and a single record from Tyrol (Gaviria-Melo et al., 2005). *L. kindtii* is most commonly found in the pelagic zone of standing eutrophic waters, often dominated by cyprinid communities, and less commonly in ponds, backwaters, and rivers (Bowersox et al., 2014; Hessen et al., 2011). It

usually occurs during warmer months and can build up high abundances during the summer (Browman et al., 1989; Herzig & Auer, 1990; Palmer et al., 2001). In Lake Neusiedl *L. kindtii* occurs from April/May to November, with maximum densities of over 500 individuals per cubic metre in the summer (Herzig, 1995).

L. kindtii is an effective hunter, often acting as the top invertebrate predator (Berezina et al., 2011; Lunte & Luecke, 1990; Vogt et al., 2013). Due to its strong prey selectivity based on body size and morphology, *L. kindtii* can regulate the herbivorous zooplankton community and prey population density (Branstrator & Lehman, 1991; De Bernardi et al., 1987; Herzig & Auer, 1990; Pichlová & Brandl, 2003; Vijverberg et al., 2005). At high densities, *L. kindtii* is able to suppress its preferred prey species, e.g. the juveniles of *Diaphanosoma sp.* (Herzig, 1995) or *Bosmina sp.* (Branstrator & Lehman, 1991). With its body size often exceeding 10mm, *L. kindtii* itself is a preferred prey item for many planktivorous fish species (Palmer et al., 2001; Uusitalo et al., 2003). A study conducted in Lake Neusiedl, established that 55% of the variance in *L. kindtii* mortality can be attributed to fish predation (Herzig, 1995).

2.5 Aim of the study

Fish ponds in the Waldviertel region are not only vital for economic reasons, but also for species and nature conservation as they provide key habitats for plant and animal species. Hence, they have been the subject of studies on economic and historical aspects of pond farming in the Waldviertel (Bauer, 2014; Fischer-Ankern, 1985; Knittler, 2005; Matzinger, 2014), but also on birds (Kraus, 1984) and of broader faunistic surveys within the establishment of the Natura 2000 site (WWF, 1998). There is, however, a lack in detailed recent studies on other biota. The present study focuses, therefore, on one of the key players in the food web of fishponds, zooplankton, with special reference to Cladocera. The last comprehensive zooplankton studies were conducted over 50 years ago by (Wawrik, 1966). Recent work on the subject were done mainly in a quantitative manner, focusing on the overall abundance of Cladocera and other Zooplankton taxa (Schlott, 2007; Schlott-Idl, 1991). It is essential to gain more detailed insight into key variables and their impact on zooplankton communities over a range of pond types.

The aim of this thesis is, therefore, to study and identify factors shaping Cladoceran communities in the Waldviertel's ponds. In detail, we searched for differences in the abiotic

set of environmental variables, such as ion contents, nutrient concentrations, total carbon, nitrogen and phosphorus, pH, and total alkalinity, as well as light supply of the range of pond types studied. Linking the species composition with environmental variables will enable new insights into key parameters for structuring the plankton community and species patterns. The overall Cladoceran diversity is expected to be rather low in the studied fish ponds due to eutrophic conditions and algal blooms. However, an increase in diversity compared to the study conducted by (Wawrik, 1966) is expected, due to the shift to extensive carp farming practices and the provision of fish feed on demand, leading to decreased rates of nutrient input (Bauer, 2014; Matzinger, 2014; Schlott et al., 2011). We further hypothesize that high fish densities (through predation) and cyanobacteria blooms (through clogging and toxins) result in lower abundances of large unselective herbivores, such as *Daphnia spp.*, whereas smaller forms, such as *Bosmina sp.*, are expected to be more common. These effects are expected to be dependent on age and density of carp (Weber & Brown, 2009) and stronger at warmer temperatures (Ivanova et al., 2022; Potužák et al., 2007) following the PEG-model for high fish predation (Sommer et al., 2012).

Additionally, this study investigated the distribution patterns of *L. kindtii* in the surveyed fish ponds. *Leptodora kindtii* is expected to be occurring during summer months, but missing in spring, due to the relatively cold temperatures in the region, and abundances are expected to be higher at warmer temperatures (Browman et al., 1989; Cummins et al., 1969). Furthermore, we expect *L. kindtii* to be co-occurring with their preferred prey *Diaphanosoma sp.* (Herzig, 1995; Herzig & Auer, 1990). Moreover, a negative effect of *L. kindtii* densities on the abundance of *Diaphanosoma* is hypothesized. Finally, our survey provides detailed information to identify key parameters favouring L. *kindtii* by correlating its abundance with environmental factors such as pond type, trophic conditions, fish stocking patterns, feeding modes, and plankton composition.

This thesis was part of a collaborative study. My colleague Chun-Chieh Yen and her supervisor Ao. Univ. Prof. Dr. Michael Schagerl focused on phytoplankton aspects (Schagerl et al., 2025). Data collection and chemical analyses were carried out jointly.

3. Materials and methods

3.1 Study sites

Sampling took place in the Waldviertel, a region situated in north-western Lower Austria, bordering to the Czech Republic. A total of fifteen fish ponds were sampled three times during 2021 (April, July, and September). The ponds are situated in the district of Gmünd, in the vicinity of three Lower Austrian towns called Heidenreichstein, Schrems and Pürbach (Fig. 1). The studied ponds were classified into three groups based on their proximity to the nearest town. Each pond was assigned an abbreviation and ID (Tab. 1). The size of the study ponds ranges from 2.76 to 57.00 ha. The ponds are situated within a radius of around 7.5 km and at similar altitude (516 to 604 meters above sea level).

Twelve of the fifteen ponds are organic fish farming ponds stocked with common carp (*Cyprinus carpio* Linnaeus, 1758). The carp are only fed on demand, with grain as the main fish feed. Of the three remaining ponds, two (Ede and Hof) are used for sport-fishing, with occasional feeding by anglers. The remaining pond Moorbad (Moo) is used as a public swimming pond, as well as sporadically by anglers. None of the fifteen ponds lie dry over the winter, the farming ponds are emptied at the fish harvest in autumn and immediately refilled. Tab. 2 provides a synopsis of the pond characteristics. Unless stated otherwise, all ponds are known since 1773, and therefore have a minimum age of 250 years

Tab. 1. Table of the sampled ponds, along with the assigned IDs and abbreviations, the locality of the pond, and its coordinates.

Pond	ID	Abbreviation	Locality	Latitude (N)	Longitude (E)
Steinbruckteich	1	Ste	Heidenreichstein	48.857899	15.146415
Winkelauer Teich	2	Win	Heidenreichstein	48.842050	15.147137
Edelwehrteich	3	Ede	Heidenreichstein	48.871793	15.131309
Streitteich	4	Str	Heidenreichstein	48.878210	15.128071
Neuteich	5	Neu	Heidenreichstein	48.870073	15.122588
Brüneiteich	6	Bru	Heidenreichstein	48.871247	15.067286
Brandteich	7	Bra	Heidenreichstein	48.857030	15.027025
Haslauer Teich	8	Has	Schrems	48.817574	15.139771
Gebhartsteich	9	Geb	Schrems	48.794701	15.130411
Moorbad	10	Moo	Schrems	48.795101	15.079439
Höfentöckteich	11	Hof	Schrems	48.782602	15.040870
Pürbacher Teich	12	Pur	Pürbach	48.769421	15.074732
Althöllteich	13	Alt	Pürbach	48.764156	15.068589
Frauenteich	14	Fra	Pürbach	48.752353	15.089276
Edlauerteich	15	Edl	Pürbach	48.756898	15.066295

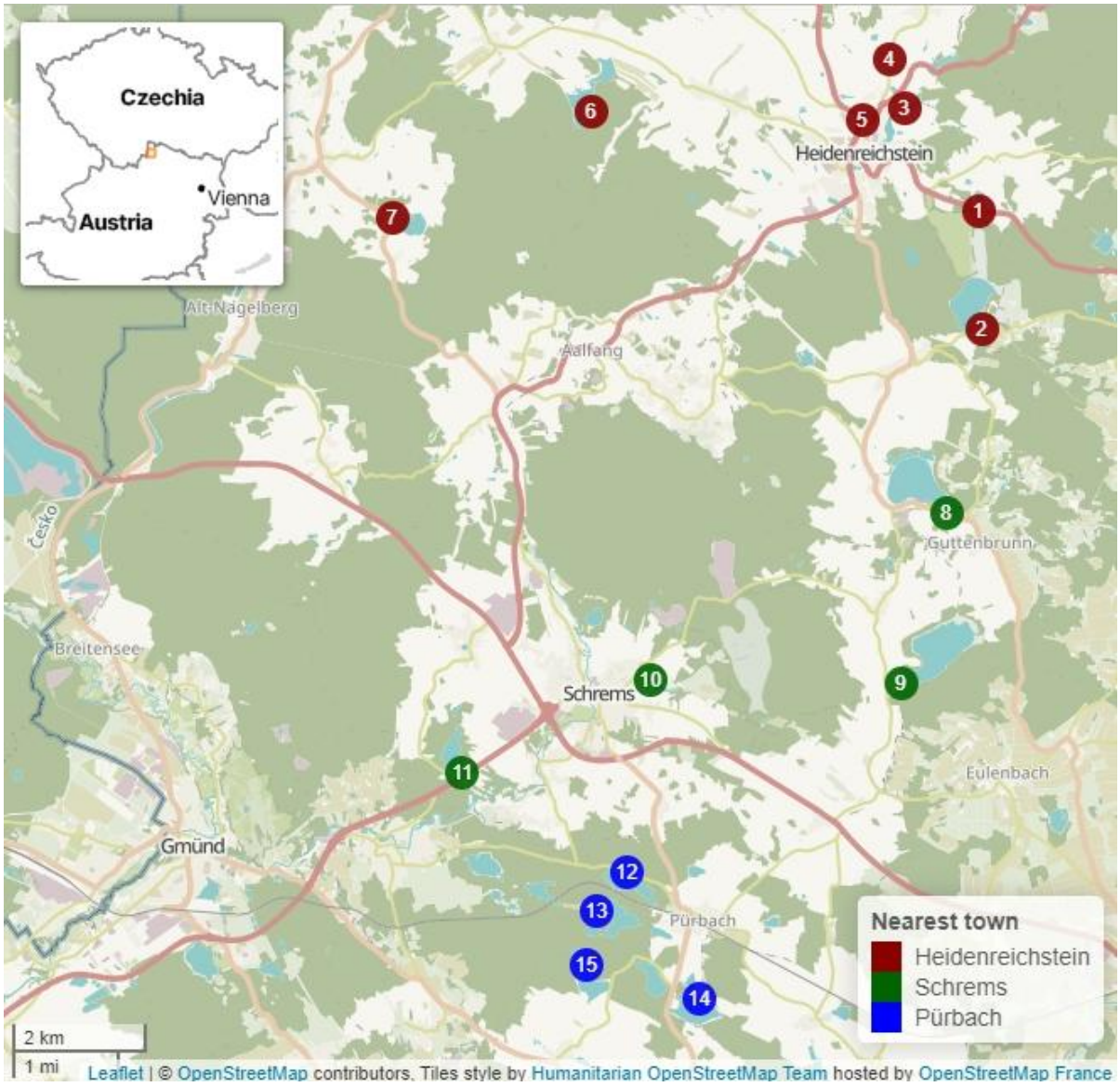

Fig. 1. Map of the sampling sites. Colours indicate pond groups according to nearest town (locality); numbers correspond to pond IDs listed in Tab. 1. The orange rectangle in the upper left insert indicates the sampling area.

Tab. 2. Synopsis of the pond characteristics. For permanently managed ponds the duration of the current management (management period) was estimated to 20 years.

Pond	Area (ha)	Age (years)	Altitude (m a. sl.)	Type of pond	Economic usage	Management period (years)	Stocking density (carp ha^{-1})	Harvest (kg ha^{-1})	Supplementary stock fish	Feeding scheme	Liming
Steinbruckteich	8.73	250	604.6	sky pond (chain of ponds)	growing pond	1	3000	260	pikeperch, whitefish	regularly with grain	no
Winkelauer Teich	49.27	250	596.8	sky pond (chain of ponds)	yielding pond	2	650	750	pikeperch, whitefish, Coregonus spp.	regularly with grain	yes
Edelwehrteich	3.13	210	560.5	brook pond (chain of ponds)	angling pond	20	no data	no data	predatory fish, whitefish	occasionally with corn, mixed feed, boilies	no
Streitteich	2.76	250	573.7	sky pond	growing pond	1	3000	260	unknown	regularly with grain	no
Neuteich	4.36	250	564.0	sky pond	growing pond	1	3000	260	none	regularly with grain	no
Brüneiteich	30.00	250	550.0	sky pond	yielding pond	1	550	700	*Coregonus spp.*	regularly with grain	yes
Brandteich	15.22	250	523.7	sky pond	growing pond	1	3000	260	*Coregonus spp.*	regularly with grain	yes
Haslauer Teich	50.00	50	559.5	brook pond (chain of ponds)	yielding pond	1	650	640	predatory fish, whitefish	regularly with grain	no
Gebhartsteich	57.00	250	546.8	brook pond (chain of ponds)	yielding pond	1	650	640	predatory fish, whitefish	regularly with grain	yes
Moorbad	3.00	250	531.6	sky pond	swimming pond	20	no data	no data	predatory fish, whitefish	occasionally with corn, mixed feed, boilies	yes
Höfentöckteich	15.00	250	516.7	sky pond	angling pond	20	no data	no data	predatory fish, whitefish	occasionally with corn, mixed feed, boilies; in spring and autumn with mixed feed	yes
Pürbacher Teich	21.20	250	525.5	sky pond (chain of ponds)	yielding pond	1	650	640	predatory fish, whitefish	regularly with grain	no
Althölteich	19.00	250	527.2	sky pond (chain of ponds)	yielding pond	1	650	640	predatory fish, whitefish	regularly with grain	no
Frauenteich	26.58	250	535.6	sky pond (chain of ponds)	yielding pond	1	650	640	predatory fish, whitefish	regularly with grain	no
Edlauerteich	20.96	250	534.4	sky pond (chain of ponds)	yielding pond	1	650	640	predatory fish, whitefish	regularly with grain	no

3.1.1 Heidenreichstein

Seven of the ponds investigated are situated in the vicinity of the town of Heidenreichstein in the northern part of the study region, with two of them in the settlement area of this town. The Edelwehrteich (Abbreviation = Ede; ID = 3) is only used for sport-fishing, so the fish are occasionally fed by anglers with grain, maize, and boilies. In the west and south, Ede directly borders the settlement area, with several family houses and paved roads (Fig. 2 C). On the north-east the pond is close to a small forest and to the east to agricultural areas. With an age of 210 years, it is at least 40 years younger than most of the other ponds and encompasses an area of 3.13 ha. Ede is part of a chain of ponds, getting its water from a brook which already passed through other ponds north-east of Ede and its outlet leading to two more ponds in the centre of Heidenreichstein. However, Ede is the only part of the chain of ponds sampled within this project. Along its shore, lawns with single trees and shrubs can be found. Given it is not used for fish farming, there is no need for drainage, hence holding water throughout the entire year. It is on a permanent management plan, and no liming is carried out. It is populated with carp, whitefish, and various predatory fish species. The second pond within the settlement area of Heidenreichstein is the Neuteich (Neu; ID = 5), with an area of 4.36 ha. It is close to the centre of the town and in the east, south and west, it is directly bordered by a road and opposite the road by a residential area (Fig. 2 E). North of Neu is some agricultural land with more houses neighbouring to the north. As most of the pond's shore directly borders the road, only little shrubs can be found. It is a sky pond as it is entirely fed by rainwater. No liming is carried out in the pond, and it is used solely as a growing pond with no other fish stocked. The stocking density of carp is 3000 fish per hectare.

North of the town and the ponds Ede and Neu is the Streitteich (Str; ID = 4), and with an area of only 2.86 ha, it is the smallest of all ponds sampled. The pond is embedded in an open landscape, surrounded by agricultural land, and higher vegetation like shrubs and trees scarce along its shore (Fig. 2 D). On the eastern banks, the pond is bordered by a road that leads up to a few houses. The pond is solely fed by rainwater, and it is used as a growing pond with a stocking density of 3000 carp per hectare. No information is available on other stock fish species, and liming is not carried out.

To the south-east of Heidenreichstein, and north of the Heidenreichsteiner Moor Nature Park lies another sky pond, the Steinbruckteich (Ste, ID = 1). Along its southern dam is a road, leading to a small settlement with a few dozen houses. On the other side of the road, south of the pond, is the Nature Park. Aside from the road and the small settlement, the surroundings are forested, and a reed belt exists along the eastern and western shores (Fig. 2 A). With 8.73 ha, it can still be considered one of the smaller ponds included in this study. Although it is a sky pond it is still part of a chain of ponds connected through channels. It is used as a growing pond not being limed. The pond contains a stocking density of 3000 carp per hectare along with some whitefish and pikeperch. Directly south of the Nature Reserve Heidenreichsteiner Moor lies a larger fish pond: the Winkelauer Teich (Win; ID = 2). With an area of 49.27 ha, it is the third largest pond sampled in this study. As the Heidenreichsteiner Moor borders in the north and forested areas border in the east, the shore is primarily forested with coniferous trees (Fig. 2. B). However, in the east, there is a reed belt. In the south, the lake is bordered by a road, and east of the lake, behind the reed belt, there is a small settlement. Win can be classified as a sky pond with the neighbouring bog included in its catchment. It is also connected to Ste and is part of the same chain of ponds. As a yielding pond, it maintains fish densities of approximately 650 carp per hectare. Liming does occur. Notably, it stands as the sole pond included in this study in which fish stocking is carried out over a two-year period. Hence, the stocked carp are harvested after their fourth summer, with a yield of approximately 750 kilograms per hectare. Among the stocked fish are whitefish, *Coregonus spp.* (“Maränen”) and pikeperch.

Situated further to the west of Heidenreichstein, the large Brüneiteich (Bru; ID = 6) with an area of approximately 30 ha, is one of the more well-known ponds in the area. The whole southern part is surrounded by coniferous forest, mostly spruce (Fig. 2 F). To the north the pond is bordered by agricultural land. It is occasionally used for swimming in summer. Bru is also the site of local festivals in the autumn when the fish are harvested, known as the “Abfischfest”. As many other sampled ponds around Heidenreichstein, Bru is classified as a sky pond. Liming is carried out and it is utilized as a yielding pond maintaining a fish density of 650 carp per hectare. Additionally, *Coregonus* species are stocked as supplementary stock fish.

South-west of Brüneiteich, more than 5 km from Heidenreichstein and near a small village called Brand, is the Brandteich (Bra; ID = 7). It covers an area of 15.22 ha. It is bordered by two roads: The larger one is west of the pond along the dam, and in the north, another road with a few houses borders the shore in certain parts (Fig. 2 G). In the south, a small, unpaved road is located a few meters from the shore. Aside from the roads, the pond is surrounded by small forests and groups of trees as well as meadows. In the northern part of the pond, a small isle can be found. Bra is mainly fed by rainwater, and liming is regularly carried out. Functioning as a growing pond, it features a stocking density of 3000 carp per hectare, with *Coregonus* species as supplementary stock fish.

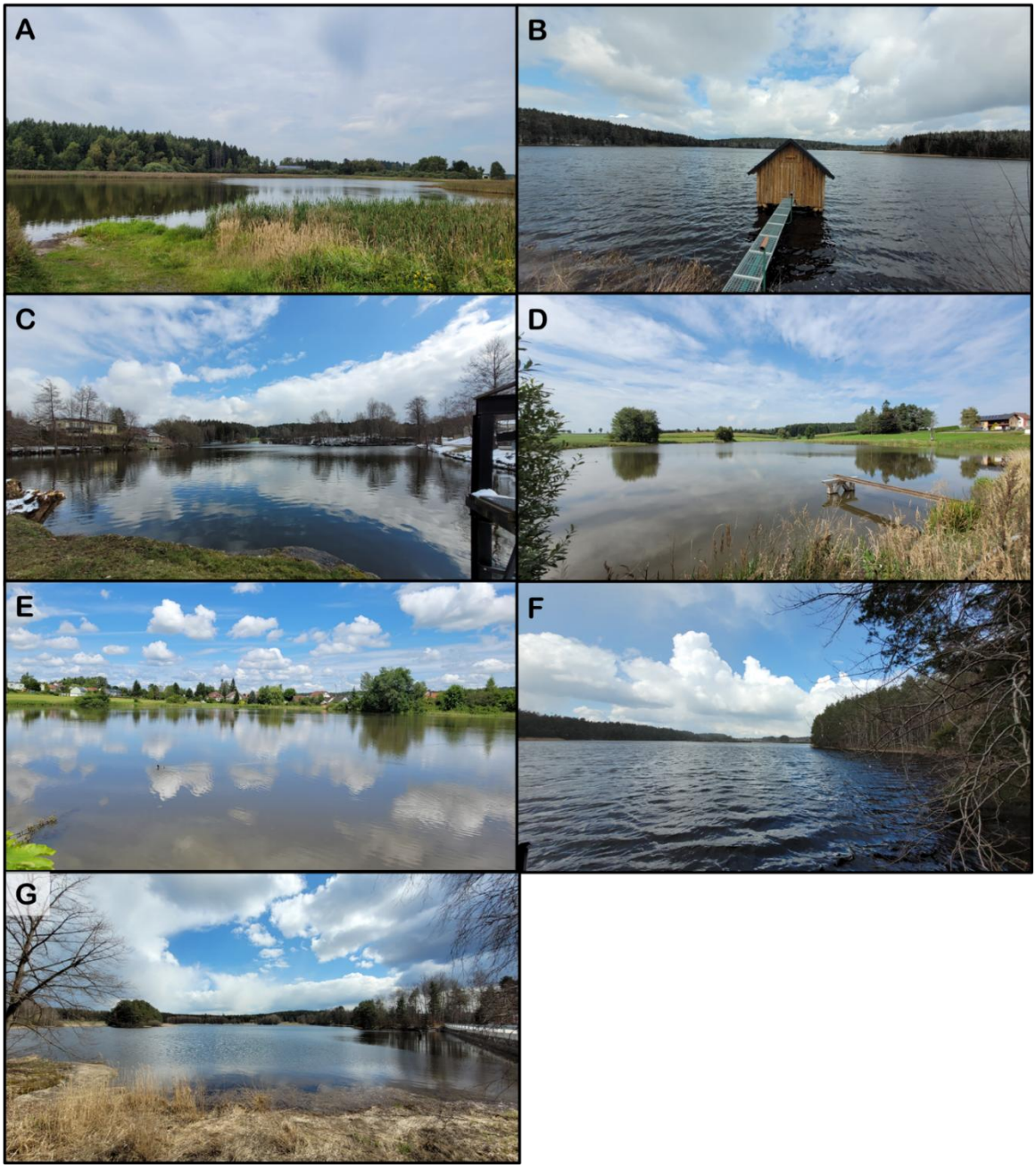

Fig. 2. Heidenreichstein group of study ponds. **A**: Steinbruckteich (Ste) with reed belts along the western and eastern shore (15 September 2021). **B:** Winkelauer Teich (Win) with a small cabin at the pond outlet, surrounded by forest, and the Heidenreichsteiner Moor in the background (07 April 2021). **C:** Edelwehrteich (Ede) from the southern shore next to the pond outlet, surrounded by lawns and houses (07 April 2021). **D:** Streitteich (Str) embedded in an agricultural landscape (15 September 2021). **E:** Neuteich (Neu) in the centre of Heidenreichstein, the shore bordering to roads and settlement area (05 July 2021). **F:** Brüneiteich (Bru) in the coniferous forest west of Heidenreichstein (07 April 2021). **G:** Brandteich (Bra) with the bordering road to the south and shallow shore to west (07 April 2021).

3.1.2 Schrems

The town of Schrems is situated in the centre of the study area, and in its vicinity, four ponds were sampled. The Moorbad (Moo; ID = 10) is located within the settlement area of Schrems. This particular pond is primarily used for public swimming during summer, and sporadically by anglers. In consequence, there are lawns with single trees along the whole shore with swimming piers and platforms reaching into the pond (Fig. 3 C). Behind the lawns, a settlement area is close to the pond to the north and west, while agricultural land is situated to the south. East of Moo, the Nature Park Schremser Hochmoor is located, harbouring the once-largest raised bog of Lower Austria. Moo is fed by water from the raised bog, which passes through the so-called "UnterWasserReich" – the Nature Park's visitor centre giving information on bogs and ponds – and then flows into the pond. As the water contains high levels of humic acid, it has a distinctive reddish-brown colour. The pond holds water over the entire year, and liming is exclusively carried out in spring to stabilise pH. Fish feeding occurs only occasionally by anglers.

North-east of Schrems lie the two largest ponds of the region, the Haslauer Teich (Has, ID = 8) and the Gebhartsteich (Geb, ID = 9). Both are brook ponds sharing the same feeder stream, with some of the water coming from Win. Both are used as yielding ponds, with fish stocking densities of 650 carp per hectare. Fish feed is only provided on demand and only consists of grain. The smaller Haslauer Teich (Fig. 3 A) with an area of 50 ha is close to deciduous as well as coniferous forests in the north-east. To the south, the pond touches a road, and some houses exist on its western side. No liming is carried out, and it is additionally stocked with predatory fish and whitefish. Notably, Has is by far the youngest of the ponds studied, with an approximate age of 50 years.

The Gebhartsteich (Fig. 3 B), covering an area of 57 ha, is the largest pond of the region and situated south of Has. Geb is connected to Has through the Schwarzabach brook. It is completely surrounded by deciduous and coniferous forest, and there are no houses or settlements nearby. The name of the pond derives from the next settlement in its vicinity called Gebharts. Liming occurs, other stock fish include predatory and whitefish. With an age of 250 years, it is as old as most of the ponds in the region. Nevertheless, its historical use as a fish pond was interrupted through periods when it lied dry, for example in 1823.

The Höfentöckteich (Hof; ID = 11) is located southwest of Schrems, close to a gravel quarry. The pond with an area of 15 ha is encircled by forest along the majority of its

shoreline. It stands alone as the sole surveyed pond where active biotechnological measures are employed for oxygenation and water mixing facilitated by windmills on the surface (Fig. 3 D). It is used for sport-fishing, with occasional feeding by anglers over the year (grain, maize, and boilies). Additionally, the fish are fed in spring and autumn with mixed feed for strengthening. Hof is fed by rainwater and, as a sport fishing pond, permanently holding water. The pond is regularly limed and stocked with predatory fish, whitefish and possibly carp.

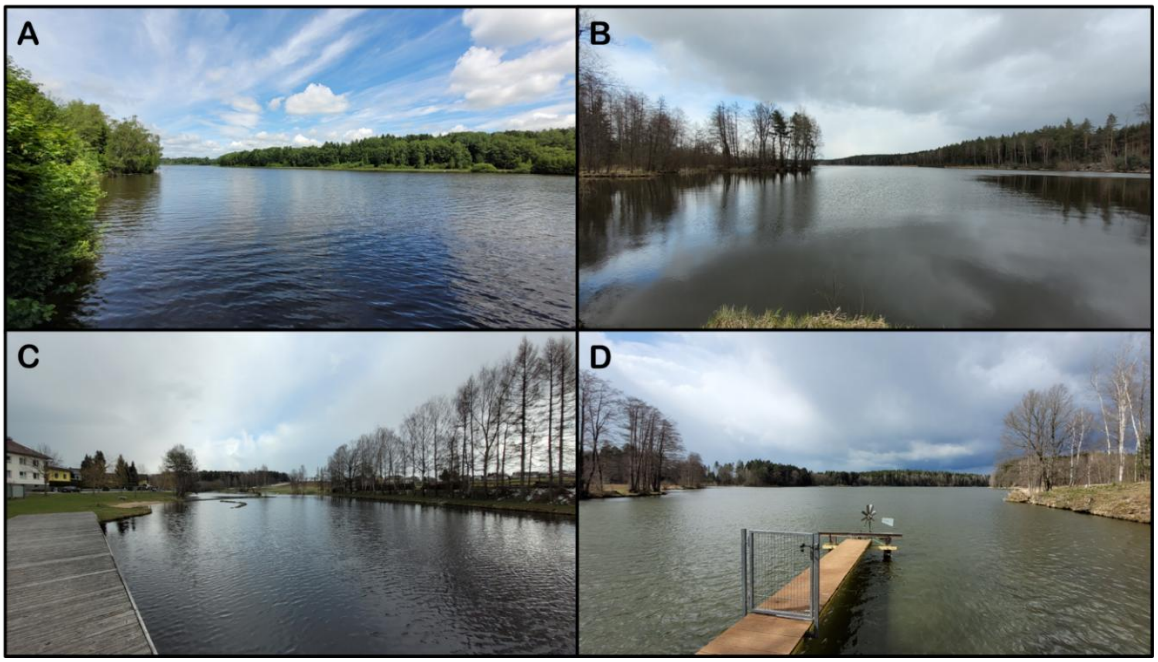

Fig. 3. Schrems group of study ponds. **A:** Haslauer Teich (Has) during summer with deciduous forest along the north-eastern shore (05 July 2021). **B:** Gebhartsteich (Geb), looking north with mixed forest around the entire pond (07 April 2021). **C:** Moorbad (Moo) with bathing platforms and lawns along its shore (07 April 2021). **D:** Höfentöckteich (Hof), south end of the fishing pond with the outlet structure and a windmill for water oxygenation (07 April 2021).

3.1.3 Pürbach

All four ponds in the vicinity of Pürbach are geographically distant from settlements, being situated to the west and south of the town. There is no liming in any of the four ponds. In addition to carp these ponds are stocked with predatory fish and whitefish. All four ponds use grain as the exclusive supplementary fish feed with an ‘on demand’ feeding scheme. The studied fish ponds around Pürbach are harvesting ponds, with stock fish densities of 650 carp per hectare, all subject to one-year management plans.

The Pürbacher Teich (Pur; ID = 12) is situated west of Pürbach, immediately north of the railway. It is surrounded by deciduous forest, with no nearby settlements (Fig. 4 A). It is a sky pond with an area of 21.2 ha. Pur is connected to the Althöllteich (Alt; ID = 13), which is embedded within the forest to the south of Pur, on the opposite side of the railway (Fig. 4 B). Alt, too, falls under the classification of a sky pond and predominantly relies on rainfall as water source, encompassing an area of 19 ha. Further south on the southern border of the forest the Edlauerteich (Edl; ID = 15) is part of the same chain of ponds, with its outlet discharging into Alt. Like the other ponds it can be classified as a sky pond fed by rainwater. The northern and western shore are bordered with forests, with some reed along the forested shoreline (Fig. 4 D). The pond is open to the south, adjoining agricultural fields. Edl encompasses an area of 20.96 ha. Lastly, the Frauenteich (Fra; ID = 14) is situated to the south of Pürbach and east of the three aforementioned ponds. The sky pond covers an area of 26.56 ha. It is characterized by forest along the southern shore and open land to the north with only a few patches of reed (Fig. 4 C).

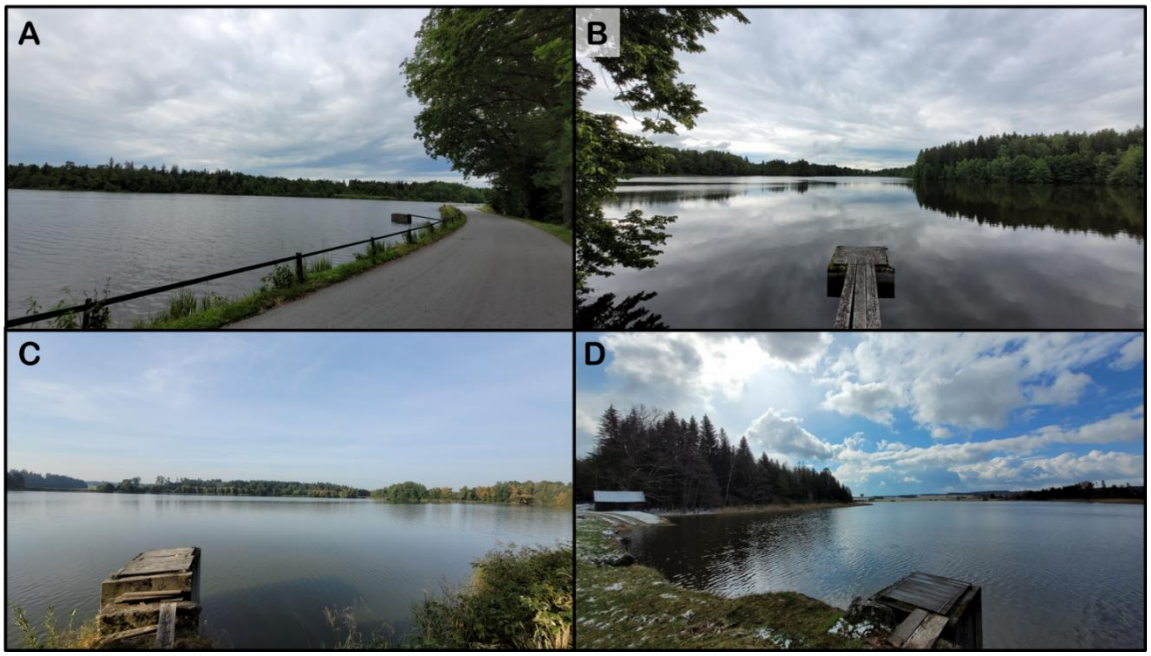

Fig. 4. Pürbach group of study ponds. **A:** Pürbacher Teich (Pur) bordering to a paved road in the north and forest along the southern shore (05 July 2021). **B:** Althöllteich (Alt) with the pond outlet on the western end and forest along the entire shore (05 July 2021). **C:** Frauenteich (Fra) with deciduous forest and some fields along its shore (15 September 2021). **D:** Edlauerteich (Edl) looking south from the outlet at the northern shore with forest along the northern half of the pond and open land to the south (07 April 2021).

3.2 Field sampling

Water samples, zooplankton samples and on-site measurements were taken simultaneously in each pond. Sampling took place three times throughout the year, in spring (7 April 2021 and 8 April 2021), summer (5 July 2021), and autumn (15 September 2021). This routine covered the typical carp farming season, which concludes with the fish harvest in the second half of September or early in October. All samples were taken as close as possible to the outlet of the pond (so-called "Mönch"), which is also the deepest point of the pond (Fig. 5). Hydrochemistry samples for laboratory analyses were taken at the same site, as we assumed water age to be highest at the outlet. At Moo all samples were taken from a bathing platform at the centre of the pond depicted in Fig. 3 C.

Fig. 5. Sampling at the pond outlet structure ("Mönch") at the Pürbacher Teich in September 2021 (by Chun Yen, 15 September 2021)

3.2.1 Physical and chemical measurements

The physical parameters water temperature (°C), pH, dissolved oxygen (mg l^{-1}, %), and conductivity (µS cm^{-1}) were measured on site with a multiparametric probe (WTW Multi 3630 IDS) with the following Sensors: FDO® 925 for dissolved oxygen, TetraCon® 925 for conductivity, and SensoLyt 900® for pH-value. For measuring the transparency of the

water the Secchi depth was taken, using a white disc with 30 cm in diameter. Total alkalinity (mg l^{-1}) was titrated on site to the endpoint of pH 4.3 with a test kit (MQuant Kompaktlabor). For hydrochemistry, a large water sample (5 L) was taken and transferred to the laboratory, where it was stored at 4°C and analysed within the next day.

3.2.2 Zooplankton sampling

The zooplankton samples were taken with a conical plankton net (mesh size of 100µm. Two types of samples were taken: for the qualitative samples three to four horizontal net hauls over five meters were carried out to collect a compact, representative sample of the occurring species. For the quantitative samples, a modified Schindler sampler was used to collect exactly twenty litres of water, both from the surface as well as the deepest water layer at the pond outlet (integrated sample). The water was then filtered through a 100µm sieve, and the filtered zooplankton transferred into flasks. The collected zooplankton was preserved with ethanol (96%) and formaldehyde (37%).

3.3 Laboratory analysis

3.3.1 Hydrochemistry

The water taken with the Schindler sampler was analysed in the laboratory for relevant nutrient and other key parameters. The measurements included non-purgeable dissolved organic carbon (NPOC [mg L^{-1}]), dissolved organic carbon (DOC [mg L^{-1}]), cations: sodium (Na^+ [mg L^{-1}]), potassium (K^+ [mg L^{-1}]), calcium (Ca^{2+} [mg L^{-1}]), magnesium (Mg^{2+} [mg L^{-1}]), ammonium (NH_4^+ [mg L^{-1}]), and anions: chloride (Cl^- [mg L^{-1}]), nitrite (NO_2^- [µg L^{-1}]), nitrate (NO_3^- [mg L^{-1}]), sulphate (SO_4^{2-} [mg L^{-1}]), phosphate (PO_4^{3-} [µg L^{-1}]), as well as total phosphorus (Ptot [mg L^{-1}]), SiO4 [mg L^{-1}], CN-analysis (C; N [mg L^{-1}], and algal pigment (Chl-a [mg L^{-1}]) concentrations. Furthermore, dry mass (DM [mg L^{-1}]) and ash mass (AM [mg L^{-1}]) were weighed for calculating organic mass (= ash free dry weight/AFDW [mg L^{-1}]).

For the NPOC analysis, samples were filtered into borosilicate glass vials using Whatman GF/F filters (pore size 0.7 µm), both pre-combusted. DOC analysis was carried out using a GE-Sievers 900 TOC Analyser (SUEZ Water Technologies & Solutions, Trevose, PA USA) with the persulfate oxidation method and an inorganic carbon removal unit. For cation (OENORM EN ISO 14911) and anion (OENORM EN ISO 10304) concentrations the

samples were analysed by using an ion chromatography (Metrohm Compact IC 761, cation column: Metrohm Metrosep C2; anion column: Metrohm Metrosep ASupp 5). Ptot was analysed with a spectrophotometer at 890 nm (Hach - Lange DR 2800) after wet combustion of the unfiltered sample (OENORM EN ISO 6878). SiO_4 concentrations were measured with the photometric unreduced silicomolybdic acid method in the filtrate as yellow β-silicomolybdic acid (λ = 400 nm) according to DIN 38405-21. Concentrations of chlorophyll-a (Chl-a) were obtained by filtering a defined volume of the sample onto GF/C filters (Ederol company). The filters were frozen at -20 °C until they were subsequently cut into small pieces and resuspended in 90% acetone. The samples were then homogenized through ultra-sonication with the Branson Sonifier 250. After extraction at 4 °C for 12 hours in the dark, the suspension was centrifuged. The supernatant was measured spectrophotometrically, and concentrations were calculated according to (Lorenzen, 1967).

For the analysis of DM, AM, and AFDW a defined volume of the sample was filtered onto pre-combusted and pre-weighed GF/C filters. For DM the filters were dried at 90 °C for 24 h and reweighed. The filters were then combusted at 450°C for 4 h and reweighed to obtain the AM. The organic mass (AFDW) was calculated with the following equation: AFDW = DM – AM. Filtration was carried out in the same manner onto GF/C filters for the CN analysis. The filters were rinsed with 10% HCl followed by rinsing with milliQ-water to remove all inorganic carbon. Subsequently, the filters were dried at 60 °C, packed into tin foil and analysed in the elemental analyser Vario MICRO Cube.

3.3.2 Cladocera community analysis

The qualitative zooplankton samples were used for species identification, obtaining a complete taxa list in the process, as well as for abundance estimations given as abundance classes. Abundance classes ranged from 1 (= sporadically, very rare) to 5 (very high abundance, mass occurrence), following the procedure given by (Wawrik, 1966). As the present study focuses on Cladocera, belonging specimens were identified to species level using the keys by (Flößner, 2000) and (Błędzki & Rybak, 2016). Copepods were identified to the order level – Cyclopoida and Calanoida. The presence of larger Rotifers was also noted. For this, approximately 3 ml of the qualitative sample were transferred with a pipette from the bottom of the undisturbed collecting vial to a microscope slide. After adding a covering slide, the sample was investigated under a binocular microscope (Nikon SMZ 1B)

at magnifications up to 35×. In addition, a microscope (Leica DM500 RH; magnification up to 400×) was used for difficult taxa. After identification, the species in the quantitative samples were counted in counting chambers (80x100 mm) and petri dishes (145 mm diameter) under the binocular microscope, and absolute abundances (individuals per litre) were calculated. Only fully intact female adult specimens were included in the count to ensure correct identification.

3.4 Statistical analysis

Transformations, significance testing, and further analyses were calculated with R base and *vegan* (Oksanen et al., 2020; R Core Team, 2025). Data handling and manipulation was conducted with *tidyverse* (Wickham et al., 2019). Plots were drawn with *ggplot2* (Wickham et al., 2007), *ggvegan* (Simpson & Oksanen, 2026) and the base plot function of R. The key variables that contribute most to the abiotic variation between the ponds were identified by the *bioenv* function of *vegan* (Oksanen et al., 2020) after standardization to zero mean and unit variance. The cluster analysis was conducted with the *simprof* function (Euclidean distance, 999 permutations), adapted from *clustsig* (Whitaker, 2019), implementing the *similarity profile analysis* method described by Clarke, Somerfield, and Gorley (Clarke et al., 2008). The LINKTREE function of Primer v6 (Clarke & Gorley, 2005) was applied to identify the threshold values for the division of the abiotic clusters. The multivariate analysis and diversity indices were calculated with *vegan* (Oksanen et al., 2020). The nMDS was calculated with *metaMDS* (k = 3, Bray-Curtis distance and 9999 permutations); the ANOSIM was calculated with the *anosim* function (9999 permutations). After forward selection with the *ordistep* function, the Canonical Correspondence Analysis was conducted with *cca*; significance testing with *anova* (Oksanen et al., 2020). The indicator species analysis was calculated with the packages *indicspecies* and *labdsv* (Cáceres & Legendre, 2009; Roberts, 2025); only characteristic species with an indicator value > 0.7 were retained in accordance with McGeoch et al., 2002. The co-occurrence analysis was performed with the *cooccur* package (Griffith et al., 2016).

4. Results

4.1 Environmental and structural parameters

The environmental factors measured at three sampling dates throughout this study are summarized in Tab. 3. A maximum Secchi depth of 157 cm was observed at Streitteich in summer whereas a minimum of 25 cm was measured at Moorbad Schrems in autumn. The water temperature of the ponds ranged from 4.6°C at Streitteich in April to 23.3°C at Brüneiteich in July. Conductivity ranged from 58.4 (Bra su) to 409.0 and 412.0 µS cm^{-1} (Neu su and Neu au), with most samples having a conductivity between 100 and 200 µS cm^{-1}. There was one sample with an alkalinity of 2.1 mmol L^{-1} (Neu su), all other samples ranged from 0.2 (Bra au) to 1.5 mmol L^{-1} (Neu au). Variance in oxygen saturation was quite low with two outliers (Fig. 6): Streitteich in September at 37.5% (3.25 mg L^{-1} at 19.7°C) and Edelwehrteich in July at 200% (16.8 mg L^{-1} at 21.6°C). Brüneiteich and Brandteich in September had the lowest sodium concentrations (< 5 mg L^{-1}), while the three samples from Neuteich had the highest concentrations with 32.8 mg L^{-1} in April up to 44.4 mg L^{-1} in July. The samples from Neuteich also had the highest concentrations of calcium (28.6 mg L^{-1} in July, 25.0 mg L^{-1} in September), the lowest concentrations were observed at Höfentöckteich in spring (1.9 mg L^{-1}). Potassium concentrations ranged from 1.9 and 2.1 mg L^{-1} at Brüneiteich in September and July to 5.4 mg L^{-1} at Edlauerteich and Frauenteich in July. Lowest magnesium concentrations were found at Brandteich in September (1.6 mg L^{-1}) and April (1.7 mg L^{-1}), whereas the highest one was measured at Neuteich in July (6.2 mg L^{-1}). A maximum chloride concentration of 64.6 mg L^{-1} was recorded at Neuteich in July, a minimum at Brandteich in September. Nitrate concentrations ranged from 0.2 mg L^{-1} (Alt su and Str su) to 9.4 mg L^{-1} (Moo sp) and sulphate concentrations from 3.9 mg L^{-1} (Bru au) to 23.1 mg L^{-1} (Geb sp). While phosphate was lowest at Pürbacher Teich in autumn (0 µg L^{-1}), total phosphorus was lowest at Streitteich in spring (21 µg L^{-1}). The highest phosphate concentration was measured at Neuteich in summer (81 µg L^{-1}), the highest total phosphorus at Streitteich in autumn (331 µg L^{-1}). With respect to nitrite, the lowest and highest concentrations were obtained at Neuteich (0.8 µg L^{-1} in September, 78 µg L^{-1} in April). There was only one sample with an ammonium concentration > 200 µg L^{-1} at Neuteich in July (454 µg L^{-1}), whereas Brandteich had the lowest concentration of ammonium in April (7 µg L^{-1}). Moorbad Schrems had the three highest measured

concentrations of silicate: 7.0 in spring, 8.5 in summer and 9.7 mg L^{-1} in autumn. All other samples had concentrations < 5 mg L^{-1}. The minimum concentration of silicate was obtained at Pürbacher Teich in autumn (0.3 mg L^{-1}). The concentration of non-purgeable organic carbon (NPOC) was smaller than 20 mg L^{-1} in 39 of the 45 samples taken. The six samples with higher concentrations were taken from Win (29.64 to 31.29 mg L^{-1}) and Moo (38.01 to 60.13 mg L^{-1}, the latter in summer). The lowest concentrations were 7.70 mg L^{-1} at Str and 8.23 mg L^{-1} at Ede in spring. Inorganic carbon (IC) concentrations ranged from 0.20 mg L^{-1} at Bra sp to 18.52 mg L^{-1} at Neu su. Total nitrogen (TN) was lowest at Bra (0.69 mg L^{-1} in spring, 0.70 in summer, and 0.82 in autumn). The maximum concentration was obtained at Str sp (5.7 mg L^{-1}). Dry weight ranged from 3.66 mg L^{-1} at Bra sp to 49.60 mg L^{-1} at Neu au and particulate organic matter (POM) from 3.14 mg L^{-1} at Str sp to 32.95 mg L^{-1} at Geb au. Chlorophyll A (Chl-a) concentrations were smaller than 0.7 mg L^{-1} in 43 samples, the smallest concentration was found at Neu su (0.02 mg L^{-1}) and the two highest concentrations at Geb sp (0.80 mg L^{-1}) and Win au (1.13 mg L^{-1}), the only sample > 1 mg L^{-1}. Moorbad Schrems in July was the only sample with a pH < 7 at 6.7. The maximum pH was 10 and measured at Höfentöckteich in September (Tab. 3).

A subsequent analysis investigated seasonal patterns of selected environmental variables over the three sampling dates (Fig. 6). The water temperature increased from 5 – 8°C in April to around 21°C in July and 20°C in September, with low variation between the ponds within each sampling date (Fig. 6). Similarly, alkalinity was significantly lower in April (mean = 0.66; SD = 0.30) compared to July (mean = 0.97; SD = 0.44; $p < 0.01$) and September (mean = 0.86; SD = 0.40; $p < 0.05$). Sulphate concentrations as well as Secchi depth decreased over the year, with a significant decrease in sulphate concentrations from April to July ($p < 0.001$) as well as from July to September ($p < 0.001$), and a significant decrease in Secchi depth from April to September ($p < 0.001$). The variance of total nitrogen (TN) concentrations decreased in July and September with only a minority of the study ponds having higher TN-concentrations. However, concentrations did not change significantly over the sampling period. No significant change in conductivity and oxygen saturation was observed over the course of the study, with conductivity measured in a 165 – 180 µS cm^{-1} range and oxygen saturation around 100%. Both, nitrate concentrations and pH-values decreased from April to July (significantly for nitrate: $p < 0.05$) and increased again in September (significantly for pH: $p < 0.0001$). TP increased significantly from April to July ($p < 0.05$) and September ($p < 0.001$). Likewise, there was a significant increase in

POM concentrations over time (April – July: $p < 0.05$; July – September: $p < 0.001$). NPOC concentrations did not change significantly; however, variance slightly increased in July and September. Likewise, no significant variations in chloride were found, the six highest concentrations (outliers in Fig 1) were found at Neu and Ste. Magnesium concentrations were significantly lower in September (mean = 3.71; SD = 1.04) than in July (mean = 4.44; SD = 1.12; p[su-au] < 0.01) or April (mean = 4.20; SD = 0.96; p[sp-au] < 0.0001). There was no significant change over time in silicate concentrations. However, there is a slight decline visible with two outliers in summer and autumn (both Moo).

Tab. 3. Master table of environmental variables. T = temperature; O_2 = oxygen concentration; O_2 = oxygen saturation; P-PO_4 = orthophosphate; P-t = total phosphorus; N-NO_2 = nitrite-nitrogen; N-NH4 = ammonium-nitrogen; Si-SiO_4 = silicate; C = total particulate carbon; N = total particulate nitrogen; NPOC = non-purgeable organic carbon; IC = inorganic carbon; TN = total nitrogen; POM = particulate organic matter; Chl a = chlorophyll-A; site labels are explained in Tab. 1; sp= spring; su= summer; au= autumn samples

Label	Surface area (ha)	Secchi depth (cm)	T (°C)	Conductivity (µS cm^{-1})	Alkalinity (mmol L^{-1})	O_2 (mg L^{-1})	O_2 (%)	Sodium (mg L^{-1})	Potassium (mg L^{-1})	Calcium (mg L^{-1})	Magnesium (mg L^{-1})	Chloride (mg L^{-1})	Nitrate (mg L^{-1})	Sulphate (mg L^{-1})	P-PO_4 (µg L^{-1})	P-t (µg L^{-1})	N-NO_2 (µg L^{-1})	N-NH_4 (µg L^{-1})	Si-SiO_4 (mg L^{-1})	C (mg L^{-1})	N (mg L^{-1})	NPOC (mg L^{-1})	IC (mg L^{-1})	TN (mg L^{-1})	Dry weight (mg L^{-1})	POM (mg L^{-1})	Chl a (mg L-1)	pH	Label
Ste sp	8.73	115	5.3	228.0	0.5	11.16	95	30.8	3.8	11.6	3.7	39.9	1.0	10.4	2	52	1.3	28	0.6	2.70	0.50	11.97	5.99	0.89	5.28	5.67	0.053	7.5	**Ste sp**
Win sp	49.27	70	7.0	139.0	0.4	10.13	91	15.2	2.6	10.5	3.5	16.6	1.7	12.6	5	43	8.8	71	3.7	2.14	0.36	30.93	2.54	1.49	5.11	3.94	0.073	7.7	**Win sp**
Ede sp	3.13	90	5.3	126.0	0.4	10.42	107	13.3	2.7	9.5	3.3	8.8	9.3	17.1	6	52	9.8	52	4.6	3.20	0.50	8.23	2.85	2.42	8.64	4.85	0.286	7.6	**Ede sp**
Str sp	2.76	150	4.6	183.0	0.4	12.03	100	10.2	3.5	17.7	4.8	8.3	2.0	21.5	3	21	47.5	33	2.2	1.35	0.25	7.70	5.09	5.72	6.41	3.14	0.030	7.5	**Str sp**
Neu sp	4.36	105	6.3	330.0	1.4	12.20	107	32.8	3.8	24.3	5.6	48.7	8.7	12.1	1	32	78.4	8	1.1	3.21	0.74	8.92	10.55	2.94	7.60	6.35	0.063	8.0	**Neu sp**
Bru sp	30.00	70	7.2	66.1	0.5	11.93	105	20.3	3.0	15.0	3.8	24.3	3.8	10.3	2	81	37.3	11	1.9	5.14	0.97	12.35	6.29	1.81	12.32	10.42	0.407	8.1	**Bru sp**
Bra sp	15.22	60	8.0	62.0	0.4	11.07	100	8.3	2.7	3.7	1.7	4.1	1.2	14.0	1	31	3.3	7	4.6	1.54	0.36	10.07	0.20	0.69	3.66	5.45	0.043	7.2	**Bra sp**
Has sp	50.00	65	6.3	148.5	0.7	12.92	111	12.3	3.7	14.2	4.4	7.8	1.3	21.3	2	58	8.9	14	1.9	4.23	0.85	10.87	6.56	1.11	11.45	4.05	0.231	8.6	**Has sp**
Geb sp	57.00	45	7.1	127.5	0.5	11.74	103	10.4	3.3	11.5	4.1	6.3	1.8	23.1	3	115	11.1	41	2.6	9.32	1.23	14.67	3.78	1.40	12.51	8.94	0.804	8.0	**Geb sp**
Moo sp	3.00	60	6.8	148.0	0.4	10.04	87	13.3	2.6	12.9	4.2	12.6	9.4	19.1	4	37	9.6	61	7.0	2.41	0.27	38.01	1.22	3.12	9.26	5.20	0.022	7.5	**Moo sp**
Hof sp	15.00	60	7.9	207.0	1.0	12.80	114	13.3	4.5	1.9	5.8	12.6	5.6	22.1	2	75	13.7	21	3.6	7.80	1.30	10.35	9.56	2.28	19.66	16.09	0.228	8.1	**Hof sp**
Pur sp	21.20	125	6.3	193.0	0.7	11.39	98	16.4	4.2	17.9	4.7	14.9	3.3	17.1	2	44	11.5	21	1.7	2.61	0.52	11.40	9.15	1.59	8.19	5.56	0.085	7.7	**Pur sp**
Alt sp	19.00	60	6.9	180.4	0.7	10.98	95	16.2	4.5	15.5	4.3	15.9	1.0	16.1	2	88	6.9	27	0.9	3.19	0.60	12.46	8.61	0.90	13.61	8.67	0.231	7.0	**Alt sp**
Fra sp	26.58	70	5.5	194.7	1.0	12.85	107	16.0	4.3	18.6	4.8	16.0	2.3	16.6	2	84	28.2	42	1.9	6.92	1.15	11.69	8.79	1.23	17.30	14.70	0.298	8.4	**Fra sp**
Edl sp	20.96	85	5.8	197.6	0.9	10.82	91	20.8	4.1	14.8	4.3	20.9	0.6	13.4	5	47	13.0	46	0.6	2.64	0.50	9.66	9.35	0.97	9.52	4.40	0.029	8.0	**Edl sp**
Ste su	8.73	43	23.2	258.0	1.0	10.48	132	30.6	3.6	15.4	4.6	38.8	0.8	5.7	6	119	1.6	19	1.2	2.26	0.33	14.15	10.49	1.22	19.66	17.97	0.105	7.4	**Ste su**
Win su	49.27	68	22.2	136.0	0.5	8.52	103	15.8	2.9	12.1	3.8	15.4	1.1	11.0	12	99	4.8	19	1.8	3.42	0.54	29.64	4.77	1.33	10.86	10.33	0.575	7.4	**Win su**
Ede su	3.13	49	21.6	148.1	0.7	16.81	200	13.0	3.5	12.9	3.8	10.5	1.5	13.2	7	105	20.4	17	4.2	1.57	0.25	10.08	6.74	1.06	8.83	5.31	0.249	8.7	**Ede su**
Str su	2.76	157	22.0	172.0	1.4	6.76	83	10.5	3.5	19.7	5.3	6.6	0.2	10.2	10	66	12.0	187	1.9	3.08	0.18	9.74	15.14	1.20	6.82	5.55	0.045	7.2	**Str su**
Neu su	4.36	140	22.4	409.0	2.1	5.50	68	44.4	4.6	28.6	6.2	64.6	2.1	6.8	81	151	16.6	454	2.3	3.07	0.17	10.51	18.52	1.47	5.70	3.22	0.018	7.2	**Neu su**
Bru su	30.00	115	23.3	63.0	0.5	9.48	118	8.2	2.1	6.9	2.4	4.1	0.3	6.2	3	56	1.8	17	0.9	4.95	0.28	14.76	3.80	0.99	5.44	5.60	0.079	7.5	**Bru su**
Bra su	15.22	130	22.2	58.4	0.3	8.83	108	9.5	2.8	4.3	1.9	4.0	0.7	11.4	5	66	1.3	19	2.2	19.39	3.25	11.74	1.63	0.70	7.80	7.62	0.153	7.3	**Bra su**
Has su	50.00	68	20.9	157.4	1.0	8.67	104	11.5	4.1	16.4	4.8	7.6	0.6	12.9	12	213	1.5	147	1.5	6.13	1.05	13.20	11.65	1.21	11.21	7.72	0.086	7.3	**Has su**
Geb su	57.00	45	21.4	142.1	0.9	9.16	114	10.1	4.1	14.9	4.9	6.1	2.0	15.2	3	92	1.0	17	0.9	19.17	3.32	15.21	9.20	1.07	24.60	19.59	0.229	7.5	**Geb su**
Moo su	3.00	29	19.5	119.0	0.6	6.06	71	12.1	2.7	13.5	3.9	9.8	2.3	12.9	9	72	27.1	35	8.5	22.54	2.21	60.13	3.06	2.44	16.09	11.43	0.170	6.7	**Moo su**
Hof su	15.00	50	21.2	202.0	1.1	7.75	93	14.1	5.1	19.8	5.5	12.4	5.0	15.4	2	85	1.3	19	3.0	12.05	1.09	9.94	12.47	1.12	16.13	14.57	0.256	7.0	**Hof su**
Pur su	21.20	70	20.6	192.9	1.0	9.77	116	15.3	4.7	18.7	4.8	13.8	3.0	12.0	2	64	0.8	14	0.6	11.63	1.03	12.02	11.79	0.96	11.31	8.99	0.107	7.8	**Pur su**
Alt su	19.00	73	21.2	198.0	1.1	7.68	93	16.9	5.1	18.2	4.9	15.2	0.2	11.4	3	99	1.0	15	0.6	8.03	1.01	12.52	12.57	1.02	13.25	9.89	0.180	7.4	**Alt su**
Fra su	26.58	30	20.2	204.0	1.2	6.62	78	15.8	5.4	19.3	4.9	14.1	0.4	13.0	7	219	3.4	62	1.4	14.93	1.91	13.20	12.87	1.28	42.85	22.89	0.423	7.2	**Fra su**
Edl su	20.96	40	20.6	208.0	1.2	6.99	83	19.9	5.4	17.6	4.8	18.8	1.3	7.3	28	322	2.4	17	3.0	10.62	1.38	13.07	13.51	1.16	28.33	14.95	0.285	7.3	**Edl su**
Ste au	8.73	30	21.6	244.0	0.7	10.07	122	24.9	2.9	10.7	3.4	30.7	1.0	4.8	1	219	1.2	21	1.3	17.73	1.73	9.61	5.96	1.16	37.11	30.63	0.262	9.0	**Ste au**
Win au	49.27	45	20.0	138.4	0.6	7.96	94	10.8	2.3	9.1	2.9	12.5	1.0	5.8	6	159	5.2	15	2.5	9.53	1.00	31.29	4.26	1.33	18.09	16.70	1.125	7.8	**Win au**
Ede au	3.13	75	20.2	134.9	0.5	11.17	131	9.3	2.8	8.7	3.0	9.8	2.4	10.3	2	53	13.0	20	3.0	3.53	0.44	9.70	5.10	1.31	7.26	5.45	0.111	8.7	**Ede au**
Str au	2.76	40	19.7	167.2	1.3	3.25	38	7.0	3.4	16.0	4.5	5.6	1.1	6.6	6	331	4.0	11	2.0	16.38	1.73	11.48	15.98	1.34	42.82	25.70	0.320	7.6	**Str au**
Neu au	4.36	28	20.7	412.0	1.5	8.40	100	38.2	4.6	25.0	5.5	58.3	5.4	9.0	1	210	0.8	12	0.7	11.99	1.26	9.71	16.80	1.02	49.60	22.19	0.179	8.3	**Neu au**
Bru au	30.00	51	19.6	62.3	0.3	9.96	115	4.2	1.9	5.3	1.8	3.8	2.0	3.9	2	107	1.6	27	0.5	11.27	1.02	14.66	3.64	0.97	20.68	19.78	0.147	9.1	**Bru au**
Bra au	15.22	110	19.8	60.9	0.2	9.08	105	4.9	2.3	3.4	1.6	3.5	1.0	8.5	2	73	1.2	44	1.5	6.89	0.69	12.68	1.42	0.82	11.98	11.59	0.389	8.7	**Bra au**
Has au	50.00	58	20.7	154.0	0.9	7.92	94	9.8	3.3	12.8	4.0	10.7	0.9	8.4	4	123	3.5	21	1.4	7.02	0.80	19.53	8.62	1.23	15.10	12.00	0.217	7.9	**Has au**
Geb au	57.00	32	23.0	136.1	0.9	11.08	138	8.2	3.3	10.7	3.7	7.8	1.9	10.1	1	166	1.9	22	1.3	19.35	1.94	17.10	6.87	1.18	42.60	32.95	0.369	9.4	**Geb au**
Moo au	3.00	25	18.3	158.3	0.4	7.52	85	10.8	2.6	13.4	4.1	14.5	5.9	12.0	16	91	43.8	179	9.7	5.26	0.53	51.54	2.27	3.47	15.53	10.38	0.108	8.1	**Moo au**
Hof au	15.00	34	19.2	190.0	1.3	11.55	132	9.4	4.4	16.2	4.8	11.2	5.3	10.2	2	126	1.3	23	2.7	18.23	2.35	9.99	9.95	1.03	30.94	29.52	0.559	10.0	**Hof au**
Pur au	21.20	52	19.2	188.0	1.0	9.64	110	11.7	4.7	15.9	4.2	12.6	3.2	9.4	0	106	0.9	18	0.3	9.41	1.25	11.78	12.05	1.06	17.64	15.03	0.218	9.0	**Pur au**
Alt au	19.00	35	19.6	172.0	1.0	10.37	119	11.5	4.5	13.1	3.8	13.4	0.6	7.5	2	157	1.0	32	0.4	16.60	2.37	12.04	9.44	1.16	28.05	24.76	0.507	9.7	**Alt au**
Fra au	26.58	35	19.5	193.8	1.3	8.82	101	11.4	5.0	17.0	4.3	11.0	1.3	9.5	6	220	0.9	44	0.5	16.72	2.43	11.59	13.06	1.16	34.94	27.46	0.681	9.0	**Fra au**
Edl au	20.96	38	19.5	182.4	1.0	7.06	81	13.8	4.7	13.3	4.0	14.3	0.9	6.5	3	224	1.2	60	0.7	14.56	1.99	12.84	11.44	1.23	36.18	23.84	0.400	8.6	**Edl au**

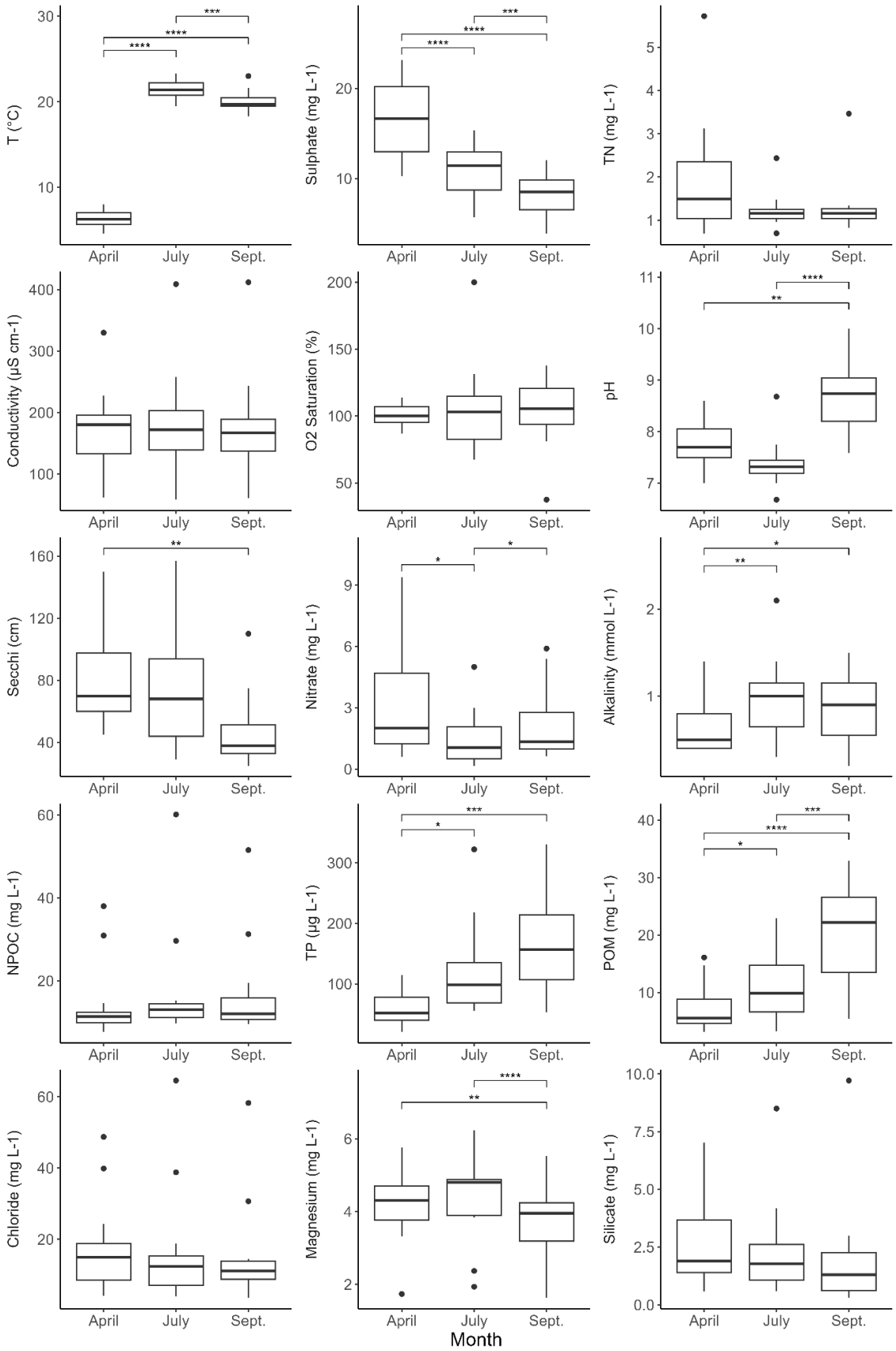

Fig. 6. Boxplots of selected environmental parameters over the year. Bold black horizontal bars indicate medians (50th percentiles), upper and lower box outlines show first and third quartiles (25th and 75th percentiles), whiskers extend to the smallest or largest data points before the upper or lower fences which are defined as third quartile plus or first quartile minus 1.5 * IQR (inter-quartile range = distance between the first and third quartiles of the hinge). Black dots are outliers (smaller or larger than 1.5*IQR). Abbreviations: T = Temperature; TN = Total nitrogen; NPOC = non-purgeable organic carbon; TP = Total phosphorus; POM = Particulate organic matter. Significance levels: not significant = not shown, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, **** = $p < 0.0001$.

For a subsequent analysis of environmental variables, strongly correlated or redundant variables were excluded to prevent multicollinearity, keeping 18 variables (Sodium, Potassium, Calcium, Magnesium, Chloride, Nitrate, Sulphate, P-PO_4, TP, N-NO_2, N-NH_4, Si-SiO_4, NPOC, pH, T, Conductivity, Secchi, Alkalinity). The BEST bioenv permutation analysis identified Magnesium, Chloride, Nitrate, NPOC, Secchi-depth and Alkalinity as the variables best explaining the abiotic dissimilarities between the ponds, based on a correlation coefficient of 0.9088. A subsequent cluster analysis based on these six environmental key factors revealed seven significant clusters, using the SIMPROF permutation test (10% significance level with 999 permutations). Letters A - G were assigned to the clusters for further analyses and referencing (Fig. 7). The trios of samples taken from Neuteich (Neu; Cluster A) and Moorbad Schrems (Moo; Cluster B) created specific monotopic clusters, separate from all other clusters. Cluster C includes the spring sample of Edelwehrteich (Ede), when the pond was overflowing the dam. The three samples from Brandteich (Bra) cluster together with the autumn sample of Edelwehrteich (Ede au) and the summer and autumn samples of Brüneiteich (Bru) (= cluster D). Cluster G at the right side of the plot consists of the spring and summer samples of Streitteich (Str), together with the spring samples of Pürbacher Teich (Pur) and Steinbruckteich (Ste). The three samples of Winkelauer Teich (Win) create the monotopic cluster E, next to the large cluster F with all the remaining ponds and sampling dates (Fig. 7, Tab. 4).

The clusters partly reflect the spatial distribution of the studied ponds, with samples from the north-west as well as the south-east of the study region clustering together. The two ponds west of Heidenreichstein (Bra, Bru) and one sample from Ede in the settlement area of Heidenreichstein are contained within cluster D. Cluster F contains all the samples taken in the vicinity of Pürbach, except for Pur sp, as well as all the samples from Schrems aside from the three samples taken at Moo. Two of the three clusters, each of which contains samples from a single pond (Cluster A, B and E), are located in settlements: Cluster A (Neu) in Heidenreichstein, Cluster B (Moo) in Schrems. Furthermore, Moo (Cluster B) and Win (Cluster E) include bogs in their respective catchment areas.

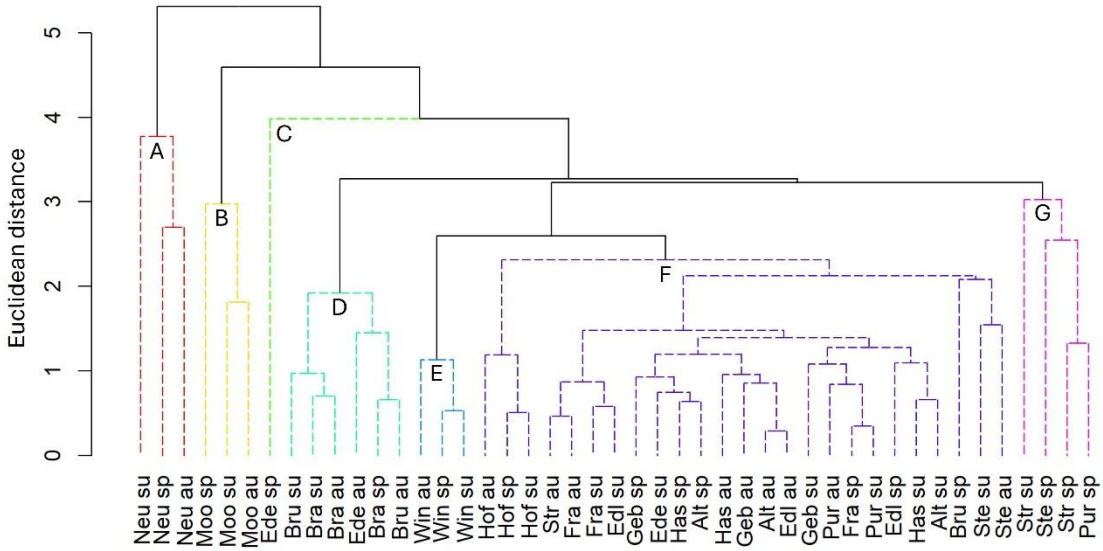

Fig. 7. Cluster analysis with the environmental factors identified by the BEST bioenv function: Each colour represents a significant cluster identified by the SIMPROF function (999 permutations, significance level set to 10%); insignificant separations are shown as dashed lines. Labels correspond to abbreviations given in Tab. 1, suffix sp = spring, su = summer, au = autumn. Letters A-G were assigned to the clusters for further referencing.

Tab. 4. Synopsis of the seven clusters (A-G) with the assigned samples. Labels correspond to abbreviations given in Tab. 1; suffix sp = spring, su = summer, au = autumn.

Cluster	**A**	**B**	**C**	**D**	**E**	**F**		**G**
Ponds	Neu sp	Moo sp	Ede sp	Bra sp	Win sp	Alt sp	Alt su	Pur sp
	Neu su	Moo su		Bra su	Win su	Alt au	Bru sp	Ste sp
	Neu au	Moo au		Bra au	Win au	Ede su	Edl sp	Str sp
				Bru su		Edl au	Edl su	Str su
				Bru au		Fra sp	Fra su	
				Ede au		Fra au	Geb sp	
						Geb su	Geb au	
						Has sp	Has su	
						Has au	Hof sp	
						Hof su	Hof au	
						Pur sp	Pur au	
						Ste su	Ste au	
						Str au		

An analysis of similarities (ANOSIM; 9999 permutations), based on the six key variables identified by the BEST bioenv function, revealed significant differences between the individual ponds ($R = 0.557$, $r < 0.001$) over the sampling period, but no significant

differences between the seasons (r = 32.1/0.32). Non-metric multidimensional scaling (NMDS), based on the six selected environmental key factors, revealed a strong spatial separation between the calculated clusters (Fig. 8). Clusters A and B are widely separated from the rest of the ponds, indicating that both Neuteich (Neu) and Moorbad Schrems (Moo) differ strongly from the other sites over all 3 sampling dates. Cluster C including Edelwehrteich (Ede (3)) in spring as well as cluster G are placed apart from the other ponds along the NMDS2 axis. Cluster E, consisting of the three Winkelauer Teich (Win (2)) samples, is located near the centre of the NMDS and close to the larger clusters D and F. Cluster F with the largest number of ponds occupies the centre of the plot with smaller distances between individual samples. Although clusters D, E and F are positioned close to each other, they remain distinct clusters with little overlap in between.

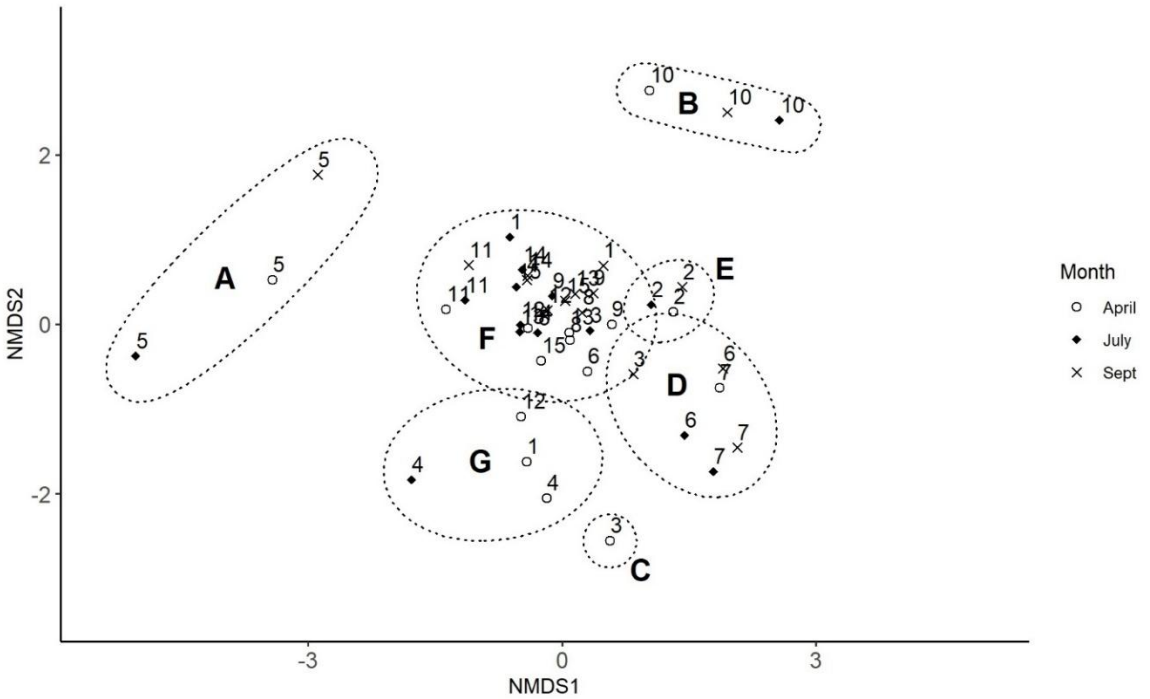

Fig. 8. Non-metric multidimensional scaling (NMDS) of the sampled ponds over the seasons, calculated with the six environmental variables selected by the BEST bioenv function. Numbers correspond to pond IDs in Tab. 1. Dashed circles indicate clusters identified by the SIMPROF cluster analysis; Bold letters correspond to the clusters defined in Tab. 4. Stress: 0.136821.

The mean, minimum and maximum values for the six key variables within each cluster are summarized in Tab. 5. The LINKTREE analysis identified the crucial factors for the division of the clusters. Cluster A differs from the other samples by higher chloride values. The concentrations of chloride in the three Neuteich samples range from 48 to 65 mg L^{-1}, with no other pond reaching concentrations of over 40 mg L^{-1}. The three samples of

Moorbad Schrems in cluster B are characterized by their significantly higher concentrations of NPOC, ranging from 38 to 61 mg L^{-1}, compared to 8 to 31 mg L^{-1} for all other samples. The single spring sample of Edelwehrteich is distinguished from the other clusters by the low concentration of NPOC (8.23 mg L^{-1}) as well as higher nitrate concentration (9.35 mg L^{-1}) compared to the remaining clusters D-G. Cluster D has lower magnesium values from 1.6 to 3 mgL^{-1}, as well as chloride concentrations below 4.11 mg L^{-1}. Compared to NPOC concentrations of clusters F and G which are below 20 mg L^{-1}, the NPOC values in Cluster E are higher with around 30 mg L^{-1} at all three sampling dates. Finally, transparency was higher in the ponds of cluster G than in the ponds of cluster F, with Secchi-depth readings ranging from 115 to 157 cm in the former.

Tab. 5. Mean, minimum (min) and maximum (max) of the six environmental key variables identified by the BEST bioenv function for clusters A – G. NPOC = non purgeable organic carbon. Discriminatory factors (LINKTREE analysis) for the clusters in bold.

Cluster	Magnesium (mg L^{-1})			Chloride (mg L^{-1})			Nitrate (mg L^{-1})			NPOC (mg L^{-1})			Secchi-depth (cm)			Alkalinity (mmol L^{-1})		
	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max	min	mean	max
A	5.53	5.78	6.23	**48.75**	**57.19**	**64.56**	2.15	5.40	8.66	8.92	9.72	10.51	28	91.0	140	1.4	1.67	2.1
B	3.95	4.08	4.17	9.84	12.31	14.49	2.34	5.88	9.40	**38.01**	**49.89**	**60.13**	25	38.0	60	0.4	0.47	0.6
C	3.32	3.32	3.32	8.76	8.76	8.76	**9.35**	**9.35**	**9.35**	**8.23**	**8.23**	**8.23**	90	90.0	90	0.4	0.40	0.4
D	**1.63**	**2.08**	**2.96**	**3.52**	**4.88**	**9.75**	0.28	1.26	2.37	9.70	12.27	14.76	51	90.2	130	0.2	0.37	0.5
E	2.90	3.41	3.83	12.51	14.83	16.61	1.00	1.26	1.73	**29.64**	**30.62**	**31.29**	45	61.0	70	0.4	0.50	0.6
F	3.41	4.44	5.76	5.63	14.34	38.79	0.22	1.90	5.58	9.61	12.46	19.53	30	51.1	85	0.5	0.96	1.3
G	3.72	4.62	5.29	6.59	17.43	39.86	0.16	1.62	3.32	7.70	10.20	11.97	**115**	**136.8**	**157**	0.4	0.75	1.4

4.2 Biotic parameters

4.2.1 Cladocera taxa composition, abundance and diversity

Total abundances of Phyllopoda in the study ponds (individuals L^{-1}) are shown in Appendix Tab. A 1. Abundance ranged from 0.1 in Edelwehrteich in spring up to 1762.1 in autumn in Streitteich. In total, 24 Cladoceran species were observed over the three sampling dates (Tab. 6; Fig. 9). The most common species was *Bosmina longirostris* (O.F. Müller, 1785) occurring in 40 of 45 samples (steadiness 89%), followed by *Daphnia galeata* Sars, 1863 (36 samples; 80%), *Chydorus sphaericus* (O.F. Müller, 1776) (28 samples; 62%) and *Ceriodaphnia pulchella* Sars, 1862 (26 samples; 58%). Five species were found in single samples only: *Alona quadrangularis* (O.F. Müller, 1776) only occurred in the summer

samples of Gebhartsteich, *Alonopsis elongata* (Sars, 1861) in autumn in Winkelauer Teich, *Pleuroxus denticulatus* Birge, 1879 in summer in Edelwehrteich, *Pleuroxus uncinatus* Baird, 1850 in autumn in Neuteich, and *Scapholeberis mucronata* (O.F. Müller, 1776) only in the autumn sample in Althöllteich. Cladoceran species richness was higher in the summer months, with 19 species in July, followed by 18 in September and 12 in April. While the most common species like *B. longirostris* and *D. galeata* occurred over the entire sampling period, twelve species occurred only in the summer months (Tab. 6). Furthermore, *B. longirostris* was the most prevalent species at each sampling date. *Daphnia longispina* (O.F. Müller, 1776) occurred in 11 ponds in April but only in two ponds in July and three ponds in September.

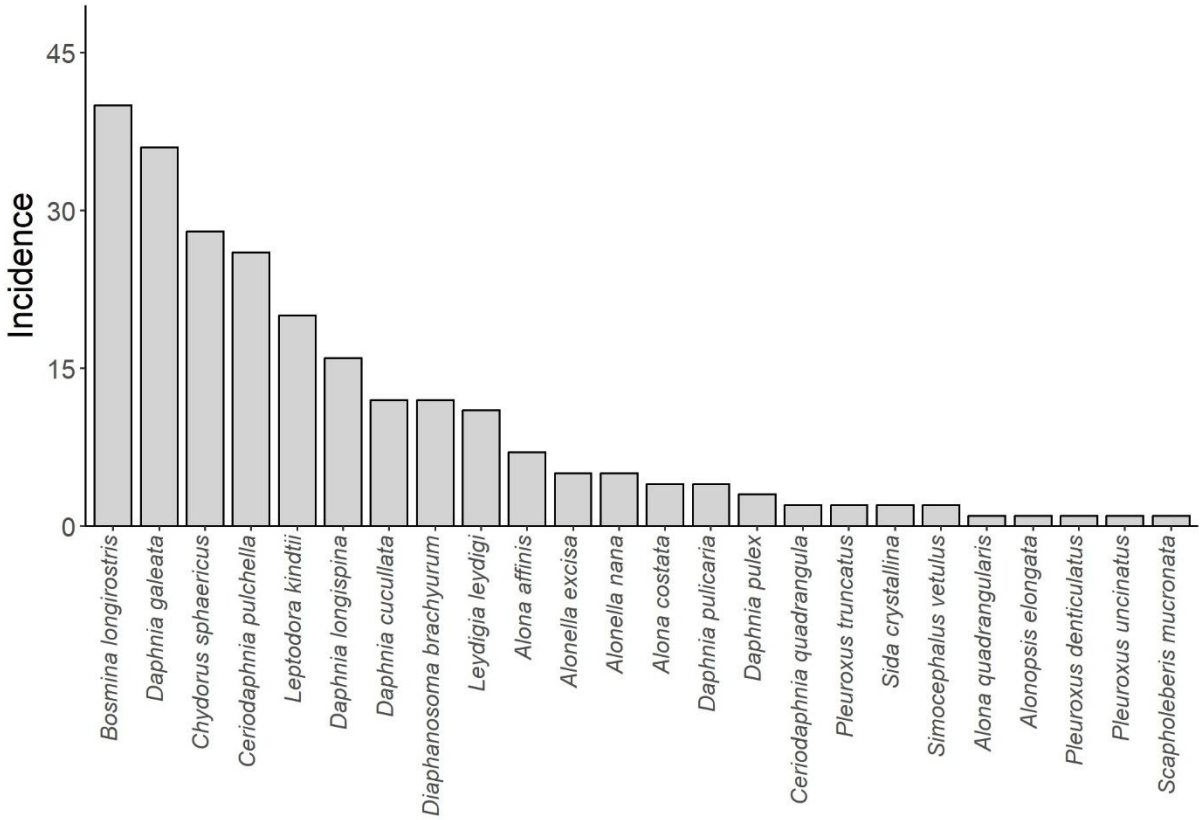

Fig. 9. Incidence plot (number of samples where a given taxon was found) of all observed species summed up over all ponds and sampling dates.

B. longirostris was the most abundant species, both in overall abundance, as well as in peak abundances in individual samples. The mean abundance across all samples was 127 Ind. per L^{-1}. There were three samples with abundances above 1000 Ind. L^{-1} of *B. longirostris* at Streitteich and Neuteich in September (Str au and Neu au) and in Edelwehrteich in July (Edl su).

Abundances of the individual species varied strongly over time, with significantly higher abundances in July and September (Tab. 6). The mean abundance of Cladocera per pond was 8 Ind. L^{-1} in April, whereas abundance was up to 204 Ind. L^{-1} in July and 265 Ind. L^{-1} in September. The highest densities of Cladocera in April were found in Althöllteich with 33 Ind. L^{-1} and Edlauerteich with 18 Ind. L^{-1}, whereas the lowest density was found in Edelwehrteich with 0.1 Ind. L^{-1} (2 specimens found in the 20 L sample). In July, Edlauerteich was again the pond with the highest abundance of Cladocera with 1489 Ind. L^{-1}, the lowest abundances were found in Moorbad Schrems (1.35 Ind. L^{-1}) and Gebhartsteich (1.6 Ind. L^{-1}). In September the two ponds with the highest Cladoceran abundances (Streitteich: 1762 Ind. L^{-1}; Neuteich: 1241 Ind. L^{-1}) coincided with mass occurrences of *B. longirostris*. The lowest abundances were found at Winkelauer Teich (2.4 Ind. L^{-1}) and Pürbacher Teich (3 Ind. L^{-1}).

Based on qualitative samples, 15 mass occurrences = (abundance class 5) could be observed (Tab. 7): one of them occurred in April, eight in July, and six in September. There were six mass occurrences of *D. galeata* and five of *B. longirostris*. For *C. sphaericus* and *C. pulchella*, abundance class 5 was recorded twice. No other species were found in such high abundances. The sample with the highest density was taken in summer at Frauenteich with mass occurrences of *B. longirostris*, *C. sphaericus* and *D. galeata*.

Tab. 6. Taxa composition of Cladocera in 15 Waldviertel fishponds in 2021, showing absolute abundances (Ind. L^{-1}) of all species. Species missing in the quantitative samples but present in the qualitative samples were assigned an abundance of <0.05. Labels correspond to abbreviations of ponds given in Tab. 1; Suffix sp = spring, su = summer, au = autumn.

Label	*Alona affinis* (Leydig, 1860)	*Alona costata* Sars, 1862	*Alona quadrangularis* (O.F. Müller, 1776)	*Alonella excisa* (Fischer, 1854)	*Alonella nana* (Baird, 1843)	*Alonopsis elongata* (Sars, 1861)	*Bosmina longirostris* (O.F. Müller, 1785)	*Ceriodaphnia pulchella* Sars, 1862	*Ceriodaphnia quadrangula* (O.F. Müller, 1785	*Chydorus sphaericus* (O.F. Müller, 1776)	*Daphnia cucullata* Sars, 1862	*Daphnia galeata* Sars, 1863	*Daphnia longispina* (O.F. Müller, 1776)	*Daphnia pulex* Leydig, 1860	*Daphnia pulicaria* Forbes, 1893	*Diaphanosoma brachyurum* (Liévin, 1848)	*Leptodora kindtii* (Focke, 1844)	*Leydigia leydigi* (Schödler, 1863)	*Pleuroxus denticulatus* Birge, 1879	*Pleuroxus truncatus* (O.F. Müller, 1785)	*Pleuroxus uncinatus* Baird, 1850	*Scapholeberis mucronata* (O.F. Müller, 1776)	*Sida crystallina* (O.F. Müller, 1776)	*Simocephalus vetulus* (O.F. Müller, 1776)
Ste sp	0	0	0	0	0	0	0	0	0	<0.05	0	0.40	0.10	<0.05	0	0	0	0	0	0	0	0	0	0
Win sp	0	0	0	0	<0.05	0	0.20	0.05	0	0	0	0.75	15	0	0	0	0	0	0	0	0	0	0	0
Ede sp	0	0	0	0	<0.05	0	0.10	<0.05	0	<0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Str sp	0	0	0	0	0.05	0	3.05	0	0.05	0	0	<0.05	0	0	0	0	0	0	0	0	0	0	0	0
Neu sp	0	0	0	0	0	0	0.10	0.40	0	0	0	0	0.15	0.30	0.15	0	0	0	0	0	0	0	0	0
Bru sp	0	0	0	0	0	0	3.25	0	0	<0.05	0	2.55	1.85	0	0	0	0	0	0	0	0	0	0	0
Bra sp	0	0	0	0	0	0	2.15	0.55	0	<0.05	0	0.40	0.50	<0.05	0	0	0	0	0	0	0	0	0	0
Has sp	0	0	0	0	0	0	4.30	0.05	0	0.30	0	6.15	0.50	0	0	0	0	0	0	0	0	0	0	0
Geb sp	0	0	0	0	0	0	1	0	0	0.20	0	0.95	0.10	0	0	0	0	0	0	0	0	0	0	0
Moo sp	<0.05	0	0	0	0	0	2.40	0	0	0	0	0	0	0	0.05	0	0	<0.05	0	0	0	0	0	0
Hof sp	0	0	0	0	0	0	3.15	0	0	0	0.15	0.50	0	0	0	0	0	0	0	0	0	0	0	0
Pur sp	0	0	0	0	0	0	3	0	0	0	0	2	0.20	0	0	0	0	0	0	0	0	0	0	0
Alt sp	0.20	0	0	0	0	0	15.75	0	0	0.60	<0.05	11.50	4.45	0	0	0	0	0.25	0	0	0	0	0	0
Fra sp	0	0	0	0	0	0	0.50	0	0	0.15	0	3.10	0.05	0	0	0	0	0.20	0	0	0	0	0	0
Edl sp	0	0	0	0	0	0	1.95	0.30	0	0.20	0	14.60	0.15	0	0	0	0	1.55	0	0	0	0	0	0
Ste su	0	<0.05	0	0	0	0	0.05	1.40	0	0	0	92.05	0	0	0	0	0	0	0	0	0	0	0	0.05
Win su	0	0	0	0	0	0	0.10	0	0	0	0.50	5	0	0	0	0.70	0.35	0	0	0	0	0	0	0
Ede su	0.05	<0.05	0	0.1	<0.05	0	2.20	0.55	0	0.4	0	0	0	0	0	0.15	<0.05	0	0.15	0	0	0	0	0
Str su	0	0	0	0	0	0	0.15	0	1	0.05	0	3.55	0	0	0	0	0	0	0	0	0	0	0	0
Neu su	0	0	0	0	0	0	0.10	92.10	0	0.5	0	184	2.35	0	0	0	0	0	0	0	0	0	0	0
Bru su	0	0	0	0	0	0	0.25	0.30	0	0	0	5.30	0	0	0	0	0.10	0	0	0	0	0	0	0
Bra su	0	0	0	0	<0.05	0	2.95	11.75	0	0	0	0	0	0	0	0.95	<0.05	0	0	0	0	0	0	0
Has su	0	0	0	0	0	0	0	0	0	0	0	191	0.35	0	0.10	0	1.85	0	0	0	0	0	0	0
Geb su	0	0	<0.05	0	0	0	0.75	0	0	<0.05	0	0.50	0	0	0	0	0.25	0.10	0	0	0	0	0	0
Moo su	0.10	0	0	0.05	0	0	0.05	0	0	0	0.25	0	0	0	0	0.50	<0.05	0.35	0	0.05	0	0	0	0
Hof su	0	0	0	0	0	0	0.65	0	0	<0.05	40.20	2.35	0	0	0	20.35	2.30	0.05	0	0	0	0	0	0
Pur su	0	0	0	0	0	0	0.05	0.05	0	0.05	0.70	0.05	0	0	0	1.75	0.10	0	0	0	0	0	0	0
Alt su	0.05	0	0	0	0	0	0.90	0	0	0.25	0	35.60	0	0	0	0	<0.05	<0.05	0	0	0	0	0	0
Fra su	0	0	0	0	0	0	648	0.10	0	60.9	0	141	0	0	0	0	0.10	3	0	0	0	0	0	0
Edl su	0	0	0	0	0	0	1321	6.30	0	43.15	0	116	0	0	0	0	3.10	0.45	0	0	0	0	0	0.05
Ste au	0	0	0	0	0	0	0.15	28.80	0	0	0	19.05	2.40	0	<0.05	0	0	0	0	0	0	0	0	0
Win au	0	<0.05	0	0	0	<0.05	0.55	0.55	0	0	0.15	1.15	0	0	0	0	0	0	0	0	0	0	0	0
Ede au	<0.05	0	0	<0.05	0	0	6.20	0.05	0	0.20	0	0	0	0	0	0	0	0	0	0	0	0	<0.05	0
Str au	0	0	0	0	0	0	1758	0.15	0	0.10	0	2.95	0.45	0	0	0	0	0	0	0	0	0	0	0
Neu au	0	0	0	0	0	0	1176	41.95	0	0.15	0	21.95	1.30	0	0	0	0	0	0	0	0.10	0	0.05	0
Bru au	0	0	0	0	0	0	42.70	0.10	0	0.10	<0.05	1.75	0	0	0	2	0.95	0	0	0	0	0	0	0
Bra au	0	0	0	0	0	0	0.30	64.95	0	0	0.25	0.35	0	0	0	0.20	0.20	0	0	0	0	0	0	0
Has au	0	0	0	0	0	0	0	3.25	0	0	0	27.15	0	0	0	0	0.05	0	0	0	0	0	0	0
Geb au	0	0	0	<0.05	0	0	0	0.30	0	0.20	2.45	0.45	0	0	0	1.05	3.20	0	0	0	0	0	0	0
Moo au	0.40	0	0	<0.05	0	0	4.60	0.60	0	0	0.3	0	0	0	0	0.30	<0.05	0.10	0	<0.05	0	0	0	0
Hof au	0	0	0	0	0	0	1.50	0	0	0.40	11.25	0.65	0	0	0	0.10	8.95	0	0	0	0	0	0	0
Pur au	0	0.10	0	0	0	0	2.50	0.10	0	0.20	0	0	0	0	0	<0.05	0.10	0	0	0	0	0	0	0
Alt au	0	0	0	0	0	0	77.80	0	0	25.95	0	8.85	0	0	0	0	<0.05	0	0	0	0	<0.05	0	0
Fra au	0	0	0	0	0	0	0	0	0	377	0	66.25	0	0	0	0	0	0	0	0	0	0	0	0
Edl au	0	0	0	0	0	0	1.10	4.90	0	0.35	0	171	0	0	0	0	0	0	0	0	0	0	0	0

Tab. 7. Taxa composition of Cladocera in 15 Waldviertel fishponds in 2021, showing relative abundances of all sampled species. Sp = spring, su = summer, au = autumn. Labels correspond to abbreviations of ponds given in Tab. 1. Abundance classes 1 range from 1 (= sporadically, very rare) to 5 (very high abundance, mass occurrence), following the procedure given by Wawrik (1966).

Label	*Alona affinis* (Leydig, 1860)	*Alona costata* Sars, 1862	*Alona quadrangularis* (O.F. Müller, 1776)	*Alonella excisa* (Fischer, 1854)	*Alonella nana* (Baird, 1843)	*Alonopsis elongata* (Sars, 1861)	*Bosmina longirostris* (O.F. Müller, 1785)	*Ceriodaphnia pulchella* Sars, 1862	*Ceriodaphnia quadrangula* (O.F. Müller, 1785)	*Chydorus sphaericus* (O.F. Müller, 1776)	*Daphnia cucullata* Sars, 1862	*Daphnia galeata* Sars, 1863	*Daphnia longispina* (O.F. Müller, 1776)	*Daphnia pulex* Leydig, 1860	*Daphnia pulicaria* Forbes, 1893	*Diaphanosoma brachyurum* (Liévin, 1848)	*Leptodora kindtii* (Focke, 1844)	*Leydigia leydigi* (Schödler, 1863)	*Pleuroxus denticulatus* Birge, 1879	*Pleuroxus truncatus* (O.F. Müller, 1785)	*Pleuroxus uncinatus* Baird, 1850	*Scapholeberis mucronata* (O.F. Müller, 1776)	*Sida crystallina* (O.F. Müller, 1776)	*Simocephalus vetulus* (O.F. Müller, 1776)
Ste sp	0	0	0	0	0	0	0	0	0	1	0	1	2	1	0	0	0	0	0	0	0	0	0	0
Win sp	0	0	0	0	1	0	1	1	0	0	0	2	4	0	0	0	0	0	0	0	0	0	0	0
Ede sp	0	0	0	0	2	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Str sp	0	0	0	0	1	0	3	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Neu sp	0	0	0	0	0	0	3	1	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0
Bru sp	0	0	0	0	0	0	3	0	0	1	0	2	2	0	0	0	0	0	0	0	0	0	0	0
Bra sp	0	0	0	0	0	0	2	1	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0
Has sp	0	0	0	0	0	0	4	1	0	2	0	3	2	0	0	0	0	0	0	0	0	0	0	0
Geb sp	0	0	0	0	0	0	4	0	0	3	0	3	2	0	0	0	0	0	0	0	0	0	0	0
Moo sp	1	0	0	0	0	0	3	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Hof sp	0	0	0	0	0	0	3	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Pur sp	0	0	0	0	0	0	5	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0
Alt sp	1	0	0	0	0	0	4	0	0	1	1	4	2	0	0	0	0	1	0	0	0	0	0	0
Fra sp	0	0	0	0	0	0	2	0	0	1	0	3	2	0	0	0	0	2	0	0	0	0	0	0
Edl sp	0	0	0	0	0	0	4	1	0	1	0	3	3	0	0	0	0	3	0	0	0	0	0	0
Ste su	0	1	0	0	0	0	1	2	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1
Win su	0	0	0	0	0	0	1	0	0	0	1	3	0	0	0	1	1	0	0	0	0	0	0	0
Ede su	1	1	0	1	1	0	2	1	0	3	0	0	0	0	0	1	2	0	1	0	0	0	0	0
Str su	0	0	0	0	0	0	2	0	2	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Neu su	0	0	0	0	0	0	1	5	0	1	0	5	1	0	0	0	0	0	0	0	0	0	0	0
Bru su	0	0	0	0	0	0	2	1	0	0	0	4	0	0	0	0	2	0	0	0	0	0	0	0
Bra su	0	0	0	0	1	0	2	3	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0
Has su	0	0	0	0	0	0	0	0	0	0	0	4	1	0	1	0	3	0	0	0	0	0	0	0
Geb su	0	0	1	0	0	0	2	0	0	2	0	2	0	0	0	0	4	1	0	0	0	0	0	0
Moo su	1	0	0	3	0	0	3	0	0	0	2	0	0	0	0	2	2	1	0	1	0	0	0	0
Hof su	0	0	0	0	0	0	2	0	0	2	5	2	0	0	0	3	4	1	0	0	0	0	0	0
Pur su	0	0	0	0	0	0	1	1	0	1	1	1	0	0	0	2	2	0	0	0	0	0	0	0
Alt su	1	0	0	0	0	0	2	0	0	2	0	4	0	0	0	0	2	1	0	0	0	0	0	0
Fra su	0	0	0	0	0	0	5	1	0	5	0	5	0	0	0	0	2	1	0	0	0	0	0	0
Edl su	0	0	0	0	0	0	5	1	0	3	0	5	0	0	0	0	3	1	0	0	0	0	0	1
Ste au	0	0	0	0	0	0	1	5	0	0	0	4	2	0	1	0	0	0	0	0	0	0	0	0
Win au	0	1	0	0	0	1	3	2	0	0	2	3	0	0	0	0	0	0	0	0	0	0	0	0
Ede au	1	0	0	1	0	0	3	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2	0
Str au	0	0	0	0	0	0	5	1	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0
Neu au	0	0	0	0	0	0	5	3	0	1	0	3	2	0	0	0	0	0	0	0	1	0	1	0
Bru au	0	0	0	0	0	0	3	1	0	2	2	2	0	0	0	2	2	0	0	0	0	0	0	0
Bra au	0	0	0	0	0	0	2	3	0	0	1	1	0	0	0	1	2	0	0	0	0	0	0	0
Has au	0	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	1	0	0	0	0	0	0	0
Geb au	0	0	0	1	0	0	0	1	0	1	3	3	0	0	0	2	4	0	0	0	0	0	0	0
Moo au	2	0	0	2	0	0	3	3	0	0	2	0	0	0	0	2	2	1	0	1	0	0	0	0
Hof au	0	0	0	0	0	0	1	0	0	1	3	2	0	0	0	1	4	0	0	0	0	0	0	0
Pur au	0	1	0	0	0	0	3	1	0	2	0	0	0	0	0	2	1	0	0	0	0	0	0	0
Alt au	0	0	0	0	0	0	4	0	0	3	0	3	0	0	0	0	2	0	0	0	0	1	0	0
Fra au	0	0	0	0	0	0	0	0	0	5	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Edl au	0	0	0	0	0	0	2	2	0	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0

Species richness varied strongly from pond to pond and between sampling dates: maxima of ten and nine species, respectively, were observed at Edelwehrteich in July (Ede su) and at Moorbad Schrems in September (Moo au), whereas lowest richness with only two species was detected at Frauenteich in September (Fra au). Pooled over the three sampling dates, richness was highest in Edelwehrteich and Gebhartsteich with 11 species, followed by Winkelauer Teich, Moorbad Schrems and Brandteich with nine species. Minimum species richness (seven species) was observed in four ponds (Frauenteich, Haslauer Teich, Höfentöckteich and Streitteich; Tab. A 2). The mean number of species was similar in all three vicinities. It was highest in Heidenreichstein at 9.14, while Schrems and Pürbach had 8.75 and 8.25 species per pond. However, there was no significant correlation between species richness and environmental factors as well as surface or age of the ponds. Shannon's H as well as Simpson's D was highest in Gebhartsteich (H = 1.80, D = 0.80), followed by Pürbacher Teich (H = 1.46, D = 0.68) and Höfentöckteich (H = 1.23, D = 0.62). Lowest diversity metrices were found at Streitteich (H = 0.03, D = 0.01) and Haslauer Teich (H = 0.25, D = 0.09) (Tab. A 2). With respect to pond groups (vicinities), Shannon's H (pooled over the three sampling dates for each pond) was lower in Heidenreichstein, and higher in Schrems and Pürbach (Fig. 10). However, no significant differences (P> 0.05) were found between the groups.

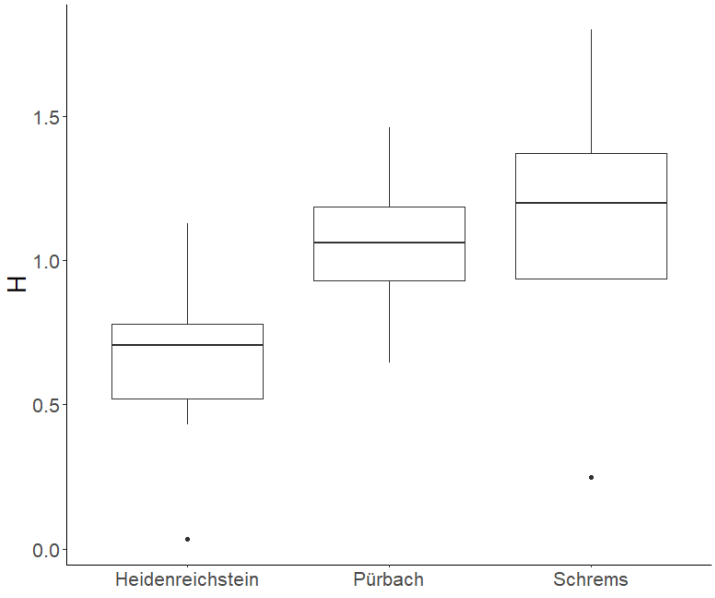

Fig. 10. Shannon diversity (H) of Cladocera in the 15 Waldviertel fish ponds, broken down into the three vicinities of Heidenreichstein, Pürbach and Schrems. Data pooled over the three sampling dates.

4.2.2 Cladocera communities

Variation in species composition was found to be higher over time (Fig. 11A) than between vicinities (Fig. 11B). A strong shift in composition was detected from spring (April samples) to summer (July samples) and autumn (September samples), whereas no clear gradient could be observed between summer and autumn (Fig. 11A). The analysis of similarities (ANOSIM; 9999 permutations with Bray-Curtis distance) results were significant for both temporal and spatial grouping variables. However, the calculated R value was higher for month (ANOSIM statistic R = 0.2346) than for region (ANOSIM statistic R = 0.0915). Since the clusters for July and September were not clearly separated, the ANOSIM was recalculated with the data obtained in the warmer months combined as a grouping variable (group 1 = April, group 2 = July and September). This procedure enhanced statistical power based on the grouping variable (ANOSIM statistic R = 0.2993). Another ANOSIM calculation was conducted with the abiotic clusters as grouping variables, resulting in an R value of 0.2782 ($p < 0.01$).

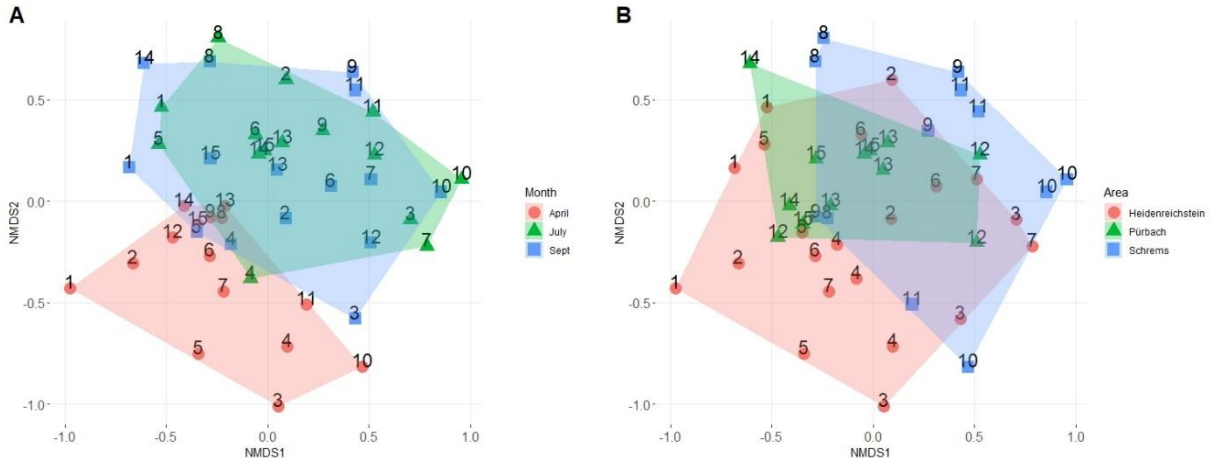

Fig. 11. Non-metric multidimensional scaling (NMDS; distance= Bray-Curtis, 2 dimensions), based on relative abundances given in Tab. 7. Labels correspond to pond-IDs listed in Tab. 1. 2D Stress: 0.201. **A**: Hulls plotted around all data points belonging to the same sampling date. ANOSIM results for month as a grouping variable: R = 0.2346, $p < 0.01$ (9999 permutations with Bray-Curtis distance) and for April and July + September as a grouping variable: R = 0.2993, $p < 0.01$ (9999 permutations with Bray-Curtis distance). **B**: Hulls plotted around all data points belonging to the same region, regardless of season. ANOSIM results for region as a grouping variable: R = 0.09153, p = 0.03 (9999 permutations with Bray-Curtis distance).

The indicator species analysis (ISA), based on relative abundance data for the clusters defined in Tab. 4, revealed four species with significant indicator values (IndVal) for single clusters. The three indicator species for cluster B were *A. affinis* (IndVal = 0.907; $p < 0.01$), *Leydigia leydigi* (Schödler, 1863) (IndVal = 0.833; $p < 0.05$) and *P. truncatus* (0.816; $p < 0.05$). *A. nana* was the only species with a significant indicator value (0.847; $p < 0.05$) for cluster C. No indicator species was detected for the remaining clusters. Two species were found to be indicator species for a combination of clusters: *D. galeata* (IndVal = 0.937) for clusters A, D, E, F and G, and *C. pulchella* (IndVal = 0.86) for clusters A, B, C, D and E. ISA calculations based on absolute abundances revealed *C. quadrangula* as indicator species for Cluster G (IndVal = 0.707, $p < 0.05$). *D. galeata* and *C. pulchella* again had significant indicator values for a combination of clusters: *C. pulchella* for clusters A and D, and *D. galeata* for clusters A, E and F.

In addition, indicator species analyses were conducted for the three groups of sampling sites (Heidenreichstein, Pürbach, Schrems). Based on relative abundances, indicator species were lacking. When using absolute abundances, two indicator species with significant indication values were detected: *C. pulchella* (IndVal = 0.801, $p < 0.05$) for the vicinity of Heidenreichstein and *C. sphaericus* (IndVal = 0.956, $p < 0.01$) for Pürbach. *L. kindtii* was found to be a significant indicator species for the Pürbach-Schrems pair (IndVal = 0.71, $p < 0.05$), although only occurring in July and September. *D. longispina* was the only species with a significant indicator value for April, valid both for relative and absolute abundances (IndVal = 0.757/0.752, $p < 0.01$), whereas indicator species were lacking for July and September. However, when pooling July and September, *L. kindtii* had a significant indicator value > 0.7 ($p < 0.01$) based on relative abundances, and *C. pulchella* (IndVal = 0.814, $p < 0.05$) based on absolute abundances. Additionally, for the July-September combination, *D. brachyurum* had a significant IndVal for the two warmer months ($p < 0.05$) which, however, was smaller than 0.7. A summary of all significant indicator species is given in Tab. 8.

Tab. 8. Summary of the indicator species analysis calculated with both relative and absolute abundances and for: the six environmental factors retained after the forward selection process (ordistep function); the three groups of sampling sites, (vicinities); and sampling months (April, July, September). Ind Val = indicator value, p = probability, n.s. = not significant. The sampling sites included in each cluster are shown in Tab. 4.

	Group	Species	Ind Val	p	IndVal	p
			with relative abundances		with absolute abundances	
Abiotic clusters	Cluster B	*Alona affinis*	0.907	0.005 **		n.s.
	Cluster B	*Leydigia leydigi*	0.833	0.010 **		n.s.
	Cluster B	*Pleuroxus truncatus*	0.816	0.040 *		n.s.
	Cluster C	*Alonella nana*	0.847	0.045 *		n.s.
	Cluster G	*Ceriodaphnia quadrangula*		n.s.	0.707	0.04 *
	Cluster A+D	*Ceriodaphnia pulchella*		n.s.	0.92	0.005 **
	Cluster A+B+C+D+E	*Ceriodaphnia pulchella*	0.86	0.025 *		n.s.
	Cluster A+E+F	*Daphnia galeata*		n.s.	0.938	0.04 *
	Cluster A+D+E+F+G	*Daphnia galeata*	0.937	0.005 **		n.s.
Vicinities	Heidenreichstein	*Ceriodaphnia pulchella*		n.s.	0.801	0.05 *
	Pürbach	*Chydorus sphaericus*		n.s.	0.956	0.005 **
	Pürbach+Schrems	*Leptodora kindtii*	0.710	0.025 *		n.s.
Month	April	*Daphnia longispina*	0.757	0.005 **	0.752	0.005 **
	July+September	*Leptodora kindtii*	0.816	0.005 **	0.683	0.025 *
	July+September	*Ceriodaphnia pulchella*		n.s.	0.814	0.030 *

Subsequently, two sets of constrained correspondence analyses (CCA) were performed. The first set was calculated with the six environmental key variables identified by the BEST permutation analysis (Magnesium, Chloride, Nitrate, NPOC, Secchi-depth and Alkalinity: Fig. 12). The model was significant ($p = 0.001$), explaining 14.58% (adjusted R2) of the differences in the species composition (total inertia = 2.6771). The first two axes are significant and display 57.52% of the constrained Eigenvalues. Among the included environmental variables magnesium ($p = 0.0592$) and alkalinity ($p = 0.1657$) did not contribute significantly to this model, whereas chloride contributed most ($F = 3.2266$; $p < 0.001$), followed by NPOC ($F = 2.6327$; $p < 0.01$) and nitrate ($F = 2.0202$; $p < 0.05$). The permutational tests ($n = 9999$) showed significant ($p < 0.05$) canonical coefficients for the other four variables.

The samples from cluster B are separated from all other samples and correlate positively with NPOC and nitrate concentrations, and negatively with the other included variables. The three samples of cluster A, as well as the single sample from cluster C, correlate positively with chloride and Secchi-depth, while the response to environmental key factors

is more scattered for the remaining groups. The two samples of clusters D and E in the upper left quadrant of Fig. 12, separated from the rest of the samples from their respective clusters, represent the only two spring samples of their clusters (Win sp and Bra sp). The large distance to the other samples suggests a seasonal shift in species composition within these clusters.

The species plot shows a strong differentiation of the Cladoceran species along the environmental variables (Fig. 13). As the most ubiquitous species, *B. longirostris* is positioned in the very centre of the plot. *Pleuroxus truncatus* (O.F. Müller 1785), *Alonella excisa* (Fischer, 1854), *Alona affinis* (Leydig, 1860) and *A. elongata* correlate with higher concentrations of NPOC. *P. truncatus* was only found at *Moo*, and *A. excisa*, and *A. affinis* were most abundant in this pond with the highest NPOC concentration throughout the sampling period. *P. uncinatus* and *Daphnia pulex* Leydig, 1860 were mostly found at higher chloride concentrations. The abundances of these two species, as well as *P. truncatus*, also correlate positively with nitrate concentrations. The occurrence of larger daphnids (*D. pulex*, *D. longispina*, *Daphnia pulicaria* Forbes, 1893) correlate with higher Secchi-depths, as they were more common in spring samples. In contrast, *Leptodora kindtii* (Focke, 1844) and *Diaphanosoma brachyurum* (Liévin, 1848) abundances correlate negatively with Secchi-depth and were more common in the warmer months. The effects of the two non-significant environmental variables alkalinity and magnesium act in the opposite direction to nitrate and NPOC.

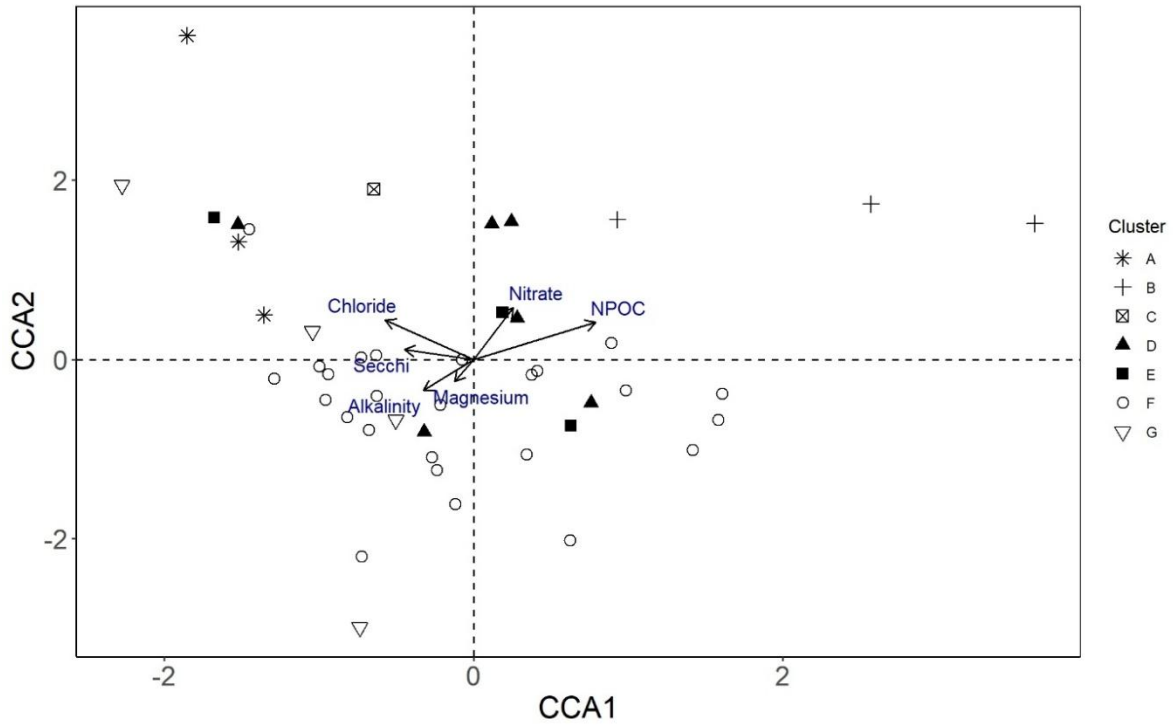

Fig. 12. CCA biplot with the six environmental key variables selected by the BEST bioenv function and the seven abiotic clusters visualized (A-G; Tab. 2). R2 = 0.2616, adjusted R2 = 0.1458, p = 0.001. Proportion explained by each axis: CCA1: 33.03% and CCA2: 24.49%.

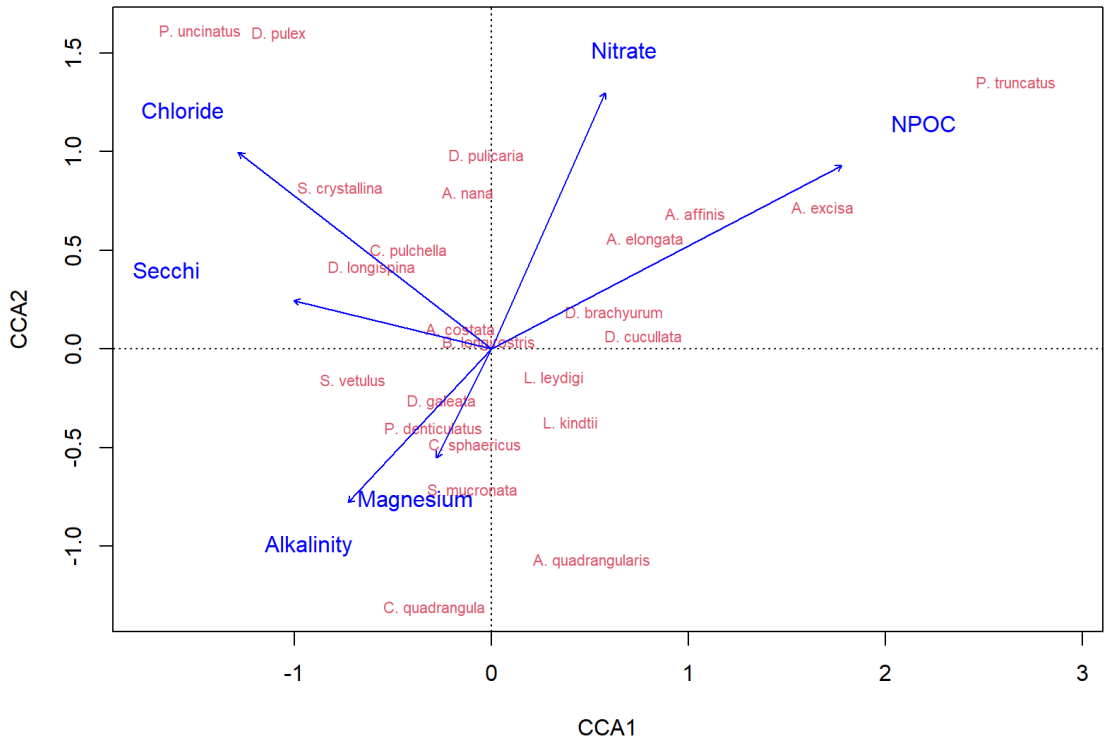

Fig. 13. CCA-biplot of the 24 Cladoceran species and their relation to the six environmental key variables selected by the BEST bioenv function.

For the second CCA set, all environmental variables, fish stocking and chlorophyll A concentrations (as a proxy for algal biomass), were included, and after forward selection (*ordistep* function), three of the 27 variables were returned as significant ($p < 0.05$) and retained: temperature, fish stocking, and silicate. The model had an adjusted R^2 of 0.1676 ($p = 0.001$) and, therefore, explains a slightly higher proportion of inertia in the species data (Fig. 14). The total inertia of the CCA was 2.6771; both displayed axes are significant ($p = 0.001$) and explain 80.47% of the constrained inertia.

The three retained variables affect the species composition in different directions. Temperature was the strongest driver with the highest contribution ($F = 4.6041$; $p < 0.001$) – further validating the seasonal shift observed in Fig. 11. While there is almost no overlap between spring samples and all other samples, samples from July and September show no clear separation along the two axes or the temperature gradient. Silicate ($F = 3.4808$; $p < 0.001$) and fish stocking ($F = 3.4445$; $p < 0.001$) had similar contribution to the model. The three samples of Moo (Moo sp, Moo su, Moo au) as well as Ede (Ede sp, Ede su, Ede au) show a strong positive correlation with silicate. All other samples are dispersed over a smaller distance along the silicate gradient, indicating a strong effect at high silicate concentrations, whereas impact at lower concentrations seems negligible. The large distances to the rest of the samples further indicate distinct and different species communities at Moo and Ede. The summer and autumn samples of the Cladoceran communities of the three ponds not used for carp farming (Hof, Ede, Moo) correlate negatively with fish stocking and are positioned furthest to the right along the x-axis, together with the samples of two larger ponds (Geb, Pur), both used as yielding ponds. On the other end of the fish stocking gradient, the samples from Str, Neu and Ste appear to be strongly affected by high abundance of fish over all sampling dates. All three are used as growing ponds with a high stocking density of carp.

The CCA showing the species scores and the three forward selected environmental variables indicates that the species are more spread out along the silicate and fish stocking gradients than along the temperature gradient (Fig. 15). The most common species *B. longirostris*, *C. sphaericus* and *C. pulchella* are positioned at the centre of the biplot. The species preferring higher temperatures include *L. kindtii* and *D. brachyurum*, which were only found in July and September, as well as *S. mucronata* (Alt au), *P. denticulatus* (Ede su), and *A. quadrangularis* (Geb su), which were only found in single samples in July or September. Colder temperatures correlate with species more common in spring: mainly

large daphniids (*D. pulex, D. pulicaria* and *D. longispina*) and *Alonella nana*. The majority of the species are found at higher values along the temperature gradient. *P. truncatus*, *A. excisa* and *A. affinis* correlate with concentrations of silicate – similar to the first CCA and NPOC concentrations (Fig. 13), while the rest of the species show little differentiation along the silicate gradient. The species correlating with higher silicate concentrations also correlate negatively with fish stocking numbers. Other species preferring lower abundance of fish were *P. denticulatus* and *P. truncatus*, *Daphnia cucullata* Sars 1862, *D. brachyurum*, and *L. kindtii*. *D. pulex*, *P. uncinatus*, *D. longispina*, and *Ceriodaphnia quadrangula* (O.F. Müller, 1785) were more abundant in samples with high stocking numbers.

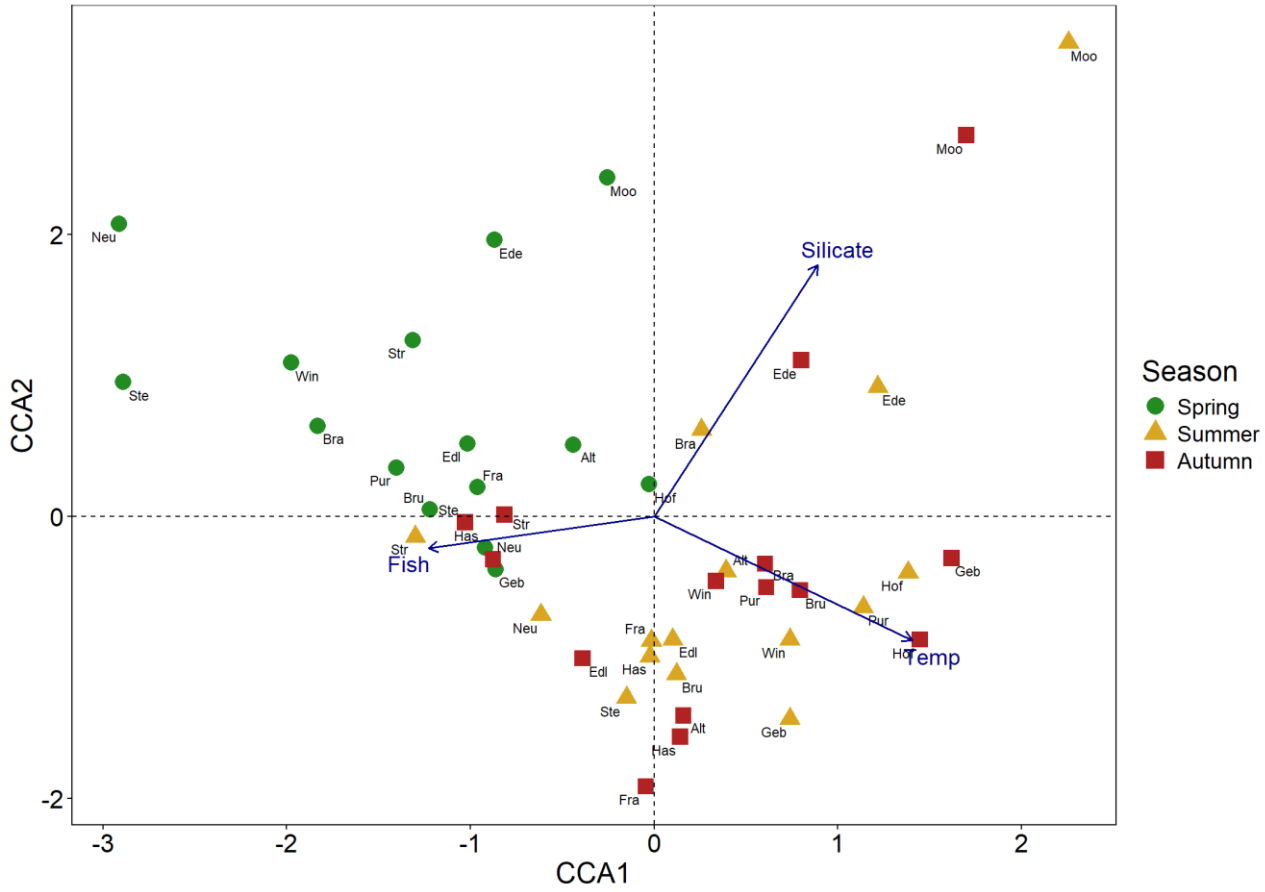

Fig. 14. CCA biplot, showing the sampling sites with the three retained significant ($p < 0.05$) environmental variables identified by forward selection with the *ordistep* function. $R^2 = 0.2240$, adjusted $R^2 = 0.1676$, $p = 0.001$. Proportion explained by axis CCA1: 51.77%, axis CCA2: 28.70%. Labels correspond to pond-IDs listed in Tab. 1.

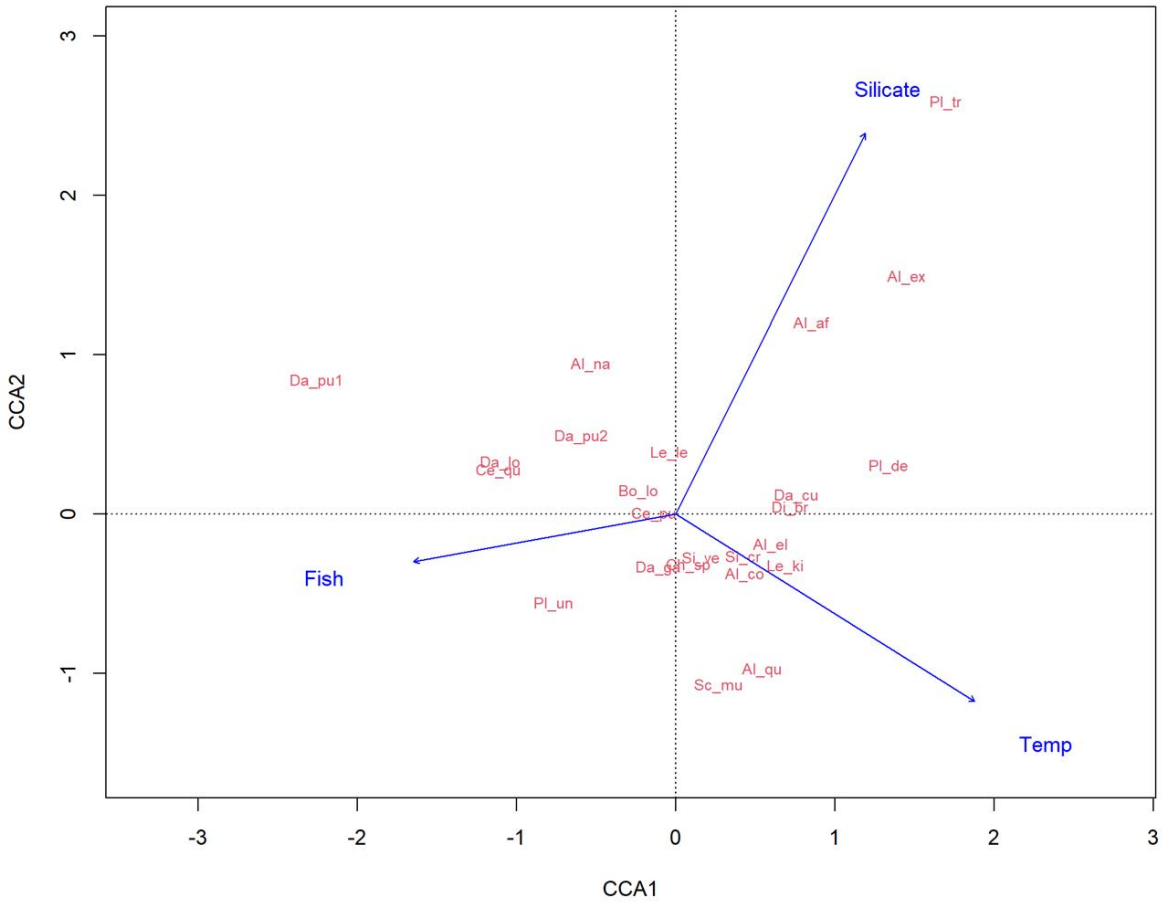

Fig. 15. CCA-biplot of the 24 Cladoceran species and three retained significant ($p < 0.05$) environmental variables identified by forward selection with the *ordistep* function. Abbreviations: Al_af = *Alona affinis*; Al_co = *Alona costata*; Al_qu = *Alona quadrangularis*; Al_ex = *Alonella excise*; Al_na = *Alonella nana*; Al_el = *Alonopsis elongata*; Bo_lo = *Bosmina longirostris*; Ce_pu = *Ceriodaphnia pulchella*; Ce_qu = *Ceriodaphnia quadrangula*; Ch_sp = *Chydorus sphaericus*; Da_cu = *Daphnia cucullata*; Da_ga = *Daphnia galeata*; Da_lo = *Daphnia longispina*; Da_pu1 = *Daphnia pulex*; Da_pu2 = *Daphnia pulicaria*; Di_br = *Diaphanosoma brachyurum*; Le_ki = *Leptodora kindtii*, Le_le = *Leydigia leydigi*; Pl_de = *Pleuroxus denticulatus*; Pl_tr = *Pleuroxus truncatus*; Pl_un = *Pleuroxus uncinatus*; Sc_mu = *Scapholeberis mucronata*; Si_cr = *Sida crystallina*; Si_ve = *Simocephalus vetulus*.

4.2.3 Autecology of *Leptodora kindtii*

Leptodora kindtii was only observed during summer, in twelve ponds in July and in eight ponds in September (Tab. 6). The species was lacking at either sampling date in Streitteich and Neuteich. The highest abundances were recorded in September at Höfentöckteich (Hof au) with 8.95 Ind L^{-1} and 3.2 Ind L^{-1} at Gebhartsteich (Geb au), equivalent to the highest relative abundance class 4 at both sites and sampling dates. For further analysis, samples were ranked into three categories based on the relative abundance of *L. kindtii*: absent, rare and common (Tab. 9). The 'absent' category includes all samples where *L. kindtii* was lacking; 'rare' includes the samples with relative abundance classes of 1-2; the 'common' category includes samples with relative abundance classes 3-5. *L. kindtii* was common in four ponds in July: Has (su), Geb (su), Hof (su) in the vicinity of Schrems, and in Edl (su) in the vicinity of Pürbach. In September, *L. kindtii* was common in the samples of Gebhartsteich (Geb au) and Höfentöckteich (Hof au). No significant correlations (Spearman correlation test [$p > 0.05$]) between the absolute abundances of *L. kindtii* and abiotic environmental variables were found. However, significant differences in three environmental variables exist between samples where *L. kindtii* was present or absent (Fig. 16). Sulphate and NPOC concentrations were significantly higher (sulphate: $t = 2.93$, $p < 0.01$, t-test; NPOC: $W = 152$, $p = 0.023$, Wilcoxon rank-sum test) when *L. kindtii* was present. Alkalinity was significantly lower in samples with *L. kindtii* present than in those without ($t = -2.21$, $p = 0.036$, t-test).

With respect to biotic variables a significant negative correlation between *L. kindtii* densities and fish stocking could be revealed (Spearman correlation test: $p < 0.01$, $rho = -0.52$). *L. kindtii* was only common in ponds with fish stocking densities of 650 carp per ha or lower. Furthermore, the abundance of *L. kindtii* correlated significantly with the abundance of *D. brachyurum*, both for relative and absolute abundances (relative abundance: $rho = 0.45$, $p = 0.014$; absolute abundances: $rho = 0.38$, $p = 0.037$; Spearman correlation test), as well as with *D. cucullata* (relative abundance: $p = 0.015$, $rho = 0.438$; absolute abundance: $p = 0.018$, $rho = 0.429$; Spearman correlation test). *D. cucullata* was most abundant in the same samples as *L. kindtii* (Hof su, Hof au, Geb au). *L. kindtii* was not detected in any of the samples included in clusters A or G (Tab. 9; sampling sites included in each cluster are summarized in Tab. 4). All samples where *L. kindtii* was common are part of cluster F. Cluster C is missing in Tab. 9 as it only contains the sample of Ede in spring and those samples were excluded from the analysis due to the lack of *L.*

kindtii in the April samples. No significant correlations were found between the abundance of *L. kindtii* and the total abundance of Cladocera or diversity metrics.

Tab. 9. Environmental key variables shaping *Leptodora kindtii* populations in the 15 Waldviertel fishponds included in the present study; showing abundance categories and significant sample parameters from July and September based on the relative abundance of *L. kindtii*. The species was found in July and September but lacking in the April samples. Fish stocking is given as numbers per ha. Sampling site acronyms are explained in Tab. 1. Means are given ± standard deviation.

Category	**absent**	**rare**	**common**
Relative abundance of *L. kindtii*	0	1-2	3-5
Mean abundance of *L. kindtii* (Ind. L^{-1})	0	0.14 ± 0.25	3.28 ± 2.98
Range of *L. kindtii* abundance (Ind. L^{-1})	0	0.01 – 0.95	0.25 – 8.95
Range of fish stocking density (carp ha^{-1})	0 - 3000	0 - 3000	10 - 650
Range of *D. brachyurum* abundance (Ind. L^{-1})	0	0 - 1.10	0 - 3.06
Mean abundance of *D. brachyurum* (Ind. L^{-1})	0	0.31 ± 0.38	0.65 ± 1.22
Range of *D. cucullata* abundance (Ind. L^{-1})	0 – 0.15	0 – 0.7	0 – 40.2
Mean abundance of *D. cucullata* (Ind. L^{-1})	0.02 ± 0.05	0.14 ± 0.23	8.98 ± 15.90
Clusters	A, D, E, F, G	B, D, E, F	F
Sampling Sites	Ste, Win, Ede, Str, Neu, Fra, Edl	Win, Ede, Bru, Bra, Has, Moo, Pur, Alt, Frau	Has, Geb, Hof, Edl

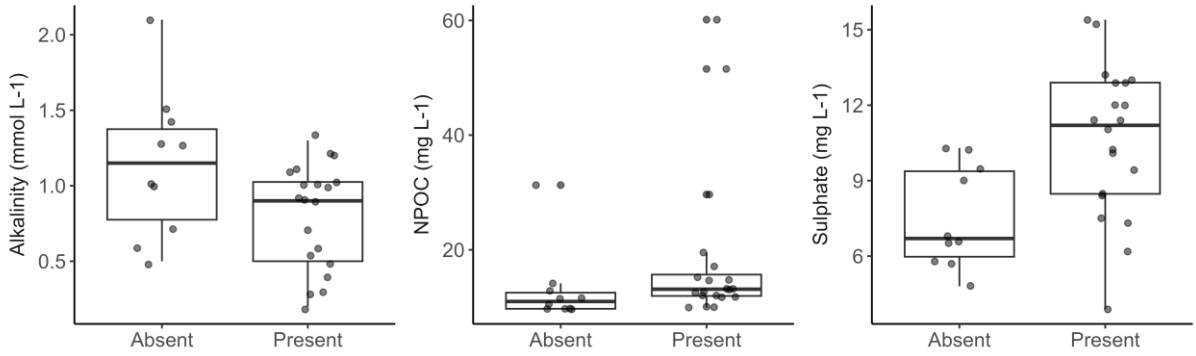

Fig. 16. Boxplots of environmental variables in samples with *L. kindtii* present or absent. The differences for all three variables are significant. Alkalinity: t = -2.209, p = 0.036 (t-test); NPOC: W = 152, p = 0.023 (Wilcoxon rank-sum test); Sulphate: t = 2.93, p = 0.007.

A subsequent co-occurrence analysis showed that there was a significant positive correlation with *D. brachyurum* (Fig. 17). *L. kindtii* and *D. brachyurum* co-occurred in twelve ponds, while the expected co-occurrence was 5.3 ponds ($p < 0.01$). After excluding all samples from April where *L. kindtii* was lacking, the result was still significant with $p = 0.001$ (co-occurrences = 12, expected co-occurrences = 8.0). Furthermore, the co-occurrence of *L. kindtii* and *L. leydigi* was significantly higher than expected ($p = 0.038$,

co-occurrences = 7, expected co-occurrences = 4.7). There was a significant negative correlation in co-occurrence between *L. kindtii* and *D. longispina* ($p < 0.01$). The two species co-occurred only in one sample while the expected number of co-occurrences was 7.1. As in the previous case, this result was still significant after excluding spring samples ($p = 0.03124$, co-occurrences = 1, expected co-occurrences = 3.3).

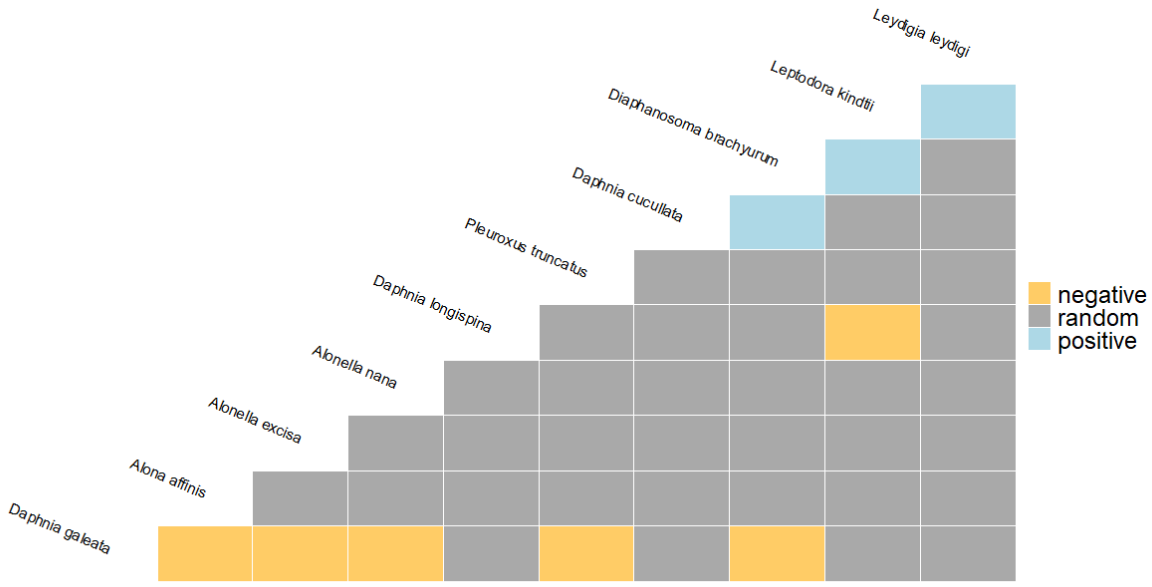

Fig. 17. Co-occurrence plot between species pairs based on incidence. Only samples of July and September when *Leptodora* was present in the study area were included. Of 276 species pair combinations, 192 pairs (69.57 %) were removed from the analysis because expected co-occurrence was < 1; 84 pairs were retained for analysis.

L. kindtii was common in four ponds: Edl and Has in July, and Geb and Hof in both July and September. Geb and Has are the two largest of the ponds studied, with a surface area of over 50 ha, while Edl and Hof are smaller, at 15 and 21 ha respectively. Hof is used as an angling pond, whereas the other three were yielding ponds stocked with carp at an intermediate density. All four ponds have higher vegetation and structure along their shore. Geb is completely surrounded by deciduous and coniferous forests, while Has is close to deciduous as well as coniferous forests in the north-east, with higher vegetation (trees or shrubs) along most of the shoreline. Edl borders forests to the north and west, with some reed along its shoreline. However, the pond is open to the south, where it adjoins

agricultural land with only sparse higher vegetation. Hof is bordered by trees or small forests and shrubs along the entirety of its shoreline. *L. kindtii* was absent from all samples taken from Streitteich and Neuteich, two of the smallest ponds at 2.76 and 4.36 ha respectively. Both were used as growing ponds with 3000 carp per ha stocked. Neu is located in the settlement area of Heidenreichstein, bordering paved roads, and only sparse higher vegetation or single trees can be found along its shore. Str was the smallest pond in the study. It is embedded in an agricultural landscape and has no higher vegetation, such as trees or shrubs, on its banks. In summary, the optimal pond for *L. kindtii* in the Waldviertel is rather large, has a low or intermediate fish stocking density, and has forest, trees or other higher vegetation on the shore.

5. Discussion

5.1 Environmental and structural parameters

In order to characterise the 15 ponds investigated in the present study, we tested for seasonal patterns and differences between study sites in the abiotic set of environmental variables. The increase in TP and POM concentration, as well as the decrease of Secchi depth over the sampling period indicate eutrophication dynamics over time. These findings corroborate an expected change, which is in line with other studies (Kajgrová et al., 2024; Pokorny et al., 1994; Pokorný & Hauser, 2002; Potužák et al., 2007) and described in detail also in the parallel study focussing on phytoplankton (Schagerl et al., 2025). The increase in turbidity (and eutrophication) is amplified by the elevated activity of carp at higher temperatures and the seasonal switch to a more benthic feeding mode (Adámek & Maršálek, 2013; Oyugi et al., 2012; Washitani et al., 2007). In addition. the observed compositional shift during the warmer months towards domination of smaller biota such as *B. longirostris*, combined with a lack of large effective grazers such as *D. longispina*, *D. pulicaria* and *D. pulex* can significantly diminish top-down control of phytoplankton through predation and may further increase turbidity (Ivanova et al., 2022). The changes in sulphate, alkalinity and pH follow the expected and commonly observed seasonal patterns in highly productive water bodies. The significant reduction of sulphate concentration is caused by microbial sulphate reduction and bioaccumulation (Holmer & Storkholm, 2001; Jana & Patel, 1985; Mann, 1958). The significant increase in alkalinity from April to the warmer months and the increase of pH-values in September is usually induced by changes in productivity and respiration as well as precipitation, water supply and evaporation (Jarrett et al., 1993; Wetzel, 2001).

The environmental variables that changed strongly over the sampling period followed a similar trend in all samples and, therefore, failed to explain spatial pond patterns and differences between the three geographically separated pond groups. Therefore, the *bestenv* analysis was conducted to detect key variables best explaining possible differences between ponds and to identify the underlying patterns more precisely than the seasonal pattern over all study ponds (Tab. 5). The cluster analysis calculated with these six variables resulted in seven clusters of ponds based on their abiotic signature. Three of the ponds showed a distinct abiotic signature, differing from all other ponds and therefore forming unique clusters for the three samples taken from each pond (cluster A, B and E). Cluster A, made

up of the three samples from Neu, was characterised by significantly higher chloride concentrations. This is likely due to the location of the pond in the town centre of Heidenreichstein adjacent to a busy road intersection where surface runoff including salt from road de-icing in winter can cause permanently elevated chloride concentrations (Dugan et al., 2017; Van Meter & Swan, 2014). The strongly elevated concentrations of NPOC found in three samples of Moorbad Schrems forming cluster B, as well as Winkelauer Teich, forming cluster E, can be explained by their respective catchment areas encompassing the peat bogs Schremser Moor (Moo) and Heidenreichsteiner Moor (Win). The leaching of humic substances from peat bogs can lead to DOC concentrations exceeding 30 mg L^{-1}, which is visible in the water's typical dark reddish-brown colour (Fig. 3 C) (Pschenyckyj et al., 2023; Strack et al., 2008). The large distance between cluster B and all other samples in (Fig. 8) suggests a strong effect of the catchment area and possibly the different usage of Moo as a recreational pond (and sparsely for angling). However, the other angling ponds Hof and Ede showed no such pattern and difference in their chemical signature, as all three samples of Hof clustered in the large cluster F and each sample of Ede was assigned to a different cluster. The single sample in cluster C was taken from Ede in spring. The pond's dam was overflowing at the time of measurement due to surface runoff from the catchment area and overflow from ponds further upstream, namely Pocherwehrteich to the north as well as a chain of smaller ponds to the south-east of Ede. This elevated water inflow most likely created the observed differences in abiotic properties, particularly the high nitrate concentration and the lower amount of NPOC. The lower concentrations of magnesium and chloride defining cluster D could be attributed to the water source of the included ponds. Bra (all three samples included in cluster D) and Bru (July and September samples in cluster D) are sky ponds and therefore mainly fed by rainwater, which has significantly lower magnesium and chloride concentrations than surface waters (Berner & Berner, 2012). Differences between clusters F and G were low; both were lacking suggestive chemical signatures, with the latter cluster separated from the samples in cluster F only by significantly higher Secchi-depths.

The obtained clusters somewhat reflect geography with respect to the regional distribution of the sampling sites within the three vicinities. While these observed regional patterns might be caused by differences in the characteristics of the substrate of the ponds and their catchment areas, they could also be the result of the predominant fish farming practice in the sampled ponds of a given vicinity. The selected ponds around Heidenreichstein were

mostly used as growing ponds with higher fish stocking, whereas the larger ponds around Pürbach and Schrems were used as yielding ponds with lower stocking of carp. The considerable differences in specific key variables between individual ponds with similar or overlapping catchments indicate that farming practices and carp stocking are the main drivers of their chemical composition rather than the natural nutrient input from their catchments (e.g., Elnady et al., 2016).

5.2 Biotic parameters

5.2.1 Diversity and abundance

With 24 species recorded, Cladoceran species richness was higher in 2021 than in a previous study conducted in 1966, which recorded 19 species at the same sampling sites (Wawrik, 1966). The mean number of species per pond increased from 5.3 (SD = 1.98) to 8.8 (SD = 1.42). Although the sampling effort in the former study varied from pond to pond, the number of Cladoceran species increased in each pond (Fig. 18), which further indicates an actual increase in species richness. This enhanced taxa richness could be attributed to the shift to more extensive carp farming practices and the provision of fish feed on demand, thereby impeding cyanobacterial blooms (Bauer, 2014; DeMott et al., 2001; Schlott et al., 2011). Comparable investigations matching design and sampling effort of the present study recorded a lower number of species, ranging from 17 Cladoceran species in Czech fish ponds to 21 species in 40 ponds in England (Stefanoudis et al., 2017; Vrba et al., 2024). The lower number in the Czech study can be attributed to blooms of cyanobacteria during summer months, which were not detected in this study (Schagerl et al., 2025). Studies of ponds stocked with fish as well as fish free or temporal water bodies report similar numbers of Cladoceran species, with 24 – 26 species found (Kuczyńska-Kippen & Pronin, 2018; Pinel-Alloul & Mimouni, 2013). The observed species richness was significantly lower than in studies investigating natural water bodies on a landscape level, e.g. 38 species in Danube sidearms (Kiss et al., 2014), consistent with the decline in (Cladoceran) diversity in eutrophic water bodies stocked with carp observed in multiple studies (Scheffer, 1990; Weber & Brown, 2009). Since our 15 study ponds are only a minor share of the 1800 ponds in the Waldviertel, total regional species richness and diversity of Cladocera are expected to drastically increase, especially when fish free ponds or astatic as well as perennial natural water bodies are included; (Kiss et al., 2014; Pinel-Alloul & Mimouni, 2013).

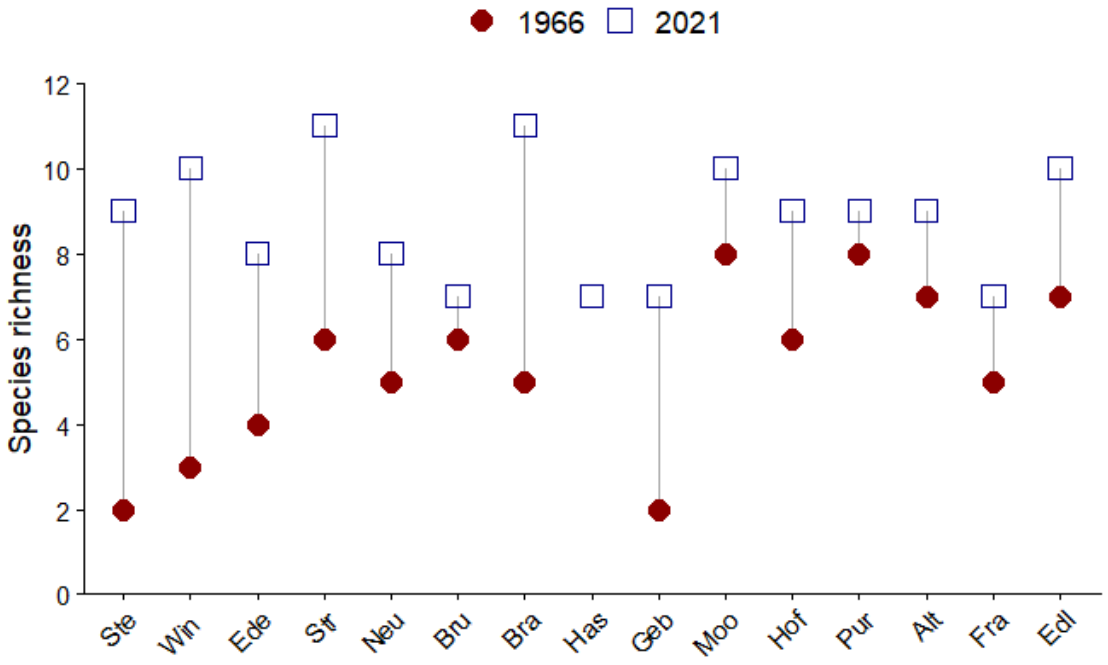

Fig. 18. Comparison of Cladoceran species richness of each pond in 1966 and 2021. Data taken from Wawrik, 1966; Haslauer Teich (Has) was not included in previous study.

Total Cladoceran abundances were significantly higher in July and September. The low abundances in April may be due to the colder climate and late onset of spring in the Waldviertel. The almost winterly temperatures in the study region during the first sampling campaign in April were probably too low for creating the spring abundance peak observed in other studies (e.g., Ivanova et al., 2022). The increase in abundance was stronger in Cladocera than Copepods, with especially smaller Cladoceran species dominating and reaching densities of over 1000 Ind L^{-1} (Tab. 6). This observation is in line with findings in other fish ponds in Poland and the Czech Republic (Brysiewicz et al., 2017; Vrba et al., 2024). The results confirm our hypothesis of lower abundances of large, non-selective herbivores and a dominance of smaller taxa, in our case *B. longirostris*, *D. galeata* and *C. sphaericus,* during the summer months. This shift to smaller, less-efficient filter feeders is well known and attributed to increased fish predation, frequently coupled with clogging of the filter apparatus by a high density of filamentous algal suspensions in summer (DeMott et al., 2001; Potužák et al., 2007; Sommer et al., 1986, 2012; Webster & Peters, 1978).

The low abundance of Cladocera in one sample (Win au) could be traced back to a mass occurrence of the flagellate *Gonyostomum semen* (Schagerl et al., 2025). The resilience of this Raphidophycean taxon against predation and their ability to release slimy threads as a

deterring mechanism which also provides a nuisance for swimmers (Trigal et al., 2013) may negatively affect grazing and, therefore, may cause abundance decline (Lebret et al., 2012). Documented mass occurrences of other algae did not display a comparable impact on Cladocera abundance in our study.

5.2.2 Community composition

Our results indicate a strong seasonal shift in species composition, exceeding spatial or regional patterns (Fig. 11). The compositional shift is characterised by the successive disappearance of larger daphniids (e.g., *D. pulex*, *D. pulicaria* and *D. longispina*), an increasing dominance of smaller species (e.g., *B. longirostris*, *C. pulchella, D. galeata*) and the appearance of summer species such as *L. kindtii* and *D. brachyurum*. This observed seasonal shift aligns with the pattern described in previous studies and the PEG model for eutrophic waters with high fish densities (Karpowicz et al., 2020; Sommer et al., 2012; Vrba et al., 2024). In addition, the genera and species that dominated in summer were also identified as dominant in comparable studies (Ivanova et al., 2022; Potužák et al., 2007). Although there were no major blooms of cyanobacteria, an observed increase in their density might have co-induced this seasonal shift (Schagerl et al., 2025). Our findings are further supported by the results of the indicator species analysis. The larger and efficient filter-feeder *D. longispina* was found to be an indicator species for April, when a clogging of the filtering apparatus by cyanobacteria is still impossible, and fish predation is reduced due to lower temperatures (Ivanova et al., 2022). *C. pulchella* was a significant indicator species for the July-September sampling campaigns and can be described as an inefficient filter feeder not prone to clogging (Potužák et al., 2007; Webster & Peters, 1978). *B. longirostris* showed no significant indicator values, as it was present throughout all sampling dates, although at significantly higher densities in summer and autumn. The second indicator species for the warmer months, *L. kindtii,* was expected to be present at higher temperatures, as it is considered a typical summer species (Herzig & Auer, 1990; Streble et al., 2017). Indeed, the conducted CCA revealed that water temperature was the strongest driver of compositional differences (Fig. 14). However, temperature rather indirectly affects the Cladoceran community *via* increased fish activity, clogging of the filtering apparatus by cyanobacteria, and the co-occurrence of summer species (Dziuba et al., 2017; Ogorelec et al., 2021). In combination, these factors provide a sound explanation for the observed temporal shift in composition.

Other than expected, large daphniid abundance showed no negative correlation with fish stocking in our study. This suggests that the onset of fish predation was delayed due to the reduced activity of carp at lower temperatures in April (Crivelli, 1981; Garcia & Adelman, 1985; Ivanova et al., 2022). Alternatively shifts in the phytoplankton community and filter clogging might have stronger impacted the observed decline of large daphnids in the study ponds. In contrast to the large daphnids, other taxa correlated negatively with fish stocking, such as *D. cucullata*, *L. kindtii* and *D. brachyurum* which seem to be susceptible to fish predation (De Bernardi et al., 1985). In the case of *P. truncatus* the observed negative correlation with fish stocking may be coincidental, as it only occurred in Moorbad Schrems (Moo); at this site the species could also benefit indirectly from low carp densities, which allowed for a higher abundance of macrophytes acting as shelters (Weber & Brown, 2009). Apart from the seasonal shift, we detected distinct regional patterns in the Cladoceran communities. Moo (cluster B) exhibited the most unique community, as indicated by the isolated position of the three samples and the substantial distances from the other samples in the CCA (Fig. 14). The community in Moo was shaped by a higher abundance of Chydoridae, which resulted in three significant indicator species from this family (*P. truncatus*, *L. leydigi* and *A. affinis*). Furthermore, the percentage of smaller Cladocera was significantly lower than in other ponds. The distinct abiotic fingerprint of Moo with significantly higher NPOC and silicate concentrations cannot fully explain its specific species composition, because other ponds with elevated NPOC concentrations, e.g. Win (cluster E), did not show such differences in its community composition, suggesting other key drivers of this divergence. One possible explanation for the observed pattern may be increased structural diversity in the littoral zone by bridge poles of the wooden walkways in the public bathing area, which could provide additional shelter for Chydoridae. The lower density of phytophagous fish, specifically carp, allows for a higher abundance of macrophytes, thereby further increasing structural diversity in shallow water bodies (Weber & Brown, 2009). The significantly higher silicate concentration at this site shaped an algal community dominated by diatoms at all sampling dates (Schagerl et al., 2025). Since Chydorids are known for using diatoms as a possible food source (Klemetsen et al., 2020), silicate *ad libitum* may also add to the unique species inventory of this site.

A different effect of elevated silicate concentrations, albeit to a lesser extent, is illustrated by the species community of Ede, the other pond taking an isolated position in the CCA analysis (Fig. 10). The three samples taken from this site are spread over three separated

clusters, suggesting that nutrient levels do not directly affect the Cladoceran composition, but a higher availability of silicate may result in a range of different phytoplankton communities. Available silicate enables higher densities of diatoms that can inhibit domination of Cyanobacteria and green algae, therefore reducing their impact on grazers and the resulting shift to smaller Cladoceran species (Hendry et al., 2018; Rocha et al., 2002). This effect may be mitigated by predation by the stocked carp in Ede, which could reduce the compositional distance between the Ede samples and the other samples. Moreover, the effect may be enhanced in Moo through the pond's different usage. Although Cluster A, including only site Neu from the Heidenreichstein pond group, is strongly isolated based on its abiotic signature (Fig. 8), its species composition did not differ significantly from the other ponds (Fig. 12). While the elevated chloride concentrations appear to impact species composition, the positions of the samples taken from Neu in Fig. 14 suggest that the seasonal shift in Neu is a lot stronger than the compositional differences in other ponds. The communities of the other clusters did not mirror their abiotic differences, suggesting that the effect of the abiotic key variables on species composition is rather small. *C. pulchella* was identified as a significant indicator species for the ponds in Heidenreichstein. This species may outcompete larger species due to the predation pressure exerted by the high density of carp stocked in the growing ponds.

In conclusion, the main factors shaping the Cladoceran communities were seasonal temperature gradients and fish predation. The effect of additional abiotic key factors, like silicate and NPOC can help explain distinct community patterns but had no strong effect on the majority of the ponds. A compositional shift towards smaller Cladocerans in warmer months over all investigated ponds was clearly evident. Our study was limited by the number of samples taken per pond, which can only provide snapshots at specific points in time, rather than a complete timeline. Species with high reproductive rates may increase in abundance quickly, while unfavourable conditions may lead to a sudden, major reduction of a population. In order to address these deficiencies, a site-specific decrease of sampling intervals during the year would be necessary.

5.2.3 Autecology of *Leptodora kindtii*

In line with its thermal requirements, *Leptodora kindtii* was frequently collected in July and September but not in April as water temperatures were still too low (Browman et al., 1989; Cummins et al., 1969; Herzig, 1995). The taxon was included in four of the seven abiotic clusters. It was lacking from cluster C, since the single sample in that cluster was taken in spring, as well as from clusters A (three Neu samples) and G (the only summer sample included was Str su). *L. kindtii* was a significant indicator species for the combination of the July and September sampling campaigns, confirming its autecological requirements and widespread distribution across the study area. The latter was favoured by the absence of cyanobacteria blooms, since filamentous algae cause *L. kindtii* to die off, as their legs and antennae become entangled in the web of filaments (Streble et al., 2017).

The CCA revealed strong correlations with both temperature (positively) and fish stocking (negatively). As a preferred food source for many fish species, occurrence and population size of *L. kindtii* may be controlled by fish predation, especially in shallow water bodies where escaping through vertical migration is impossible (Herzig, 1995; Lunte & Luecke, 1990; Uusitalo et al., 2003). The effect of common carp on *L. kindtii* abundance may not only be determined by stocking densities, but also the age class of the stocked carp. With increasing age, carp shift their diet from planktivorous to increasingly benthivorous (García-Berthou, 2001; Kloskowski, 2011). While the carp in growing ponds (stocked at weights of 20-50 g) may still feed on zooplankton, particularly larger species such as *L. kindtii*, older carp in yielding ponds are predominantly benthivorous and unlikely to consume *L. kindtii* (Wagaw et al., 2024). This change in feeding behaviour might be the main cause of the observed correlation, given that growing ponds are stocked at significantly higher densities.

Furthermore, *L. kindtii* was found to be an indicator species for the Pürbach-Schrems site combination, where it occurred in 14 out of 16 samples, and the majority of the ponds are yielding ponds. In contrast, in Heidenreichstein, where predominantly growing ponds were sampled, *L. kindtii* did not occur in eight of the 14 samples, and was not found at any sampling date in three growing ponds (Ste, Str and Neu). The highest abundance of *L. kindtii* in Heidenreichstein was found at Bru, a larger yielding pond. This further supports carp age dependant feeding behaviour in combination with stocking density as the main drivers for the occurrence of *L. kindtii*. The absence of *L. kindtii* in cluster G (Str su) is possibly due to the high transparency (i.e. higher Secchi-depths) in this sample and the

resulting increase in fish predation. The higher transparency, probably caused by the low abundance of phytoplankton (chlorophyll-A = 0.045 mg L^{-1}), enhances prey detection and leads to more pronounced size-selective predation of Cladocera, as they cannot evade predation through vertical migration (Estlander et al., 2009; Pekcan-Hekim et al., 2010).

Optimum conditions present in the four ponds included in cluster F enabled the highest densities of *L. kindtii* observed in the present study. With almost 9 individuals per litre, the abundance at Höfentöckteich in September exceeded the highest observed in Lake Neusiedl (Herzig, 1994). Along with lower fish stocking, these four ponds are characterised as rather large and surrounded by forest, trees or other types of higher vegetation along the shore. Riparian vegetation such as reed belts and submerged macrophytes in littoral zones could provide possible refuge from fish predation. *L. kindtii* has exhibited the ability to utilise diel horizontal migration to evade predation in shallow ecosystems, where vertical refuges are missing (Corum, 2023; Pekcan-Hekim et al., 2010). The absence of *L. kindtii* in Ste, Str and Neu further supports the importance of shoreline vegetation. This finding also suggests that water runoff from adjoining agricultural land could have a negative effect on *L. kindtii*, which is highly sensitive to toxic chemicals (Sakamoto et al., 2010). A shoreline forest or vegetated riparian buffer zone could decrease the direct water input due to its filtering effect.

Interaction with other species

Densities of *L. kindtii* were positively and significantly correlated with the densities of *Diaphanosoma brachyurum* as well as *Daphnia cucullata*. The co-occurrence with *D. brachyurum* and *D. cucullata* is probably triggered by the same benefits favouring *Leptodora*, because the former are also expected to profit from reduced predation in ponds with lower fish stocking and occur during summer (Flößner, 2000). The fine filter mesh size of *D. brachyurum* enables it to efficiently feed on bacteria and, therefore, to occur during summer in highly eutrophic systems (Geller & Müller, 1981). By its smaller size, transparency and small clutch size, *D. cucullata* avoids predation by fish but allows larger daphniids to outcompete it in fish-free environments or at low fish activity (Laforsch & Tollrian, 2004). Furthermore, the riparian vegetation and littoral structure found at ponds where *L. kindtii* was more common may also provide refuge from fish for *D. brachyurum* and *D. cucullata*. Although *L. kindtii* reached abundances above 0.5 ind. L^{-1} at several sites where distinct top-down effects on prey species populations can be expected (Branstrator & Lehman, 1991; Herzig, 1994), no detrimental effect on the abundance of *D. brachyurum*

was detected. This suggests that predation pressure by *L. kindtii* could have been reduced or interrupted by increased fish predation and/or availability of other food sources (Pichlová & Brandl, 2003). However, the design of this study does not allow to draw further conclusions on those predator-prey relationships.

The negative co-occurrence with *D. longispina* is probably a result of the observed seasonal shift driven by the factors described above, combined with the absence of *L. kindtii* in April. While some studies suggest that *L. kindtii* is able to suppress or even eliminate certain species, it is highly unlikely that *L. kindtii* is the main driver of the seasonal succession of daphniids in the studied system (Pichlová & Brandl, 2003; Stich, 2004).

This study helped to identify the main drivers shaping Cladocera communities in Waldviertel fish ponds. Extensive fish farming practices allow for a high regional species diversity, with a total of 24 Cladoceran species observed across 15 ponds. Ponds with lower fish stocking densities and riparian structures provide ideal conditions for *L. kindtii*. The multitude of ponds in the Waldviertel offers a diverse array of habitats for Cladocera and other organisms, forming a highly interesting and partly understudied ecosystem.

6. Zusammenfassung

Die vorliegende Studie untersuchte die Zooplanktongemeinschaften mit Fokus auf die Cladoceren in Fischteichen des Waldviertels. Ziel der Arbeit war es, wichtige abiotische und biotische Steuerungsfaktoren für die Artenzusammensetzung der Cladocera in den Teichen zu definieren. Besonderes Augenmerk wurde auf die Frage gelegt, welche Bedingungen das Vorkommen des räuberischen Glaskrebschens *Leptodora kindtii* beeinflussen. Hierfür wurden 15 Teiche im April, Juli und September 2021 beprobt, wobei insgesamt 28 gewässermorphologische, chemische und physikalische Deskriptoren erhoben wurden. Zooplankton wurde mit Netzen von 100 µm Maschenweite gesammelt, das Arteninventar erhoben und die absoluten und relativen Abundanzen ermittelt. Die Ergebnisse zeigen größere chemische Unterschiede zwischen den Teichen als zwischen den Sammelzeitpunkten. Es konnten sechs Schlüsselfaktoren (Secchi-Tiefe, Alkalinität, Magnesium, Chlorid, Nitrat und NPOC-Kohlenstoff) identifiziert und die Teiche in sieben Clustern gruppiert werden. Insgesamt wurden 24 Cladocera-Arten gefunden, wobei eine deutliche saisonale Verschiebung der Artenzusammensetzung vom Frühjahr zum Sommer hin beobachtet wurde. Temperatur, Fischbesatz und Silikatkonzentration hatten den stärksten Einfluss auf die Artenzusammensetzung und konnten die räumlichen Muster sowie die teichspezifische Artenzusammensetzungen erklären. *L. kindtii* trat ausschließlich in den Sommermonaten auf, und zwar in größerer Dichte bei geringerem Fischbesatz und signifikant häufiger bei syntopem Vorkommen mit *Diaphanosoma brachyurum* und *Daphnia cucullata*. Die Unterschiede in der chemischen Zusammensetzung lassen auf einen starken Einfluss der direkten Umgebung sowie der Bewirtschaftungsart der Teiche schließen, wobei beide Faktorenkomplexe direkt auf die Artenzusammensetzung einwirken. Der Fischbesatz und uferbegleitende Vegetation scheinen die dominanten Faktoren für die Häufigkeit von *L. kindtii* zu sein. Ein negativer Effekt von *L. kindtii* auf bevorzugte Beutearten oder die Artenzusammensetzung konnte nicht festgestellt werden und legt nahe, dass *L. kindtii* aufgrund der Prädation durch die Besatzfische keine ausreichende Dichte aufbauen kann, um einen top-down-Effekt auf die Häufigkeiten bevorzugter Beutearten auszuüben.

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8. Appendix

Tab. A 1. Total abundances of Phyllopoda in the study ponds (individuals L-1). Corresponding data for Copepoda (not included in the present thesis) are shown as a reference. Abbreviations: sp = spring, su = summer, au = autumn.

Pond	Season	Phyllopoda	Copepoda
Steinbruckteich	sp	0.5	52.6
Winkelauer Teich	sp	16.0	14.4
Edelwehrteich	sp	0.1	0.3
Streitteich	sp	3.2	0.2
Neuteich	sp	1.1	30.9
Brüneiteich	sp	7.6	21.7
Brandteich	sp	3.6	69.0
Haslauer Teich	sp	11.3	16.7
Gebhartsteich	sp	2.3	6.2
Moorbad	sp	2.5	0.9
Höfentöckteich	sp	3.8	6.5
Pürbacher Teich	sp	5.2	36.4
Althöllteich	sp	32.8	34.1
Frauenteich	sp	4.0	43.5
Edlauerteich	sp	18.8	22.7
Steinbruckteich	su	93.6	52.8
Winkelauer Teich	su	6.7	68.7
Edelwehrteich	su	3.6	13.5
Streitteich	su	4.8	51.2
Neuteich	su	279.3	48.2
Brüneiteich	su	6.0	28.8
Brandteich	su	15.7	26.7
Haslauer Teich	su	193.4	5.4
Gebhartsteich	su	1.6	36.1
Moorbad	su	1.4	34.8
Höfentöckteich	su	65.9	122.3
Pürbacher Teich	su	2.8	91.8
Althöllteich	su	36.8	57.5
Frauenteich	su	852.2	195.5
Edlauerteich	su	1489.2	109.9
Steinbruckteich	au	50.4	6.1
Winkelauer Teich	au	2.4	9.2
Edelwehrteich	au	6.5	3.4
Streitteich	au	1762.1	81.3
Neuteich	au	1241.2	253.9
Brüneiteich	au	47.6	49.4
Brandteich	au	66.3	39.4
Haslauer Teich	au	30.5	58.5
Gebhartsteich	au	7.7	88.7
Moorbad	au	6.3	58.8
Höfentöckteich	au	22.9	123.3
Pürbacher Teich	au	3.0	6.9
Althöllteich	au	112.6	282.9
Frauenteich	au	443.5	672.3
Edlauerteich	au	177.2	106.3

Tab. A 2. Species richness (S), Shannon's H (H), and Simpson's D (D) for each pond pooled over the three sampling dates. Abbreviations of ponds correspond to labels in Tab. 1

Pond	**S**	**H**	**D**
Steinbruckteich	9	0.61	0.36
Winkelauer Teich	11	1.13	0.56
Edelwehrteich	12	0.73	0.30
Streitteich	8	0.03	0.01
Neuteich	10	0.71	0.38
Brüneiteich	9	0.84	0.40
Brandteich	11	0.43	0.18
Haslauer Teich	8	0.25	0.09
Gebhartsteich	12	1.80	0.80
Moorbad	11	1.17	0.50
Höfentöckteich	8	1.23	0.62
Pürbacher Teich	10	1.46	0.68
Althöllteich	10	1.10	0.61
Frauenteich	8	1.02	0.61
Edlauerteich	8	0.65	0.35