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"Aquatic macrophytes in two neighbouring Austrian running waters (Fischa, Wiener Neustädter Canal): Indication of hydromorphological and historical differences"

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1. Abstract

The presence and diversity of aquatic macrophytes depends on a manifold relationship of abiotic and biotic factors. Among other biota aquatic macrophytes are indicator elements of water quality, applied for the assessment of the ecological status of a waterbody in EU-Member States (Water-Framework-Directive 2000/60/EC, European Commission). In this study, the macrophyte communities of two fundamentally different waterbodies in Lower Austria are compared: the near-natural River Fischa and the artificial Wiener Neustädter Canal (Wiener Neustädter Kanal/ further onwards: WNC). Of special interest is their largely parallel course, crossing the landscape of the 'Viennese Basin' towards River Danube. Further, each of the two waterbodies can be split into two sections, respectively, with different conditions in hydromorphology and flow behaviour. Based on data from earlier surveys, a historical outline is also included. The applied method of mapping macrophytes is compliant with the European Standard (EN 14184:2014) for surveying macrophytes in running waters, following the concept of Kohler et al. 1971 and Kohler & Janauer 1995. By subsequent application of several approaches in multivariate statistics, the differences between the two water bodies are demonstrated. The results confirm the expectation that the aquatic macrophyte communities of the two waterbodies are significantly different concerning diversity and individual indicator species. Overall, River Fischa showed a greater species inventory, which is most probably caused by its more diversified environmental background, in contrast to the predominantly homogenous conditions in the artificial Wiener Neustädter Canal (WNC). The aquatic plant community composition of each running water varied over the documented surveys, spanning a time of 39 years. This periodical monitoring of macrophyte communities of whole river courses enables the detection of significant alterations and may be used to explain the consequences of past environmental changes on species composition and may help facing them in the future.

Keywords
Macrophytes, Fischa, Wiener Neustädter Kanal/ Wiener Neustädter Canal, community composition, diversity

Zusammenfassung

Das Vorkommen und die Diversität von aquatischen Makrophyten ist abhängig von einem Komplex an abiotischen und biotischen Faktoren. Diese Organismengruppe wird, unter anderem, auch als Indikator-Element für Wasserqualität im Hinblick auf die Beurteilung des ökologischen Status eines Gewässers verwendet (EU-Wasserrahmen-Richtlinie, Water-Framework-Directive 2000/60/EC European Commission). In dieser vergleichenden Studie werden die Makrophyten-Gemeinschaften von zwei grundlegend verschiedenen Flüssen in Niederösterreich gegenübergestellt: die relativ naturnahe Fischa und der künstlich angelegte Wiener Neustädter Kanal (im Folgenden: WNC). Von besonderem Augenmerk ist ihr annähernd paralleler Verlauf durch die Landschaft des Wiener Beckens in Richtung der Donau, sowie die weitere Auftrennung innerhalb der Wasserkörper in Abschnitte unterschiedlicher Fließeigenschaften. Auf Grundlage früher erhobener Daten kann auch ein historischer Abriss dargestellt werden. Die Kartierung der Makrophytenvegetation basierte auf der Methode nach Kohler et al. (1971) und Kohler & Janauer (1995), und ist mit dem Europäischen Standard (EN 14184:2014) konform. Durch weiterführende Anwendung von verschiedenen multivariaten statistischen Ansätzen konnten die Unterschiede der Gewässervegetation dargestellt werden. Die Daten bestätigen die Annahme, dass sich die Artengemeinschaften der zwei Fließgewässer im Hinblick auf Diversität und Indikatorarten signifikant voneinander unterscheiden. Generell enthält die Fischa ein größeres Arteninventar, das wahrscheinlich auf die veränderlichen zugrundeliegenden Umweltparameter zurückzuführen ist, die im Gegensatz zu den teilweise sehr homogenen Bedingungen im künstlich erbauten Wiener Neustädter Kanal stehen. Auch die Zusammensetzung der Makrophyten-Arten jedes Wasserkörpers variiert über die dokumentierten Untersuchungen der letzten 39 Jahre. Die mehrmalige Beobachtung der Makrophyten-Arten ganzer Flussverläufe ermöglicht die Feststellung signifikanter Veränderungen in der Vergangenheit und könnte in Zukunft auch für Prognosen hinsichtlich der Auswirkungen von Umweltveränderungen auf die Artenzusammensetzung verwendet werden.

2. Introduction

Chambers et al. (2008) defined aquatic macrophytes as aquatic photosynthetic organisms that are large enough to be seen, or even determined with the naked eye. They grow permanently or periodically submerged, floating on, or growing up through the water surface. Aquatic macrophytes are represented in seven plant divisions: Cyanobacteria, Chlorophyta, Rhodophyta, Xanthophyta, Bryophyta, Pteridophyta, and Spermatophyta.

The presence and the diversity of aquatic macrophytes depend on water quality, water depth, flow velocity, and substrate characteristics, as they vary greatly in their anatomy, physiology, life-history traits, and ability to tolerate physical, chemical and biological stressors (Lacoul & Freedman 2006). Therefore macrophytes reflect the quality of the aquatic environment (Janauer et al. 2018) and are used as indicator elements for water quality parameters, including hydromorphology and trophic state, mentioned in the Water-Framework-Directive 2000/60/EC (European Commission). Among other organism groups, they play an essential role in the evaluation of the ecological conditions of water bodies.

Because of their longevity (months to years) and very limited motility (usually limited to propagule movement), they are especially representative for long-term environmental conditions (Dallas et al. 2010), including the accurate localization of sources of pressures (Melzer 1999), as well as their area of impact alongside a section of running water, which is essential (WFD 2000 – Guidance on the monitoring of the biological quality elements, Part 4 – Macrophytes, 2015). Macrophytes are used, together with other organism groups, to assess the ecological status of a water body in five categories (high to bad) (Water-Framework-Directive 2000/60/EC, European Commission) in the EU-Member States.

Another function of macrophytes in their environment is their importance as structural elements. By enhancing surface structures through their bio-architecture they provide safe habitats for young fish or invertebrates (Gabaldón et al. 2018; Silva & Henry 2017) and therefore supply cover, feeding and breeding sites and primary production for many other biota (Dallas et al. 2010).

Likewise, particle transport is strongly affected by macrophyte beds. As near-bed velocity and sediment composition within macrophyte beds are closely related to differences in macrophyte morphology and patch structure, particles are retained within macrophyte beds and along stream stretches with high plant cover; hence they can markedly reduce downstream transport (Sand-Jensen 1998).

The presence or absence of aquatic plants in a river depends on many different environmental parameters.

According to Shelford's law of tolerance (Kuhar et al. 2011), an organism's presence and success depends on a multifaceted set of conditions. Organisms in nature rarely live in their optimum range of given environmental factors, where some factors might have greater importance than others.

The most intuitive factors are light intensity, which varies with shading of riverbed and turbidity of water, as well as water temperature, which is increasing rapidly over the last decades (Carpenter et al. 1992; Webb & Nobilis 1995; Van Beek et al. 2012; Van Vliet et al. 2013) and is predicted to cause severe shifts in freshwater availability and species distribution (IPPC Special Report, Chapter 3, Hoegh-Guldberg et al. 2018). Nutrients, which are often enhanced by human activities (Smith et al. 1999), seem to be less causative for strong macrophyte growth in the first place (Allan & Castillo 1995). Excessive nutrient input mostly plays a minor role in waterbodies in Austria, due to an extensive and well working network of wastewater treatment plants that was established in Austria during the last decades and successfully applies biological treatment stages to reduce phosphorus and nitrogen concentrations (BMNT 2018). The underlying geology plays an important role also because the number of species is usually lower in silicate base-rock areas than in areas with calcareous base-rock (Janauer et al. 2018). Importance of various ecological factors may even change depending on different biogeographical regions (Hrivnàk et al. 2013). Discharge has a substantial impact on the macrophyte presence and community composition as well. Streams with large seasonal amplitude in discharge often have their primary growing season in summer due to low flow and high light availability, whereas in streams with constant water level, macrophytes can be found during any season (Sand-Jensen 1998).

Even growth forms are affected by different flow velocities, as plants try to reduce total drag by streamlining (Albayrak et al. 2010) and reduced branch numbers (Neuhold et al. 2018).

Following Hrivnàk et al. (2007) human impact represents a specific problem, as it modifies some of the above-mentioned natural factors, chemical parameters, some hydrological characteristics, and consequently diversity and abundance of macrophytes.

3. Study area

Both waterbodies are located in the eastern part of Austria in the state of Lower Austria. A substantial part of their course flows in parallel towards the River Danube.

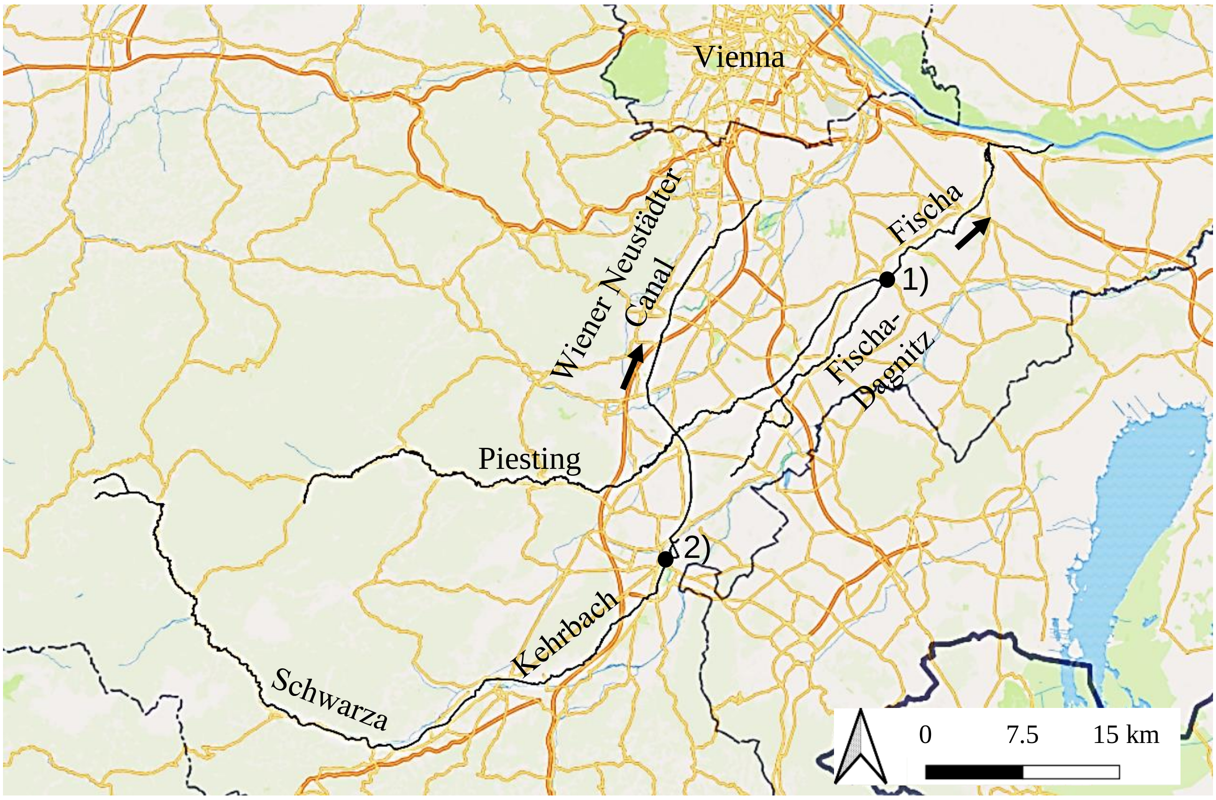


Fig.1: River Fischa and Wiener Neustädter Canal (WNC) with their main tributaries Piesting and Schwarza via Kehrbach. 1) Confluence Fischa and Piesting. 2) Confluence Kehrbach and WNC. The arrows mark the direction of flow. The map was created with QGIS (version 3.12).

3.1. Fischa

The River **Fischa-Dagnitz** originates from two springs in a small woodland close to the village of Haschendorf (229 m a.s.l.) in the Wiener Becken (the ‘Viennese Basin’, an elongated cauldron subsidence). For the following 25 km the little river is mostly fed by groundwater that is collected in the alluvial cone next to the village of Wöllersdorf. Its relevance as a Danube tributary is enhanced by the confluence with the River Piesting, whose catchment reaches westwards into the uplands of the Lower Austrian Limestone Alps (Fischa-Netze 2019). In contrast to the Fischa the Piesting is mainly dependent on surface runoff and precipitation. Even though Piesting has a higher discharge at the confluence, the merged waterbody is called Fischa from there onward.

Other small tributaries, fed in part by groundwater, are the little Reisenbach stream, which diverts from the Neue Fischa at Pottendorf and re-enters at Enzersdorf/Fischa, and the Führbach stream, which merges with the Fischa at Wienerherberg.

After 51 km of total length (UBA 2019) the confluence of the Fischa with the River Danube is located a few kilometers downstream of the city of Fischamend (154m a.s.l.). The catchment size at the mouth to the Danube adds up to about 581 km² (UBA 2019), of which 377 km² (UBA 2019) comprise the Piesting catchment (Fig.1).

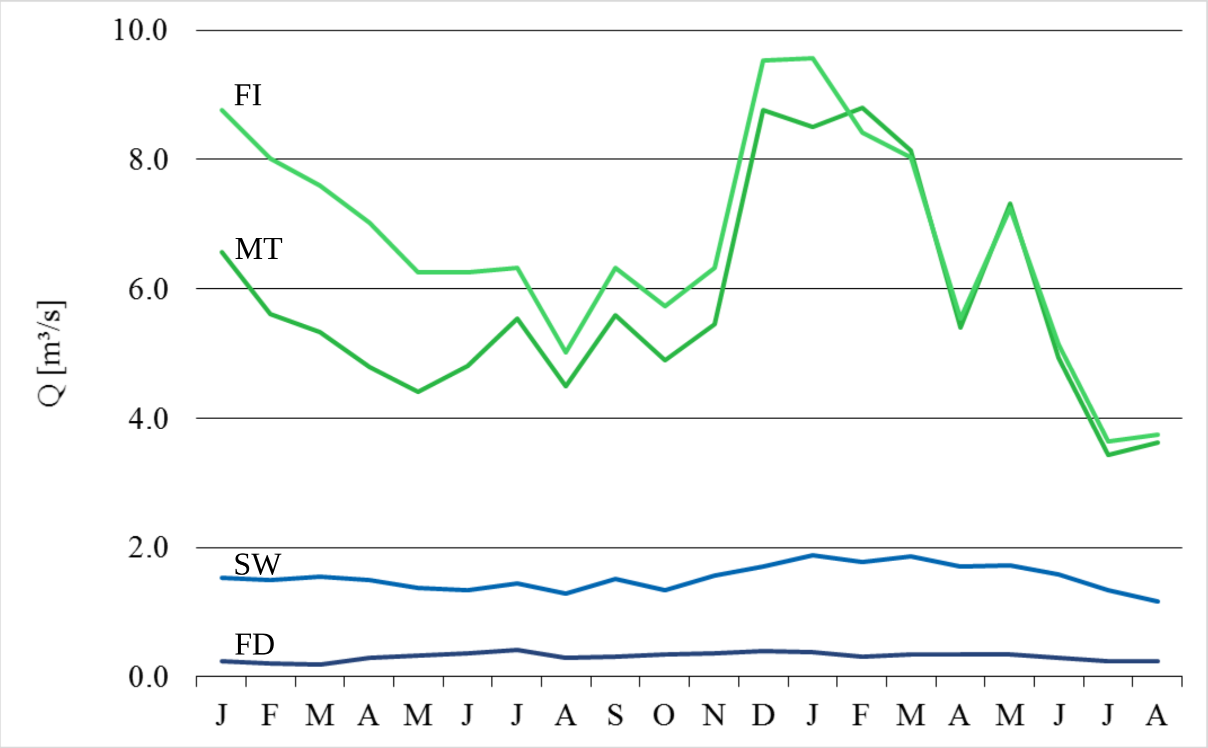


Fig.2: River Fischa: Discharge (Q; $m^3 \cdot s^{-1}$) 2018/19. Data provided by Municipal Waterworks Moosbrunn. Measurements taken at Fischa-Dagnitz: Spring (FD) and Schranawand (SW), representative for upper reach; Marienthal railway bridge (MT) and Fischamend measuring bridge (FI), representative for lower reach.

In accord with the geographical conditions discharge shows a clear pattern. The depth of the Fischa increases from the source towards the confluence and is more than twice as deep where it merges with the Piesting. The groundwater-dependent headwaters of the Fischa show quite uniform water levels throughout the year (Fig.2; metering points: Fischa-Dagnitz spring and Schranawand). Seasonal discharge variation is apparent in the section downstream of the confluence of the two rivers, primarily depending on precipitation and surface runoff in the Piesting catchment (Fig.2; metering points: Marienthal and Fischamend). During autumn, with high precipitation rates in the catchment area, discharge rapidly increases in the river reach downstream of the confluence, whereas the lowest rate is reached between May and August.

A similar pattern can be detected when looking at the temperature conditions (Fig.3). Groundwater emerges with about 11.5°C over the whole year. In contrast, surface water bodies show a high temperature amplitude between summer and winter. The lowest value was about 6 °C in February, 2018. The summer temperature reached its maximum in August, with about 17°C. This corresponds to an annual variation of more than 10°C.

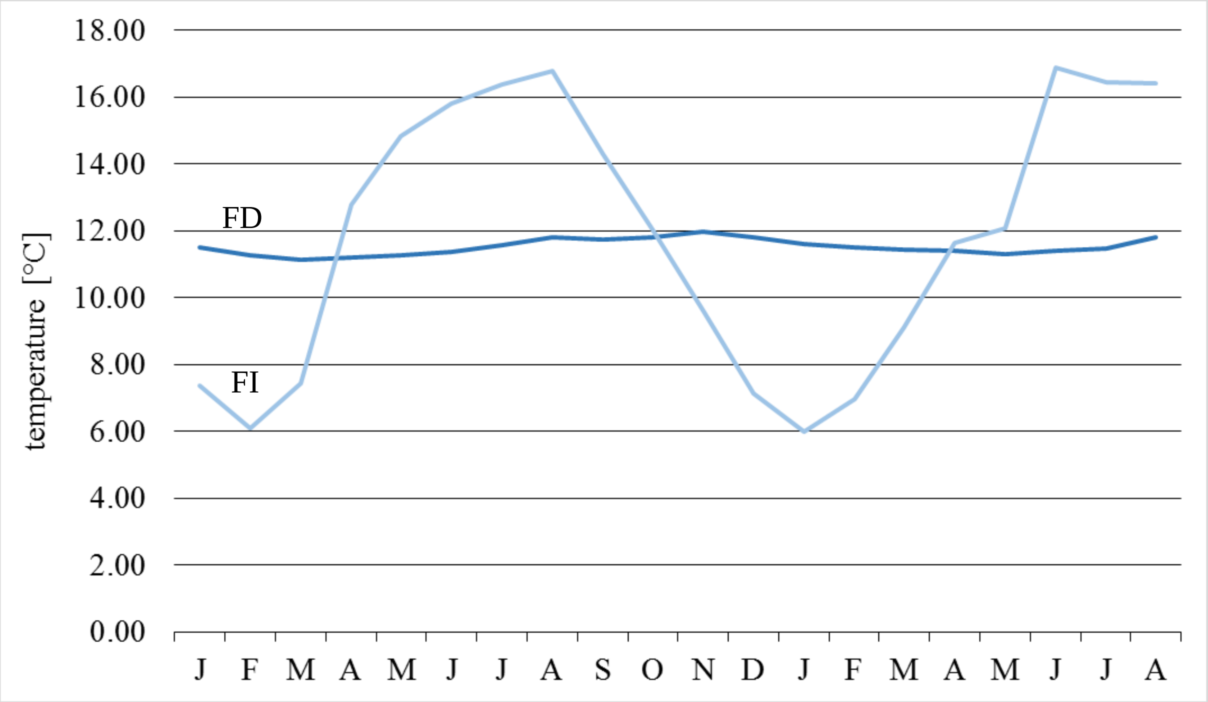


Fig.3: River Fischa: Temperature (°C) 2018/19. Data provided by Municipal Waterworks Moosbrunn. Measurements were taken at Fischa-Dagnitz spring (FD), upper reach and Fischamend measuring bridge (FI), lower reach.

Regarding these physical conditions, the Fischa can be divided into two sections. The upper region (Fischa-Dagnitz), spring to the confluence with the Piesting, is the “upper reach” (ur). The river reach downstream to the mouth at Fischamend is the “lower reach” (lr). Whether these two parts are mirrored in the aquatic vegetation will show the following analysis.

The Fischa was not regulated for most of its length at least until the early 20th century (see GKME200, 1915, map sheet 34E-48N). Some parts of the original meandering watercourse are preserved, mostly located between the small municipalities. When looking at maps of the 19th century (FL 1809-1818. Österreich ob und unter der Enns - Franziszeische Landesaufnahme) the extent of regulation is apparent.

One example is the relocation of the mouth of River Fischa five kilometers downstream in Fischamend in 1868, to create a safe port for cargo shipping, especially in the winter months (Melichar 2019). Another one is the branching off of side arms, powering a series of industrial mills, established by numerous industrial companies along the river. Corn mills, textile and spinning factories, as well as industries needing electric power took benefitted from the constant water flow conditions, which had gained the river economic importance (Ebreichsdorf 2019).

About 40 years ago (Tab.1), when the first macrophyte survey took place, the water quality of the River Fischa had been poor from spring to mouth. It was the time when waste water treatment plants had just shortly started operating along the river (Janauer 1988). In the following years, local communities started to build and improve their wastewater treatment plants (information provided by the municipalities via email). Since then, water quality improved. In 2005 the Fischa was characterized by consistent good quality.

Table 1: River Fischa: Saprobic water quality. Section numbers refer to the current study (Tab. Appendix), I = oligosaprobic, II = β-mesosaprobic, III = α-mesosaprobic, IV = polysaprobic, n.a. …not analysed

References: $^{1)}$ BMLUF 1977/78, $^{2)}$ BMLUF 1979-84, $^{3)}$ NOEL 1999/ 2005

Fischa survey units	1-12	47-55	69-75	89-90	96-99	103-108
water quality 1971-1977 $^{1)}$	I	II/ II-III	I-II/ II	II-III/ III	II-III/ II	III-IV/ III
water quality 1979-1984 $^{2)}$	I-II/ II	n.a.	n.a.	II-III/ III	III	II-III/ III
water quality 1999 $^{3)}$	I-II	II	II	II	II-III	II-III
water quality 2005 $^{3)}$	n.a.	II	II	II	II	n.a.

Even though quality classification following the saprobic system was discussed intensely and is no longer in use, it provides a general overview of the situation of water quality over the last decades. In short, classification of saprobic water quality is based on the consumption of biologically easily degradable organic substances. The occurrence of specific organisms (macroinvertebrates, algae etc.) and the chemical-physical condition determine the class affiliation (ÖNORM M 6232 1997).

3.2. Wiener Neustädter Canal

The **Wiener Neustädter Canal** (WNC) flows for some of its present length in NE-direction about parallel to the Fischa. This canal was planned under the Habsburg-Emperor Franz II. to connect the important coal, timber and brick industries, located in the south, with Vienna, the Capital of the Austro-Hungarian Empire. From 1797 to 1803 the canal connection to Wiener Neustadt was finished. The complete project of building a canal from Vienna to the Adriatic Sea at Trieste, in today's Italy, was never realized, as the Austro-Hungarian-Monarchy soon lost the Italian regions. After some extensive remediation works, mills, textile factories and engineering works were established successfully along the canal and facilitated profitable shipping. But at the same time rail services got more developed and finally took over most of the transport. Increasingly, small power plants along the canal became more and more important and nowadays recreational purposes predominate.

These days the Wiener Neustädter Canal flows for about 36 km almost straight-lined from Wiener Neustadt to Biedermannsdorf/Laxenburg, passing 36 barrages and 8 aqueducts, and then merges with the River Mödling since 1973. The former canal stretch onwards to Vienna became economically obsolete and was pulled down.

Since 1916 the canal is served with water coming from Kehrbach (1.0-1.8 m^3/s), which diverts itself from River Schwarza, 16 km south of Wiener Neustadt, at Peisching (Fig.1). Like River Piesting, the main tributary of the Fischa, the Schwarza originates in the Schneeberg region and feeds the rivers of the 'Viennese Basin'. A few kilometres after the diversion of the Kehrbach powerplant canal, River Schwarza meets with River Pitten, creating the River Leitha. Further downstream water is then diverted to the Mühlbach, which unites with the Kehrbach canal a short length upstream of starting the Wiener Neustädter Canal (Tinhofer 2017).

The WNC is fed by water diverted from the Kehrbach by a side weir. The residual water of Kehrbach crosses the WNC via an aqueduct and finally flows into the River Warme Fischa.

Every autumn maintenance work is conducted along the canal. For this purpose, the water level is lowered to a minimum (Fig.4). Then collections of driftwood and garbage are removed and in some places also dredging operations take place, where also macrophytes are cut and reduced to ensure a consistent runoff regime (Gasteiner 2001). Additionally, the bank vegetation is cleared regularly by cutting mechanically.

Although the canal seems to be a homogenous and uniform system, we can also recognize two major sections. The upper section – the upper reach – is characterized by homogenous and uniform flow conditions. Starting at market town Kottingbrunn – about 17 km downstream of the WNC origin – the lower reach covers a series of barrages, passages and impoundments that disrupt the continuous water flow, almost down to the end of the WNC.

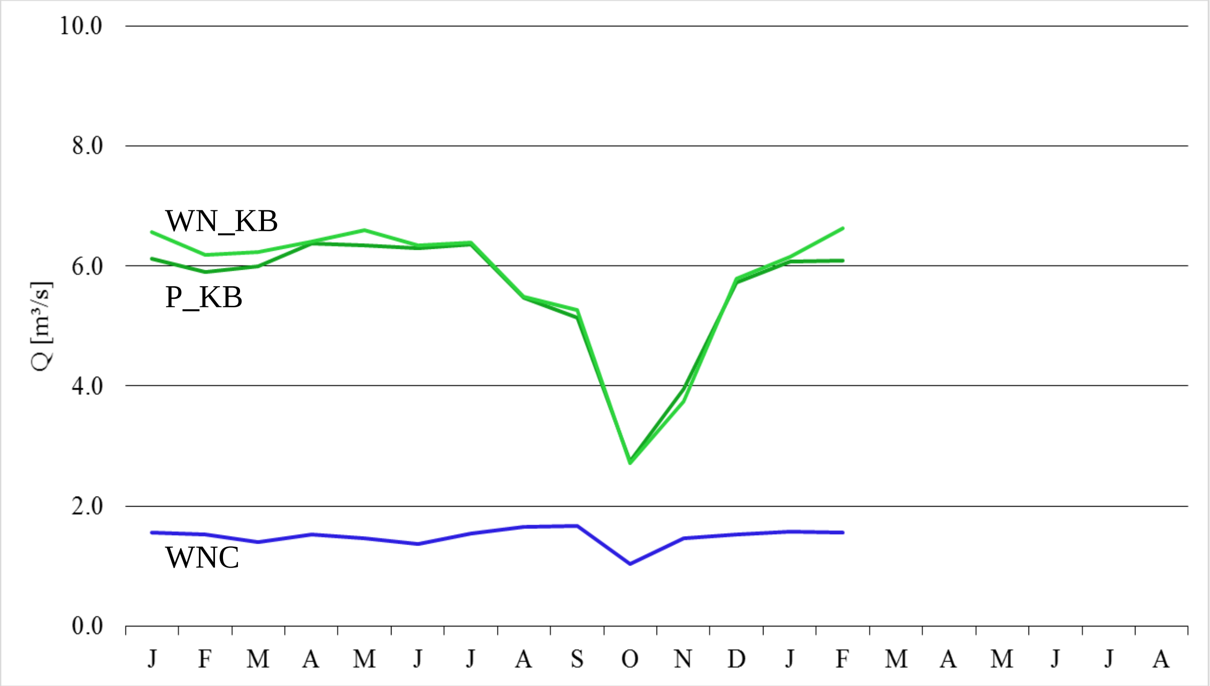


Fig.4: Wiener Neustädter Canal: Discharge (Q; $m^3 \cdot s^{-1}$) 2018/19. Data provided by Hydrographic Service of Lower Austria. Two measurements were taken at Kehrbach: Peisching bridge (P_KB), Wiener Neustadt J.Strauss-Gasse (WN_KB), and one right at the source of Wiener Neustädter Canal (WNC).

Nearly all municipalities dispose of their effluent of treated sewage into other neighbouring water bodies. Only the wastewater treatment plant of the city of Bad Vöslau and Gumpoldskirchen is connected to the canal, but there are plenty of discharges of surface water coming from surface-sealed areas (information provided by the municipality via email).

Water quality of the Wiener Neustädter Canal was also assessed during the last decades using the saprobic system, as mentioned above. Table 2 provides a rough insight into the situation of water quality along the canal. Over the years almost no changes were detected. Due to the lack of main discharges of waste water, the canal was always just affected by moderate nutrient levels.

Table 2: Wiener Neustädter Canal: Saprobic water quality. Section numbers refer to the current study (Tab. Appendix), I = oligosaprobic, II = β-mesosaprobic, III = α-mesosaprobic, IV = polysaprobic, n.a. …not analysed
References: (1) BMLUF 1977/78, (2) BMLUF 1979-84, (3) NOEL 1999/ 2005

Wiener Neustädter Canal						
survey unit	1-7	16-21	52-58	59-62	72-82	87-89
water quality 1971-1977 (1)	III	II-III/ III	II-III/ II	II-III/ II	II-III/ II	II-III
water quality 1979-1984 (2)	III	II-III	II-III/ III	II-III/ III	III/ II-III	II-III
water quality 2005 (3)	n.a.	II-III	II-III	n.a.	II-III	n.a.

4. Hypothesis

The two waterbodies studied, the River Fischa and the Wiener Neustädter Canal are of very different character, despite the fact that they are located rather close by.

Both water bodies also show a common phenomenon, as their upper, and their lower reaches show differences, which can easily be observed. These characteristics also triggered the expectation that macrophyte communities may be different.

This study aims at showing the conditions having impact on the occurrence of aquatic plants. It also includes the results of four (River Fischa) and three (Wiener Neustädter Canal) survey campaigns, respectively, which covered a period of 39 years.

Specific hypotheses are:

1. Is there a difference in the macrophyte species composition between River Fischa and the Wiener Neustädter Canal?
2. Is there a difference between the upper and lower reach of each waterbody regarding environmental parameters and macrophyte species composition?
3. Is there a change in the aquatic plant community composition over the last 39 years in each of the two waterbodies?

The results will be of current interest concerning ecological succession of macrophyte communities in the artificial canal on the one hand and a waterbody with the character of a near-natural stream on the other. The outcomes may even gain more importance in the light of progressing future climate change and river regulation measures.

5. Material and Methods

5.1. Available data set

Several studies had been carried out on the macrophyte community of these waterbodies.

Table 3: Available data set

Fischa	1979	Janauer G.A. (1981): Die Zonierung submerser Wasserpflanzen und ihre Beziehung zur Gewässerbelastung am Beispiel der Fischa (Niederösterreich) Verhandlungen der zoologisch-botanischen Gesellschaft in Österreich. 120. pp. 73-97.
	1999	Drofenik V. (2002): Die Makrophyten-Vegetation der Fließgewässer Fischa und Führbach (Niederösterreich). Diploma thesis, Vienna 2002.
	2018	this study
WNC	1992	Janauer G.A. (personal information, not published)
	1994	Janauer G.A. (personal information, not published)
	1999	Gasteiner I. (2001): GIS-unterstütze Totalinventarisierung der Makrophytenvegetation des Wiener Neustädter Kanals im Spiegel anthropogener Eingriffe (Diploma thesis, Vienna 2001)
	2018	this study

This Master Thesis had the core objective of contrasting these studies to my collected data, and to support outlining the potential developments and trends.

5.2. Surveying macrophytes

Field-work was carried out during August 2018. The applied approach of mapping macrophytes is recommended by the current guideline of monitoring macrophytes in Austria (WFD 2000 – Guidance on the monitoring of the biological quality elements, Part A4 – Macrophytes, 2015), following the method of Kohler et al. 1971, and Kohler & Janauer 1995. This method caught international attention in the Joint Danube Surveys (Janauer et al. 2007; Stanković et al. 2015), organized by the International Commission for the Protection of the Danube River (ICPDR), and is nowadays integrated in the European Standard (EN 14184:2014) for surveying macrophytes in running waters and determined for analysis in relation to the Water Framework Directive.

The running waters were surveyed in their full length, except for parts that could not be approached. In this process the complete length of a waterbody is subdivided into sections of different length to quantify plant mass. As opposed to Holmes & Whitton (1977), who used uniform section lengths, here, similar environmental conditions are the decisive factor, rather than the same length. Additionally, records of prominent buildings, like bridges or barrages were used as geographical marks in the past (Appendix 11.1), but this is replaced by GPS tracking, today. These precisely located sections allow for efficient and comparable subsequent surveys.

All higher plants living primarily submerged, and amphiphytic species like *Berula erecta* were recorded in this study. Due to the lack of ripe fruits, the genus *Callitriche* could not be determined to species level.

The recording was done by tracking the running water along its banks and keeping a close watch on the macrophyte community. For further determination of species, samples were taken with a telescopic rake.

Kohler et al. (1971) invented a scale of five categories to estimate “Pflanzenmenge” of each species in each section (Plant Quantity Index, PMI). Categories 1-5 are defined as very rare, rare, common, abundant, highly abundant (Tab.4). “Pflanzenmenge” is defined as the combination of the number of single finds per survey unit and the plant mass at each of these sites simultaneously (Kohler 1978). Therefore, cover, and also the vertical development of aquatic plant species are assessed in relationship with the part of the whole waterbody of a survey unit, which is inhabited by this species (Janauer et al. 2018). This allows the estimation of plant mass in a section (PME) in a quite robust and simple way. Established in German language, Holmes & Whitton (1975) introduced English terms for each category, with slightly different wording (rare, occasional, frequent, abundant and very abundant).

Overall, what is estimated is not abundance in its traditional way, like vegetation cover, but more the spatial extent of a species, which is adjusted to its growth form (Janauer et al. 1993). Because of its practical and simple application, this method is quite robust to subjectivity of the respective researcher.

Survey units that could not be approached because of building areas, farmed fields or for other reasons of inaccessibility, are marked as “nk”, which is based on the German phrase “nicht kartiert”, meaning “not mapped”. These sites were excluded from statistical analysis. This is, for example, the case for the last five kilometres of River Fischa downstream of Fischamend town.

Table 4: Estimate scale for the Plant Quantity (PM) as Plant Quantity Index (PMI)
modified from: WFD 2000 – Guidance on the monitoring of the biological quality elements, Part A4, 2015

Estimate level (PMI)	**Verbal description ÖNORM M 6232**	**Plant Quantity (PM)**	**Explanatory remarks to Plant Quantity**
1	very rare, scattered	1	Only single plants, up to 5 individuals
2	rare	8	Approximately 6 to 10 single plants, loosely scattered occurrence in the survey unit or up to 5 single plant stocks
3	common	27	Cannot be overlooked, but not frequent; “to be found without having to search for it”
4	abundant	64	Occurring frequently, but not in masses; incomplete cover exhibiting large gaps
5	highly abundant, in masses	125	Dominant, found more or less everywhere; cover markedly more than 50 %

From this index (PMI) the actual quantity of plants (PM) can be approximated. The cubic equation

Formula 1: $f_{(x)} = x^3$

represents the extension of plant populations in a spatial way (Melzer 1986; Janauer et al. 1993; Janauer & Heindl 1998).

For graphical presentation the five exponential estimate categories, used in the field, are reduced to a linear three-part scale. Therefore, the two highest and the two lowest levels are merged: occasional/ frequent/ abundant (Kohler 1978; Kohler 2000).

The Relative Plant Mass (RPM) shows the quantitative significance of individual species in a river section (Pall & Janauer 1995). It represents plant mass of a specific species as the percentage of the entire plant mass of all the species occurring in a specific water body (Pall 2018). It is calculated for each species in each survey unit. Weighted by the length of survey units, it is a more precise parameter than frequency (www.midcc.at, MIDCC Multifunctional Integrated Study Danube Corridor and Catchment - Presenting results).

Formula 2: Calculation of the relative plant mass (RPM) (Pall & Janauer 1995)

$$\mathrm{RPM}[\%]= \frac{\sum_{i=1}^{n}\left(M_i^3 \cdot L_i\right)\cdot 100}{\sum_{j=1}^{k}\left(\sum_{i=1}^{n}\left(M_{ji}^3 \cdot L_i\right)\right)}$$

RPM…relative plant mass of a species

M_i… estimated plant index of this species in section i

L_i… length of section i

j…current index of different species

Information of RPM is about proportion and the resulting dominance of different macrophyte species over the course of the surveyed river.

To show the distribution of absolute plant mass of the different plants, the mean abundance indices MMO and MMT have to be calculated (Janauer et al. 1993).

By calculating the mean abundance indices (MMI, in German: ‘Mittlerer Mengenindex’) the spatial extension is considered for all the survey units in which the respective species are growing. The distribution of species is weighted by the length of survey units. This provides evidence of how endangered a species could be generally, even when it may occur locally in high abundance within a survey unit. Indices are distinguished between MMO (mean abundance index of individual species with respect to the survey units where this species occurs) and MMT, which is the mean abundance index of this species with regard to the full length of the river reach investigated, i.e., accumulated length of the contiguous survey units (Janauer et al. 1993, Kohler & Janauer 1995).

Formula 3: Calculation of the mean mass indices (Janauer et al. 1993)

$$\mathrm{MMT}=\sqrt[3]{\frac{\sum_{i=1}^{n} M_i^3 \cdot L_i}{L}} \qquad \mathrm{MMO}=\sqrt[3]{\frac{\sum_{i=1}^{n} M_i^3 \cdot L_i}{\sum_{i=x}^{n} L_i}}$$

MMT…mean mass index of a species over all investigated sections

MMO…mean mass index of a species over all sections, where this species occurs

M_i…estimated plant index of a species in section i

L_i… length of section i

L…total length of investigated area sections

Following Kohler & Janauer (1995) species can be grouped by their MMT and MMO values. They are either considered as widespread and occurring with high biomass, or with patchy distribution, rare and low growing.

By repeatedly studying macrophytes in water bodies, differences in species distribution patterns between years can be recorded. Out of this, important information on processes of succession and possible anthropogenic and natural alterations of water quality may be revealed. These results become even more valuable if they are combined with physical-chemical data, as changes in vegetation are often caused by them. Mapping of macrophytes over some years indicates causal connections between plant distribution and site of study (Kohler 1978; Hrivnák et al. 2009; Schweinitz et al. 2012).

Distribution diagrams, MMT/MMO and RPM are created by means of the Kohler-on-the-Web (KoW) software. It is a free web-based tool for visualization and calculation of aquatic plant survey results (Janauer et al. 2018).

5.3. Environmental parameters

On a single day and within a time period of few hours, water samples were collected at specific sites of the two waterbodies and taken into the laboratory to measure nutrient levels during the period of optimal growth of the plants. The analyses were carried out using the Eurofins Umwelt Österreich GmbH & Co KG (Austria) facilities, and include ammonia (method: EN ISO 11732: 2005-02), phosphate and total phosphorous (method: EN ISO 6878: 2004-06).

Additionally, temperature, conductivity and pH were measured (HachLange HQ40D Portable, WTW Cond3110). Supplementary, routine measurements of discharge and temperature, were provided by Municipal Waterworks Moosbrunn and the Government of Lower Austria (Fig.2, Fig.3, Fig.4).

Relevant habitat parameters like flow velocity and shading were recorded numerically. The characteristics of bank structure and sediments were summarized in classes.

5.4. Statistics

Indicator Species Analysis (ISA). Dufrêne & Legendre (1997) recommend this method to find patterns in species distribution. It calculates indicator species values by multiplying the relative abundance of each species in a specific section type by the relative frequency of species occurrence in that section type (Janauer et al. 2007).

Indicator species are defined as the most characteristic species of each group, found mostly in a single group of the typology and present in the majority of the sites belonging to that group (Dufrêne & Legendre 1997) and therefore reflecting the environmental state or impacts of environmental change within an area (De Cáceres 2019).

The statistical significance of the species indicator values is evaluated using a randomization procedure (permutation test). This method is built-in in the r package *indicspecies* (ver. 1.7.8.) of RStudio Version 1.2.5001 (RStudio Team, 2015).

Like in Janauer et al. (2018), this was used to identify the species that characterize each of the two waterbodies and their respective sections in the survey in 2018, which therefore contains the most recent data.

Non-metric Multidimensional Scaling (NMDS). This ordination method was used to get an overview of the situation of macrophytes in the different years of recording and was also carried out in RStudio Version 1.2.5001 (RStudio Team, 2015). Changes in species abundances are expressed in differences of the centroids (means) of each year.

NMDS is based on ranked distances of abundance data. In this analysis, the Bray-Curtis-Distance was used, because of its applicability to abundance data ignoring joint absences (Janauer et al. 2018).

“Stress” is a measure of distance from monotonicity in the relationship between the dissimilarity (distance) in the original and the ordination space. The closer the points are located to a monotonic line, the better the fit and the lower the stress (McCune & Grace, 2002).

To assess significance in the different positions of centroids, a permutational multivariate analysis of variance (PERMANOVA) was conducted pairwise on the distance matrix. The resulting p-Values were corrected by the method of Holm 1979, built in the R function *p.adjust*. For doing so, the R function *pairwise.adonis* by Martinez Arbizu P. (2019) was used.

Simpson Diversity. This index was calculated to compare species diversity in each vegetated survey unit of the two running waters and the different recording years. This is possible because of its robustness against different sample sizes. Simpson's index of dominance represents the likelihood that two randomly chosen individuals of a specific section will be the same species (Magurran 2004). It varies inversely with diversity. To measure diversity, the complement of Simpson's index of dominance was used. It represents the likelihood that two randomly chosen individuals will be different species (McCune & Grace 2002).

Formula 4: Simpson's index of diversity (1-D) (McCune & Grace, 2002)

$$\text{Diversity} = 1\text{- D} = 1\text{-} \sum_{i}^{s} p_i^2$$

Results ranging from zero to one make direct comparison of diversity in different waterbodies possible. A value of zero indicates no diversity, whereas a value of one represents maximum diversity.

For calculating Simpson's index of diversity the statistics software Past 3.26 (Hammer et al. 2001) was used. For testing statistical significance of the results a Mann-Whitney two-sample test was conducted in RStudio Version 1.2.5001 (RStudio Team, 2015), also generating the notched box-plots.

6. Results

6.1. Characterization of water bodies

In 2018 River Fischa was inhabited by 19 different macrophyte species in total, whereas in the Wiener Neustädter Canal (WNC) only nine species were detected. There were also differences in the number of survey units without species. There were more than twice as many units without plant growth in the canal than in the Fischa. Some sections could not be mapped, because of restricted access, like building areas or inaccessible woodland. As they were often quite long, the average length of survey units is high.

Table 5: Characterization of the River Fischa and Wiener Neustädter Canal (WNC) in 2018. ur…upper reach, lr…lower reach, SU…survey unit, nk…not mapped
$^{1)}$ UBA 2019, $^{2)}$ length measured during survey 2018 via GPS

	Fischa ur	**Fischa lr**	**Fischa total**	**WNC ur**	**WNC lr**	**WNC total**
length (km)	$25^{1)}$/ $28^{2)}$	$26^{1)}$/ $24.5^{2)}$	$51^{1)}$/ $52.5^{2)}$	17	18	$36^{1)}$
total catchment (km²)$^{1)}$	62.5	518.6	581.1			1 295.21
number of SU	65	43	109	27	62	89
average length of SU (m)	339	710	487	626	297	397
number of *nk*-SU			23 (21%)			14 (16%)
total species number			19			9
max. species number/ SU			8			4
SU without species			6 (6%)			19 (21%)

Table 6: Chemical data: a) River Fischa. Sampling sites of the upper reach (ur): H…Haschendorf, W…Weigelsdorf, G…Gramatneusiedl; and the lower reach (lr): M…Marienthal, S…Schwadorf, F…Fischamend; b) Wiener Neustädter Canal (upper reach: T…Theresienfeld; lower reach: BV…Bad Vöslau, B…Baden, G…Guntramsdorf). Analysis of NH_4-N, PO_4 and P_{total} done by Eurofins Umwelt Österreich GmbH & Co. KG

a) Fischa

site	**km**	**section**	**temp. °C**	**cond. µS cm^{-1}**	**pH**	**NH_4-N mg l^{-1}**	**PO_4 mg l^{-1}**	**P_{total} mg l^{-1}**
H	1.8	F-ur	14.4	617	7.5	0.014	0.007	0.011
W	10.3	F-ur	14.6	810	7.7	0.014	0.007	< 0.005
G	24.0	F-ur	14.2	650	7.9	< 0.010	0.007	< 0.005
M	25.0	F-lr	15.6	650	8.0	0.043	0.023	0.019
S	35.2	F-lr	18.2	671	8.1	0.018	0.018	0.029
F	39.4	F-lr	19.4	677	8.2	0.017	0.018	0.010

b) Wiener Neustädter Canal

site	**km**	**section**	**temp. °C**	**cond. µS cm^{-1}**	**pH**	**NH_4-N mg l^{-1}**	**PO_4 mg l^{-1}**	**P_{total} mg l^{-1}**
T	5.9	W-ur	21.3	446	8.4	< 0.01	0.022	0.036
BV	18.4	W-lr	22.4	531	8.5	0.032	0.021	0.042
B	22.3	W-lr	23.0	685	8.3	0.110	0.012	0.026
G	31.7	W-lr	23.4	615	8.6	0.020	0.076	0.104

Passing downstream in both surface waters temperature and pH values were increasing, even though nutrient levels were fluctuating to some extent. In the River Fischa, the data showed a clear enrichment at the measuring site located directly after the confluence with River Piesting (Tab.6, Marienthal). In WNC the two most downstream measuring points (Tab.6) showed the highest concentration of ammonium nitrogen (sampling point: Baden) and phosphorus (sampling point: Guntramsdorf).

6.2. Environmental parameters

All the following descriptions refer to observations, or measurements, during the recording in August 2018.

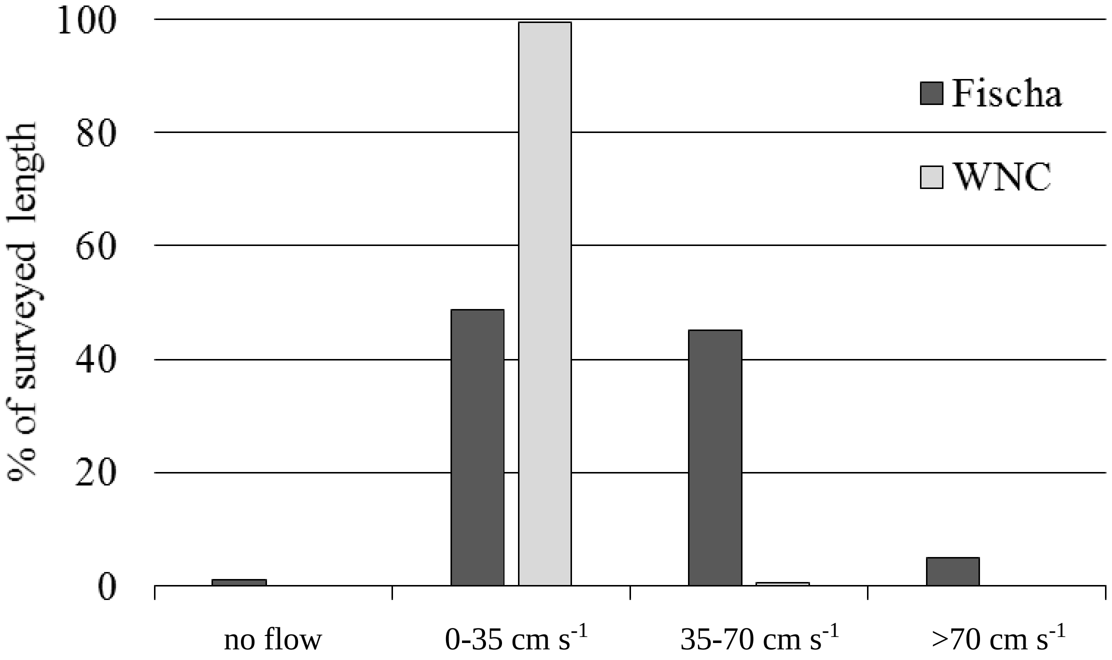


Fig.5: River Fischa and WNC: Flow class distribution

Flow velocity. Water flow in River Fischa was quite more diverse than in the Wiener Neustädter Canal (Fig.5). At the time of this study flow velocity was recorded in four categories. About 49 % of the surveyed river length was characterized by a flow velocity of 0-35 cm s^{-1}, but closely followed by velocities of 35-70 cm s^{-1} (45 % of surveyed length). In the Wiener Neustädter Canal, almost constant flow velocities of 0- 35 cm s^{-1} (99%) were recorded along the whole length of the canal. Only 1% of the surveyed canal length showed faster flow (35-70 cm s^{-1}). These values are based on the mean values of the individual survey units. Differences in velocity within a single survey unit may be caused by the backwater of former locks or power plants.

Shaddow. Depending on the size of vegetation growing over the water surface (large bushes, trees, etc.) shading effects were calculated by shading in percent of survey unit area (Fig.6). As direct shade of vegetation changes with sun position over the day another way of assessing shading effect was to estimate overhanging parts of riparian vegetation in classes. In August 2018 River Fischa was characterised by a broad spectrum of shading categories, as 41% of the surveyed length were shaded to the extent of 50-75% and only 1.5% were exposed to full sunlight. Wiener Neustädter Canal was dominated by one class (no shading, 92%) for most of its length.

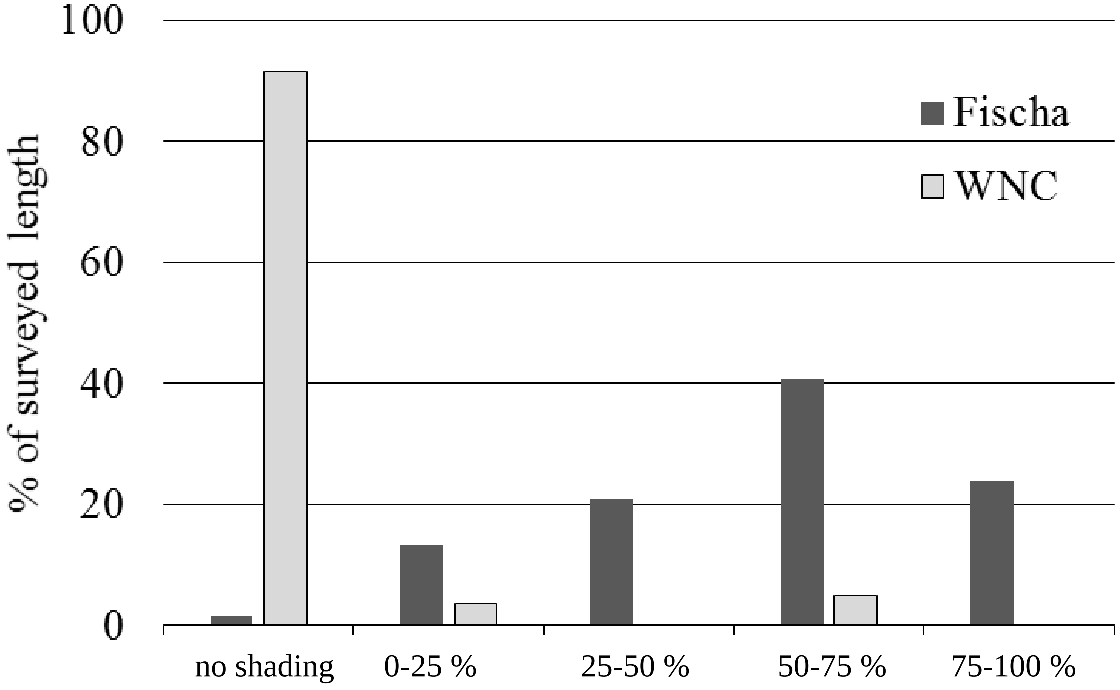


Fig.6: River Fischa and WNC: Shading of water surface (%)

Banks. Various forms of banks appear in the River Fischa, i.a. shallow, near-natural areas, steep eroded undercut banks, as well as heavily modified shapes (rip-raps, concrete, etc.).
On the other hand, the Wiener Neustädter Canal is bordered by steep and high artificial banks. There are no sharp bends or meanders, like in River Fischa. In the lower reach of the canal the 'continuum of flow,' is frequently constrained by narrowed passages of former locks who's gates had been removed. At some of these locations small hydropower plants are still in use today. There the cross section is narrowed by concrete walls of the former locks. This causes turbulences directly after the lock site, then calming down until it the backwater of the next lock is reached.

Sediments. In River Fischa the variety of different grain sizes is much greater, than in Wiener Neustädter Canal. The dynamic currents in the former produce very variable substrates in stretches of potential macrophyte habitats. In contrast, as a consequence of the impoundments, the flow velocity in Wiener Neustädter Canal is slow and fine sediments are accumulating between the locks. As well, the rather constant water flow is insufficient for transporting gravel.

6.3. Species

Species list. In this survey, a total number of 21 species of submerged and partly amphiphytic plants was detected in 198 survey units, comprising the entire lengths of the two waterbodies. Altogether 27 different macrophyte taxa were recorded in these two water bodies over the last decades (Tab.7). 19 species were recorded in at least two surveys.

Table 7: List of species detected in River Fischa and Wiener Neustädter Canal during the studies. Abbr.: abbreviated genus and species names. Verification of species names follows The Plant List (www.theplantlist.org) and algaebase (www.algaebase.org). *… vulnerable/ endangered according to Niklfeld H. & Schratt-Ehrendorfer L. (1999)

WNC presence				**abbr.**	**species name**	**FISCHA presence**		
1992	1994	1999	2018			1979	1999	2018
				Ber ere	*Berula erecta* (Huds.) Coville	X	X	X
				Cal ham*	*Callitriche hamulata* Kütz. ex W.D.J. Koch		X	
				Cal sp.	*Callitriche sp.*	X		X
				Cha glo	*Chara globularis* Thuiller		X	X
				Cha vul	*Chara vulgaris* L.	X		
X	X	X	X	Elo can	*Elodea canadensis* Michx.	X	X	X
				Gly flu	*Glyceria fluitans* (L.) R.Br.	X	X	X
				Gro den*	*Groenlandia densa* (L.) Fourr.	X	X	X
				Lem tri	*Lemmna trisulca* L.	X		
				Myo sco	*Myosotis scorpioides* L.		X	X
X	X	X	X	Myr spi	*Myriophyllum spicatum* L.	X	X	X
				Myr ver	*Myriophyllum verticillatum* L.	X		
				Nas off*	*Nasturtium officinale* R.Br.		X	X
				Nit opa	*Nitella opaca* C. Agardh	X		
			X	Nym alb	*Nymphaea alba* L.			
			X	Per amp	*Persicaria amphibia* (L.) Delarbre			
				Pha aru	*Phalaris arundinacea* L.		X	X
X	X	X	X	Pot cri	*Potamogeton crispus* L.	X	X	X
				Pot obt*	*Potamogeton obtusifolius* Mert. & W.D.J.Koch		X	X

WNC presence				**abbr.**	**species name**	**FISCHA presence**		
1992	1994	1999	2018			1979	1999	2018
X	X	X	X	Pot per	*Potamogeton perfoliatus* L.	X		X
				Ran cir*	*Ranunculus circinatus* Sibth.	X	X	X
X	X	X		Ran tri	*Ranunculus trichophyllus* Chaix ex Vill.	X	X	X
X	X	X	X	Stu pec	*Stuckenia pectinata* (L.) Börner	X	X	X
				Tol glo	*Tolypella glomerata* (Desvaux) Leonhardi		X	
			X	Ver ana	*Veronica anagallis-aquatica* L.		X	X
				Ver bec	*Veronica beccabunga* L.			X
	X		X	Zan pal	*Zannichellia palustris* L.	X	X	X
6	**7**	**6**	**9**		**sum**	**16**	**18**	**19**

In both water bodies a slightly increasing species number was recognised as an overall trend over the years.

Four species were found in both waterbodies in every year: *Elodea canadensis*, *Myriophyllum spicatum*, *Potamogeton crispus*, *Stuckenia pectinata*. Among others *Nitella opaca* and *Persicaria amphibia* were only found once.

Spatial distribution of species. The following diagrams and data are generated and printed with permission from the free service provided by www.midcc.at © 2001-2018 by Exler Norbert.

The detailed spatial distribution of species in August 2018 is illustrated in the distribution diagram (Fig.7). The depicted lengths of the survey units are proportional to the actual length. The height of the black bars indicates the abundance of species in each survey unit. For reasons of practicability, the scale of five categories is combined to a three-level scale (Janauer & Kohler 1995).

In 2018 River Fischa was characterised by the frequent occurrence of *Berula erecta* (Fig.7). Its main distribution lied in the upper river stretch, while it only colonized few survey units in the lower reach. The river was clearly split into two sections. Most of the recorded species concentrated their occurrence on either the upper or the lower reach. The only three species developing considerable biomass in both sections were *Berula erecta*, *Veronica anagallis-aquatica* and *Veronica beccabunga*.

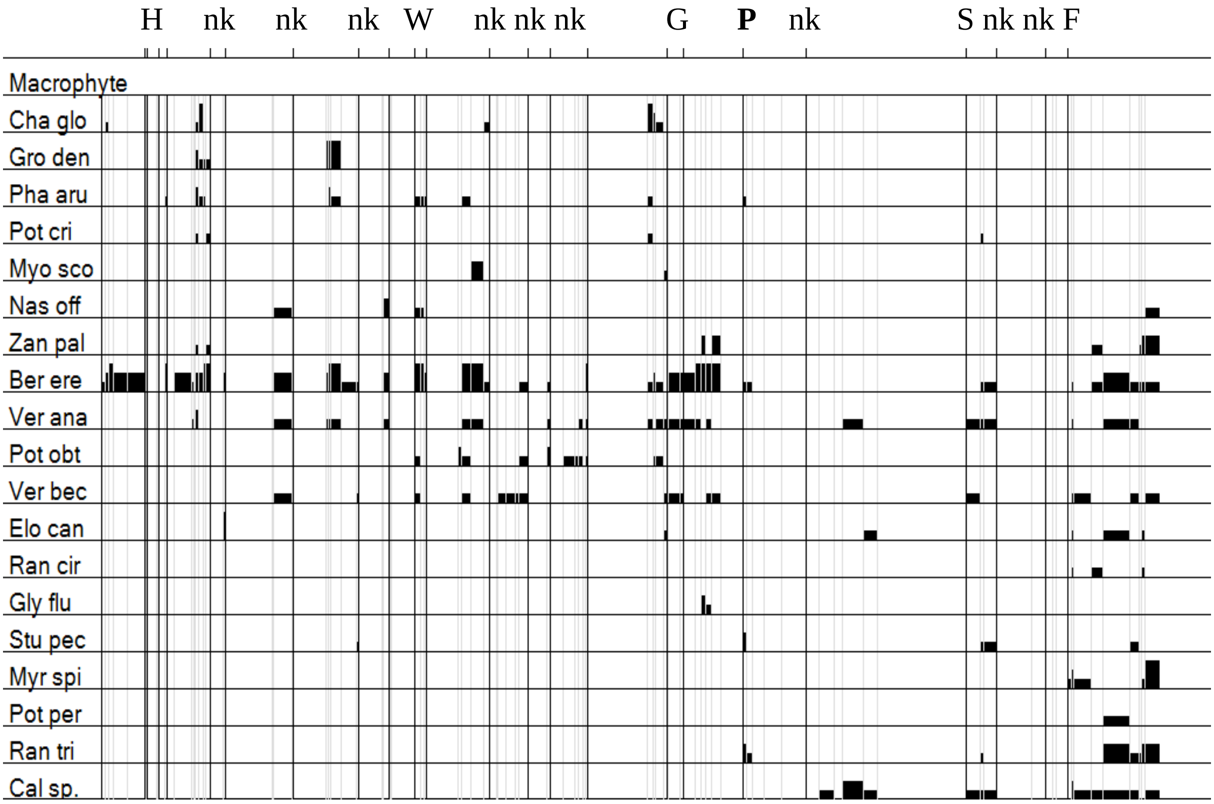


Fig.7: River Fischa: Distribution diagram (Survey 2018). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped. Measuring points: H…Haschendorf, W…Weigelsdorf, G…Gramatneusiedl, P…confluence with River Piesting, S…Schwadorf, F…Fischamend

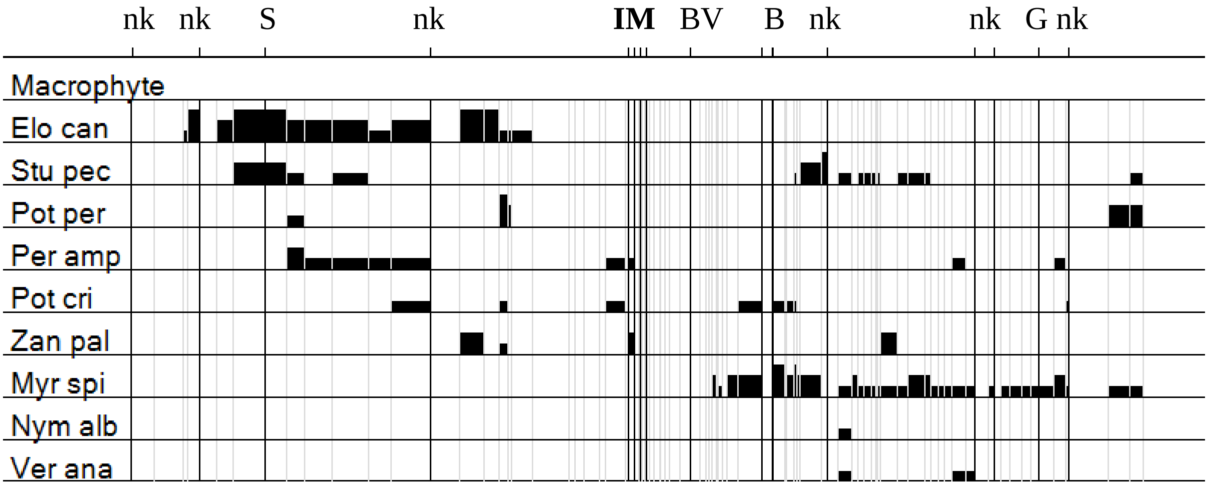


Fig.8: Wiener Neustädter Canal: Distribution diagram (Survey 2018). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped. Measuring points: S…Sollenau, IM…beginning of impoundments, BV…Bad Vöslau, B…Baden, G…Guntramsdorf

Fig. 8 shows the distribution of species in the Wiener Neustädter Canal in 2018. The upper reach was dominated by *Elodea canadensis*. The most common species in the lower reach was *Myriophyllum spicatum*.

Indicator species analysis (ISA). Even though distribution diagrams already indicate present differences in macrophyte species composition between the two waterbodies, the application of an Indicator Species Analysis enables to gain even more detailed information about community distinctions. Analysis of the most recent data (survey 2018) reveals the current characteristic species for the specific water bodies or sections and whether the water bodies can be distinguished by their inhabiting plants.

The conducted permutational analysis provides information about significant occurrences.

Reading Tab.8, a value of 0 means no indication, whereas 100 stands for perfect indication.

Table 8: River Fischa and WNC: Indicator species analysis (2018). This table shows the indicator values (IV), significance ($p \leq 0.05$ marked in bold) and relative frequency (%) of species in the respective waterbody (F…Fischa, W…WNC) and section (ur…upper reach, lr…lower reach). Abbreviations of species names: see Tab. 7.

2018

species	**indicator value (IV)**	**p- Value**	**relative frequency (%) in reach**			
			F-ur	**F-lr**	**W-ur**	**W-lr**
Pha aru	58.3	**0.002**	**23**	5	0	0
Pot obt	43.2	**0.005**	**18**	5	0	0
Nas off	39.9	**0.010**	**12**	2	0	0
Gro den	37.0	**0.013**	**11**	0	0	0
Myo sco	19.4	0.571	3	2	0	0
Cal sp.	59.4	**0.001**	0	**28**	0	0
Ran tri	48.5	**0.001**	0	**19**	0	0
Ran cir	28.8	0.061	2	7	0	0
Gly flu	24.3	0.069	0	5	0	0
Elo can	91.6	**0.001**	3	12	**55**	0
Per amp	56.9	**0.001**	0	0	**22**	4
Pot per	37.1	**0.015**	0	2	**11**	5
Myr spi	87.5	**0.001**	0	12	0	**61**
Nym alb	15.6	0.672	0	0	0	2

species	indicator value (IV)	p-Value	relative frequency (%) in reach			
			F-ur	**F-lr**	**W-ur**	**W-lr**
Ber ere	84.0	**0.001**	**60**	**49**	0	0
Ver ana	60.8	**0.001**	**26**	**35**	0	5
Ver bec	49.7	**0.001**	**17**	**23**	0	0
Cha fra	32.5	0.092	9	7	0	0
Stu pec	50.9	**0.007**	2	9	**15**	**21**
Zan pal	34.8	0.084	3	**14**	**7**	3
Pot cri			3	5	11	8

The highest number of indicator species was found in the upper reach of River Fischa. Four species were primarily found in this section: *Phalaris arundinacea, Potamogeton obtusifolius, Nasturtium officinale* and *Groenlandia densa*. Two others (*Callitriche* sp. and *Ranunculus trichophyllus*) were exclusively recorded in the lower reach.

Combining both river sections, *Berula erecta*, as well as two *Veronica* species (*V. anagallis-aquatica* and *V. beccabunga*) were proven significantly characteristic for the vegetation of River Fischa.

In the Wiener Neustädter Canal three species in the upper reach (*Elodea canadensis*, *Persicaria amphibia* and *Potamogeton perfoliatus*) and one species (*Myriophyllum spicatum*) in the lower reach showed statistical significance.

Stuckenia pectinata was the only species reaching significance in both reaches and, therefore, can be assumed as characteristic for WNC.

One species, *Potamogeton crispus*, did not show any indicative character, as it occurs in all of the sites regularly.

Historical development. As illustrated in Fig. 7 and the following two diagrams, the most common species in River Fischa over the total river length and throughout all surveyed years was *Berula erecta*. Although its main distribution was located in the upper reach of the river, it also inhabited some sites in the lower reach. It was associated with various other species that alternate in appearance and quantity.

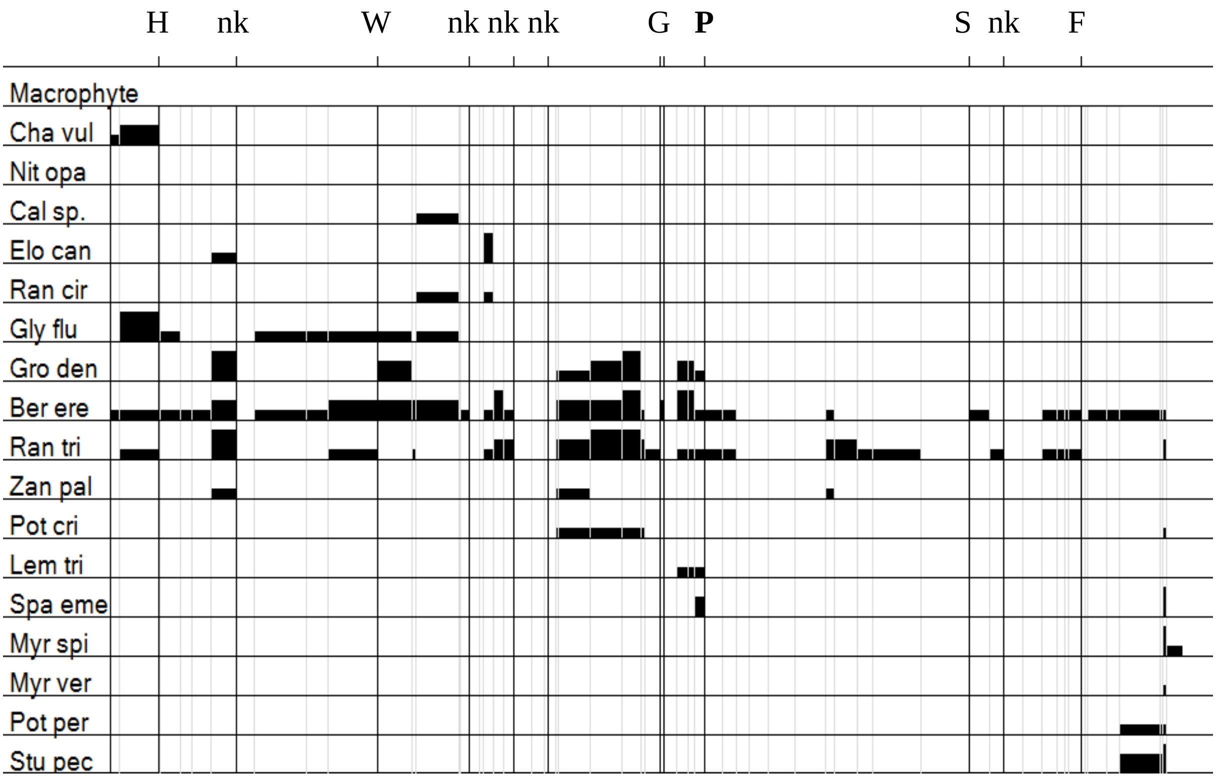


Fig.9: River Fischa: Distribution diagram (Survey 1979). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped. Abbreviation of measuring points: see Fig.7.

In 1979 (Fig.9), *Berula erecta* was mostly accompanied by *Ranunculus trichophyllus*. Among other rare species, some spots of *Lemna trisulca*, *Myriophyllum verticillatum* and *Nitella opaca* were recorded. Whereas some species occurred only in the upper reach of River Fischa (*Chara vulgaris*, *Callitriche sp.*, *Elodea canadensis*, *Ranunculus circinatus* etc.), some others were only found in the lower part (i.a. *Myriophyllum spicatum*, *Potamogeton perfoliatus* and *Stuckenia pectinata*).

The survey of 1999 (Fig.10) was dominated by a high vegetation cover in the upper reach of River Fischa. Especially *Berula erecta* occurred frequently in quite high amounts. *Ranunculus trichophyllus* lost most of its distribution and was only found in few survey units. The lower reach was only sparsely populated by five species: *Myosotis scorpioides*, *Myriophyllum spicatum*, *Ranunculus trichophyllus*, *Stuckenia pectinata* and *Veronica anagallis-aquatica*.

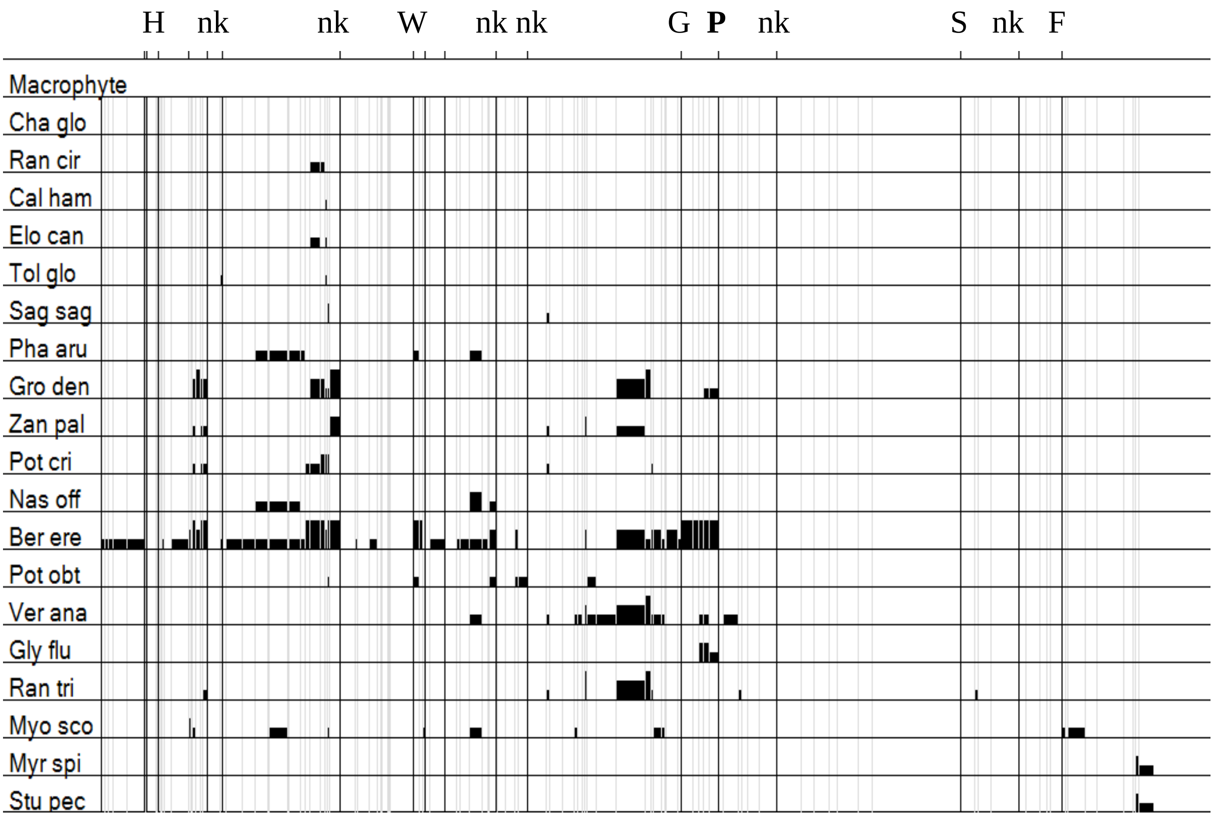


Fig.10: River Fischa: Distribution diagram (Survey 1999). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped. Abbreviation of measuring points: see Fig.7.

The survey of 2018 (Fig.7) resulted in a species inventory quite similar to the one of 1999. Many of the then occurring species were found again. Several of them changed in their plant mass and distribution pattern, but *Berula erecta* still dominated the picture.

Two species of Veronica (*V. anagallis-aquatica* and *V. beccabunga*) expanded their distribution and were now found evenly along the whole river.

Even though the difference in plant cover between upper and lower reach was not as apparent as in 1999, still the upper part hosted more aquatic vegetation than the lower one. The section between the confluence with River Piesting and Schwadorf only inhabitated 7 species.

The situation looks different in Wiener Neustädter Canal. In Fig. 8 and the following three diagrams the dominance of two species becomes apparent: *Elodea canadensis* and *Myriophyllum spicatum* – but distinctly separated from each other, as they had their main area of distribution in different sections of the waterbody.

The survey of 1992 (Fig.11) was characterized by the quantitatively dominating occurrence of the both above-named species. Additionally, *Stuckenia pectinata* was found widespread along the course of the canal.

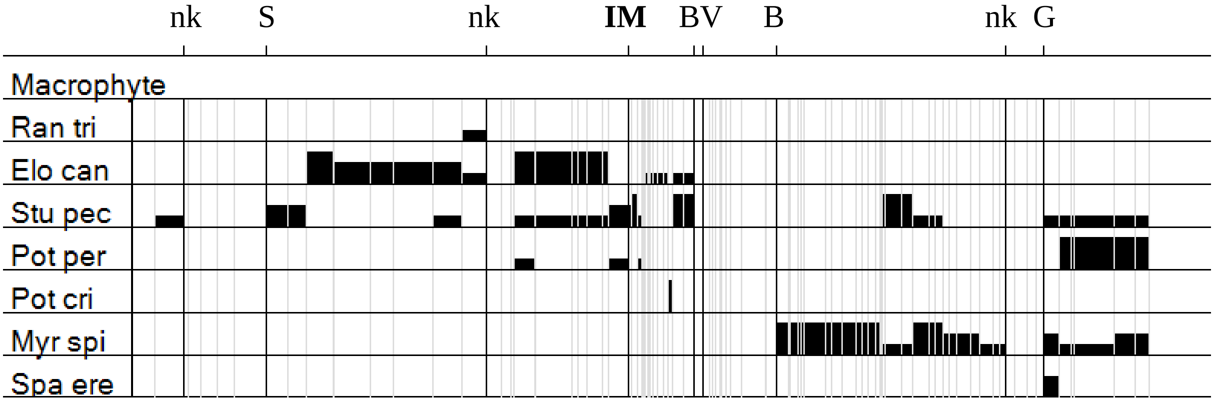


Fig.11. Wiener Neustädter Canal: Distribution diagram (Survey 1992). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped, Abbreviation of measuring points: see Fig.8.

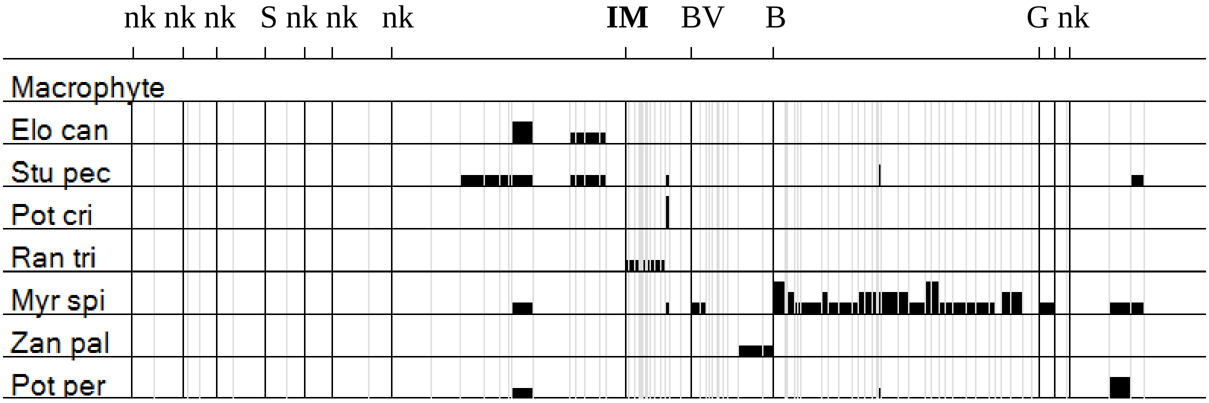


Fig.12. Wiener Neustädter Canal: Distribution diagram (Survey 1994). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped, Abbreviation of measuring points: see Fig.8.

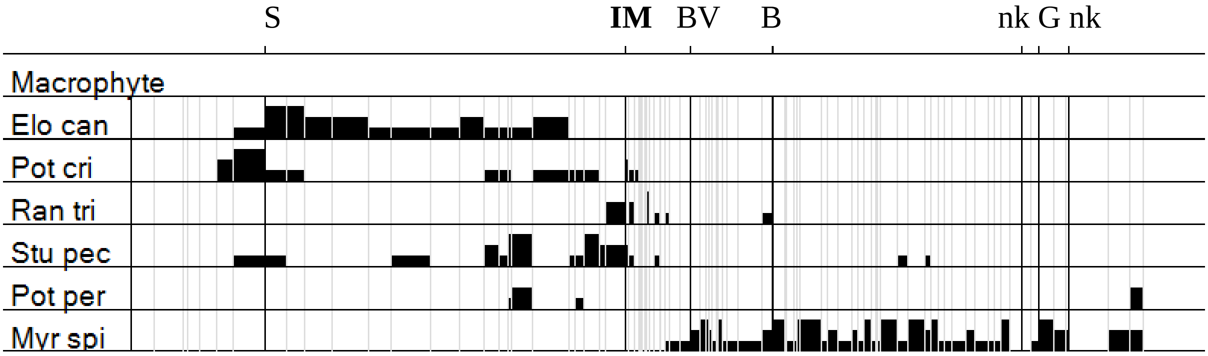


Fig.13. Wiener Neustädter Canal: Distribution diagram (Survey 1999). The height of the black bars shown in three levels, indicate the abundance classes 1+2/3/4+5. Abbreviation of species names: see Table 7, nk…"nicht kartiert"/ not mapped, Abbreviation of measuring points: see Fig.8.

Two years later (in 1994, Fig.12) the upper reach of WNC was not investigated continuously. Most of the survey units were not mapped. In the lower reach *Myriophyllum spicatum* maintained its high prevalence.

Based on the surveys of 1999 (Fig.13) and 2018 (Fig.8) the main distributions of species more or less stayed the same. In 2018 some more occasional species were recorded, i.a. *Persicaria amphibia*, *Nymphaea alba* and *Veronica anagallis-aquatica*.
Overall, the species turnover was quite low over the surveyed years.

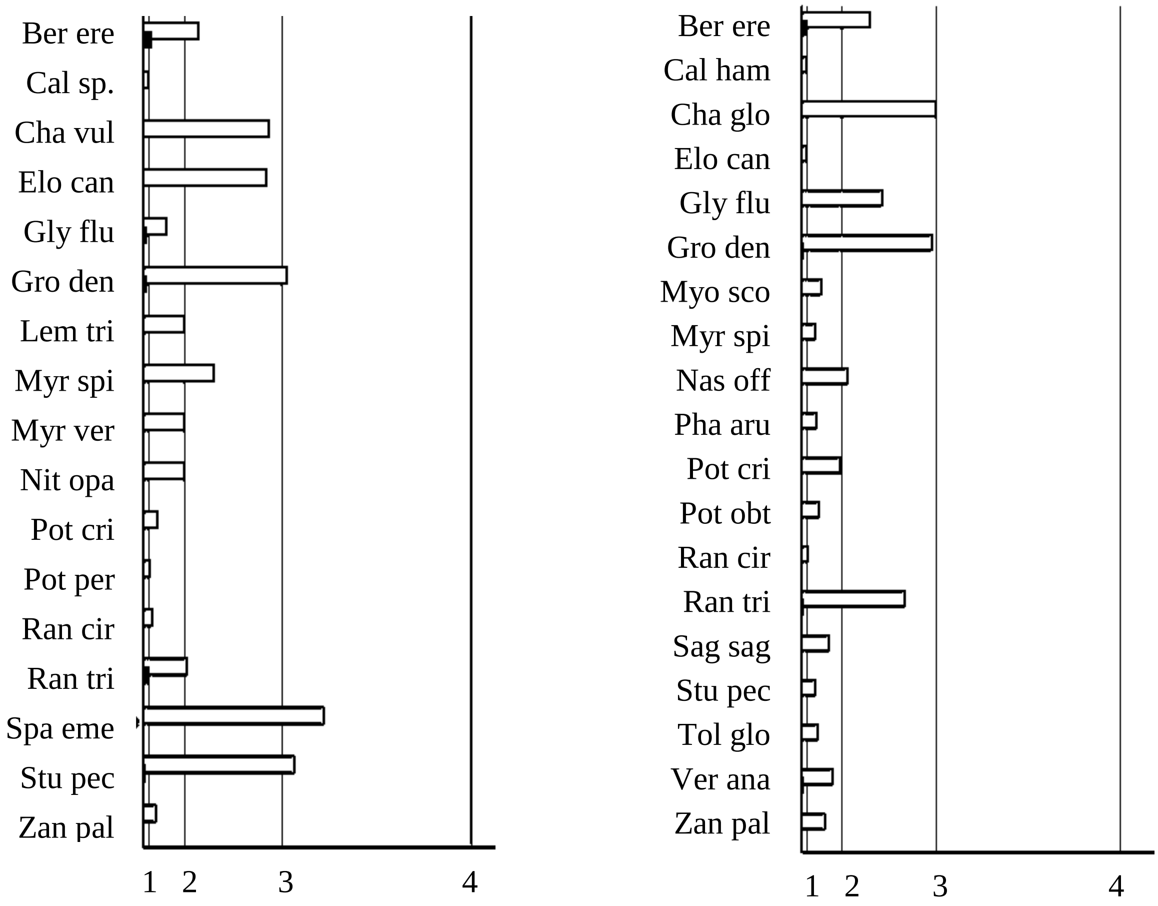
The calculation of mean mass indices MMT (mean mass index over all survey units) and MMO (mean mass index of all survey units with presence of the specific species) is displayed in Fig.14 and Fig.15.
Some species in River Fischa (Fig.14) had relatively high MMO values. In regard to MMT, values are too low to be shown in this figure. *Berula erecta* was the only species, who had some notable holistic distribution in all three survey campaigns.

Some aquatic species in the Wiener Neustädter Canal showed very high MMO values (Fig.15, *Potamogeton crispus*), but very low values for MMT as well. *Elodea canadensis*, *Myriophyllum spicatum* and *Stuckenia pectinata* were the most evenly distributed species over the whole canal length.

In Fig.16 and Fig.17, species are ranked regarding abundance and the length of their survey units. Species below 1% RPM are combined in “Residual”.
In River Fischa the dominating species was *Berula erecta* (Fig.16), with up to 30% of the relative plant mass. Residuals’ group of species added up to 2 to 4%. This group includes the ‘rare’ species.
In the Wiener Neustädter Canal three different species dominated the picture (Fig.17). In three campaigns of survey *Myriophyllum spicatum* was first in dominance (RPM = 30-50%). It was followed by *Elodea canadensis* and *Stuckenia pectinata.*

a) 1979

b) 1999



c) 2018

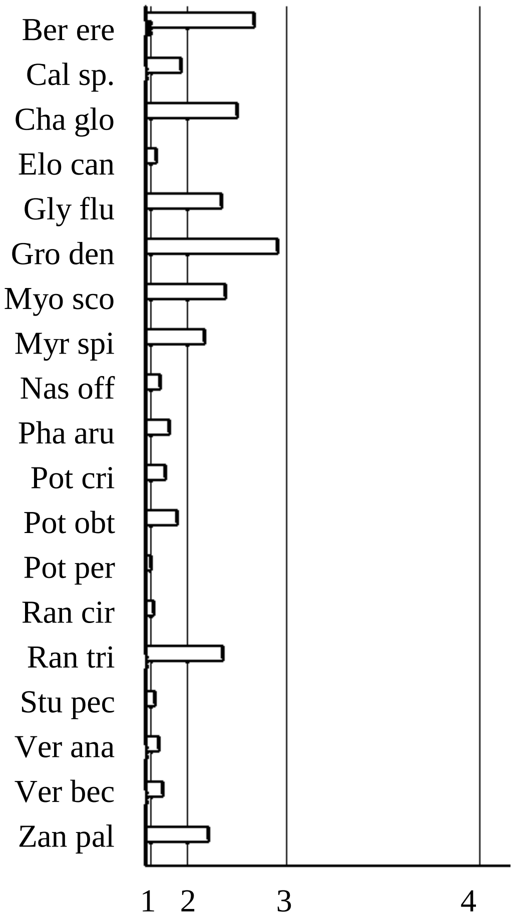


Fig.14: River Fischa: mean mass indices (MMO, MMT) (a) 1979, b) 1999, c) 2018).

blank bars…MMO, black bars…MMT
Abbreviation of species names: see Table 7

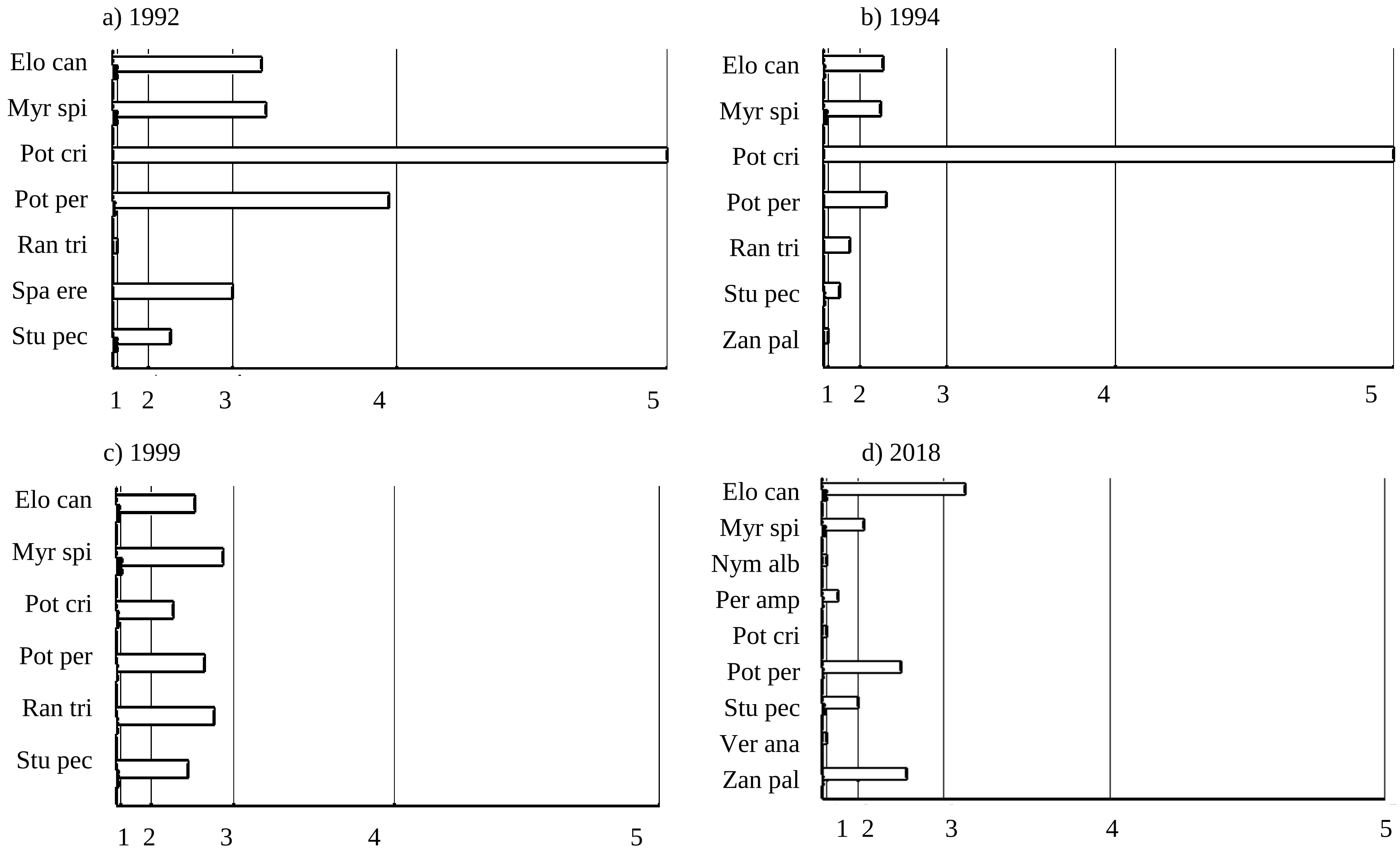
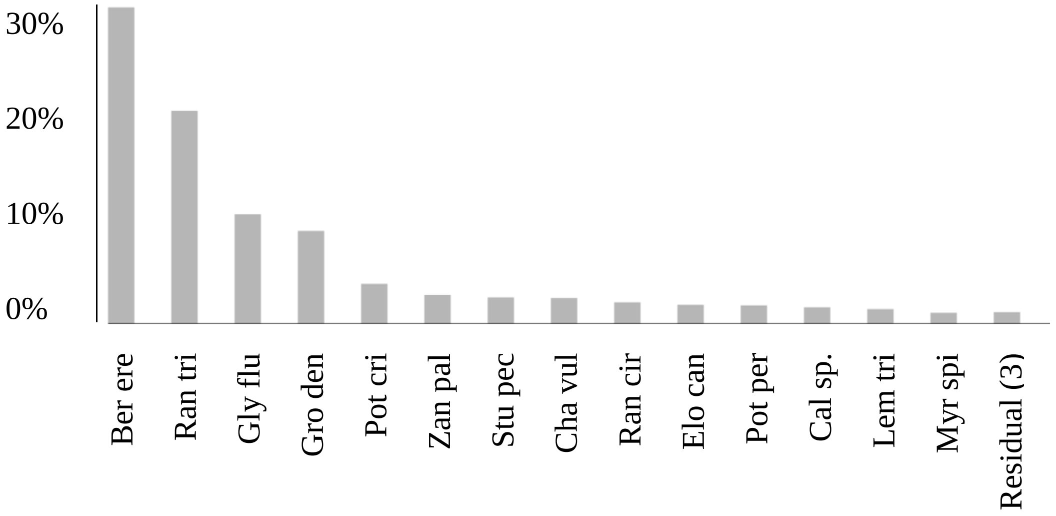
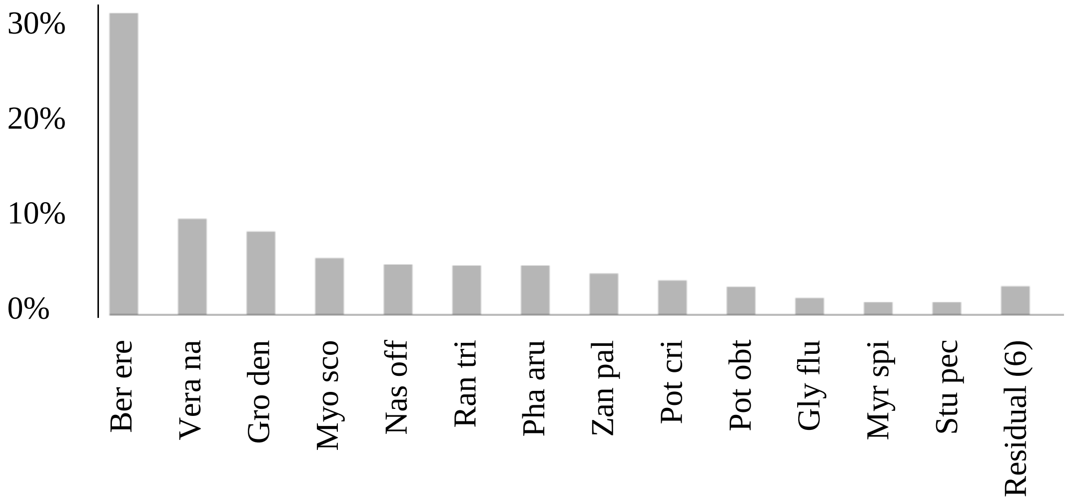


Fig.15: Wiener Neustädter Canal: Mean mass indices (MMO, MMT) (a) 1992, b) 1994, c) 1999, d) 2018). blank bars…MMO, black bars…MMT, Abbreviation of species names: see Table 7

a) 1979



b) 1999



c) 2018

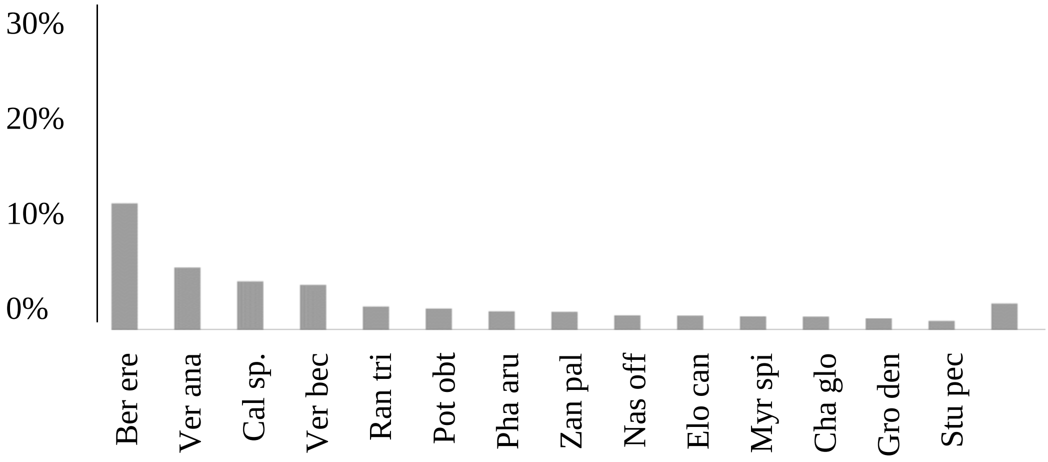


Fig.16: River Fischa: Relative plant mass (RPM) (a) 1979, b) 1999, c) 2018). Residual…Sum of all species with RPM < 1%. Brackets: number of residual species. Abbreviation of species names: see Table 7

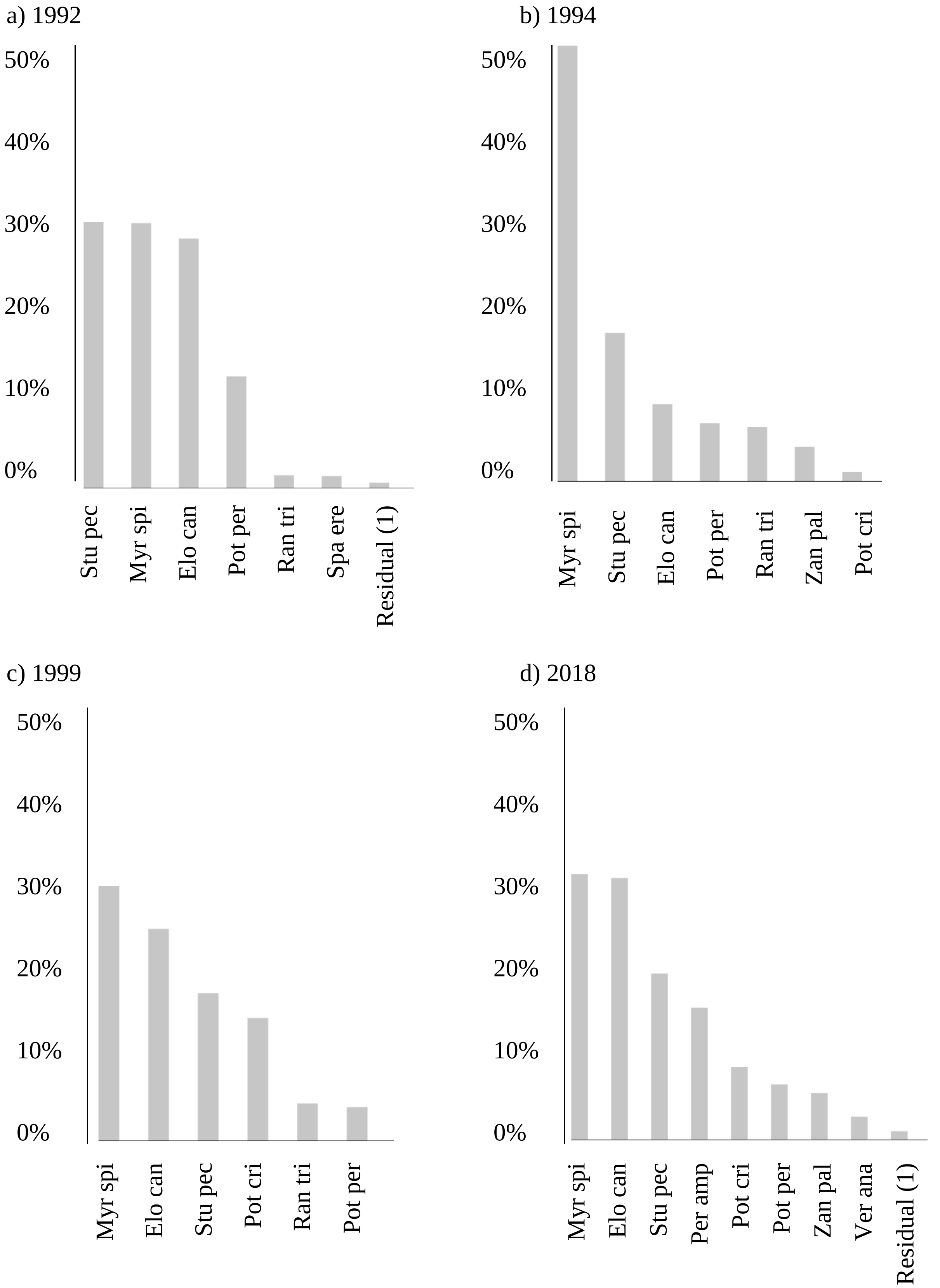


Fig.17: Wiener Neustädter Canal: Relative plant mass (RPM) (a) 1992, b) 1994, c) 1999, d) 2018). Residual…species with RPM < 1%. Brackets: number of residual species. Abbreviation of species names: see Table 7

Non-metric Multidimensional Scaling (NMDS). Fig.18 and Fig.19 give an overview over the changes in species abundance over the recorded years. As centroids depict the center of the respective point clouds, the ordinations state clearly that some years have a more similar species composition than other years.

Stresslevels of the ordination lie at 0.18 (Fischa) and 0.13 (Wiener Neustädter Canal), which provides good representation of the actual proportions.

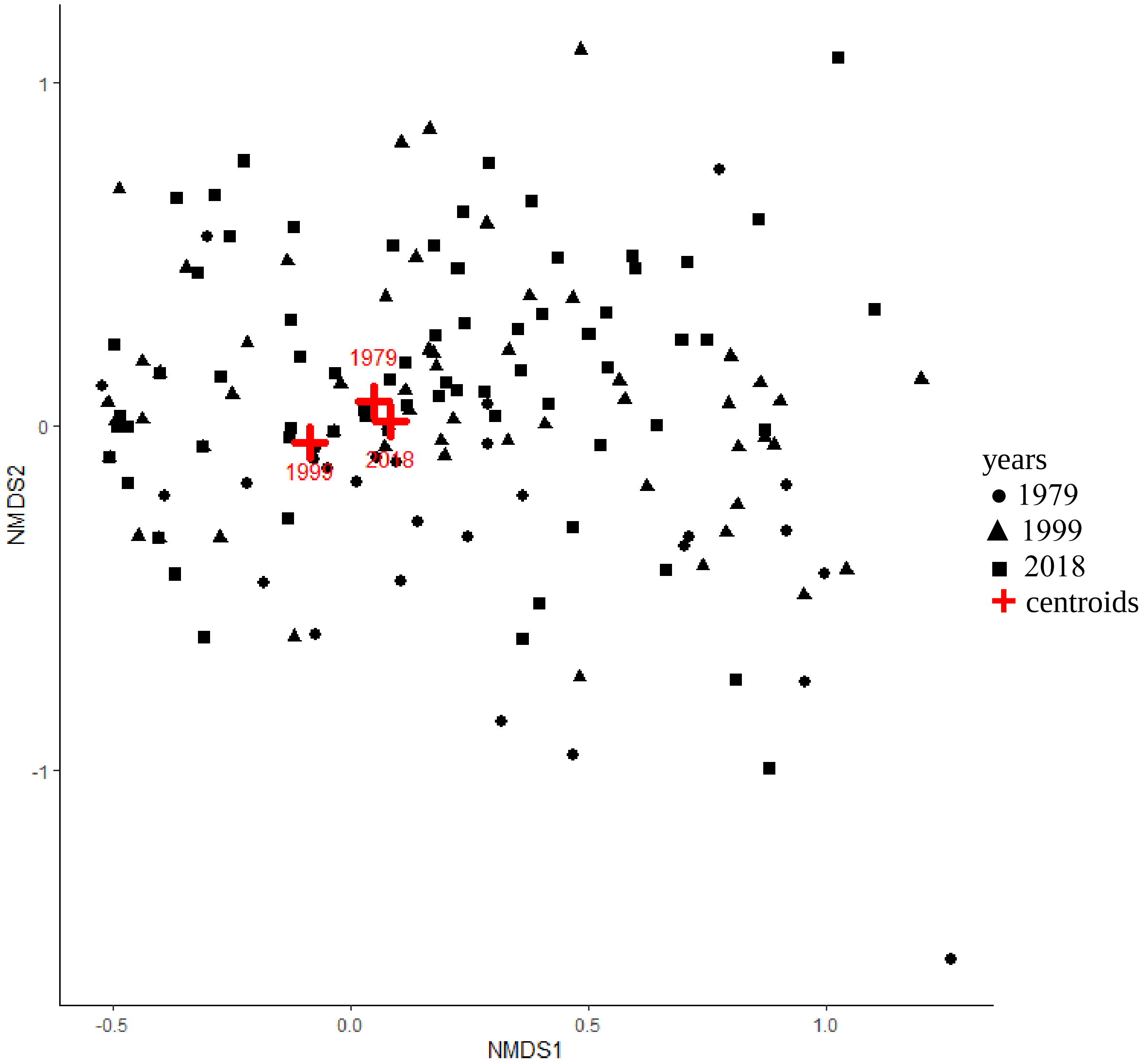


Fig.18: River Fischa: Non-metric Multidimensional Scaling (NMDS) ordination of all survey units (1979, 1999, 2018). Centroid values depicted as **+** (bold crosses).

The results of the pairwise permutational multivariate analysis of variance (PERMANOVA) show statistical evidence for some of the assumed differences in the abundance data of the conducted surveys in River Fischa (Tab.9).

There are significant differences in the macrophyte community between the years 1979 and 2018, as well as 1979 and 2018, but not for 1979 and 1999.

Table 9: River Fischa: Pairwise permutational multivariate analysis of variance (PERMANOVA). F-statistics and p-Values (adjusted by Holm 1979; $p \leq 0.05$ marked in bold; three decimals only).

years	F	adjusted p-value
Fischa		
1979 vs. 1999	3.367	0.048
1979 vs. 2018	5.770	**0.003**
1999 vs. 2018	6.979	**0.003**

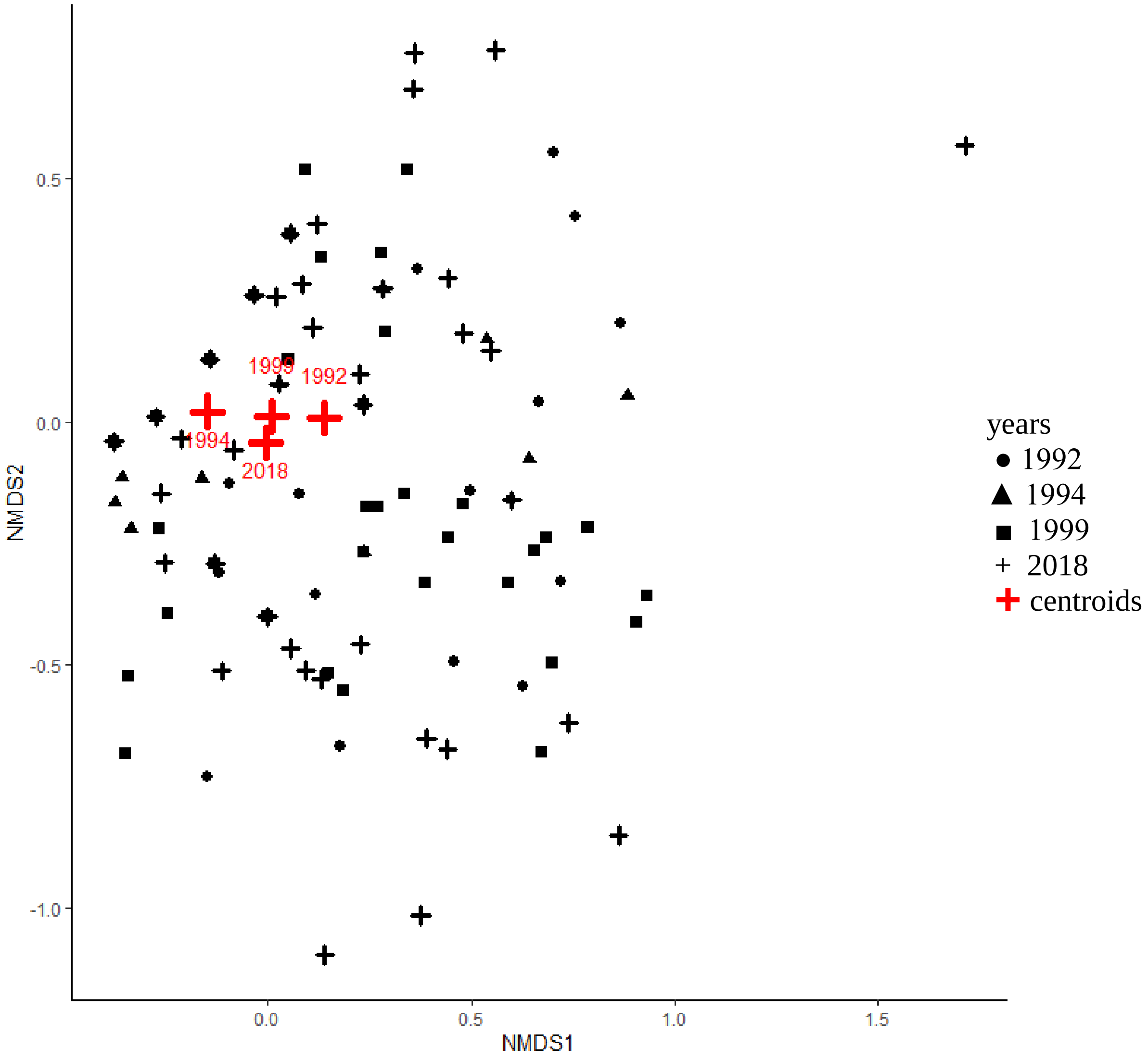


Fig.19: Wiener Neustädter Canal: Non-metric Multidimensional Scaling (NMDS) ordination of all survey units l (1992, 1994, 1999, 2018). Centroid values depicted as **+** (bold crosses).

Concerning WNC, the permutation shows some significant results, but for 1994 vs. 1999, and 1994 vs. 2018, the results are not significant (Tab.10, p > 0.05).

Table 10: WNC: Pairwise permutational multivariate analysis of variance (PERMANOVA). F-statistics and p-Values (adjusted by Holm 1979; $p \leq 0.05$ marked in bold; three decimals only).

years	F	adjusted p-value
WNC		
1992 vs. 1994	9.765	**0.006**
1992 vs. 1999	3.894	**0.006**
1992 vs. 2018	7.001	**0.006**
1994 vs. 1999	4.273	0.018
1994 vs. 2018	2.515	0.246
1999 vs. 2018	5.043	**0.006**

Simpson diversity. Calculation of the Simpson diversity index incorporates abundance data of each individual survey unit that shows some plant cover and therefore allows more detailed analysis than presence-absence data. It also enables comparing results of different rivers and river sections directly.

Table 11: River Fischa and WNC: Mann-Whitney two-sample test of Simpson diversities. Depicted are U-statistics and p-Values ($p \leq 0.05$ marked in bold)

Waterbody/Section/Year	**U-Value**	**p-Value**
F-UR all vs. F-LR all	3 991.5	0.5623
F 1979 vs. F 1999	1 744.0	0.5360
F 1999 vs. F 2018	2 511.5	0.1244
F 1979 vs. F2018	1 515.0	0.4404
W-UR all vs. W-LR all	3 795.5	**< 0.0001**
W 1992 vs. W 1994	2 146.5	**0.03641**
W 1994 vs. W 1999	1 884.5	0.1226
W 1999 vs. W 2018	1 564.0	**0.005422**
W 1992 vs. W 2018	1 321.5	**0.007641**
W 1994 vs. W 2018	969.5	**< 0.0001**
F all vs. W all	34 888.0	**< 0.0001**

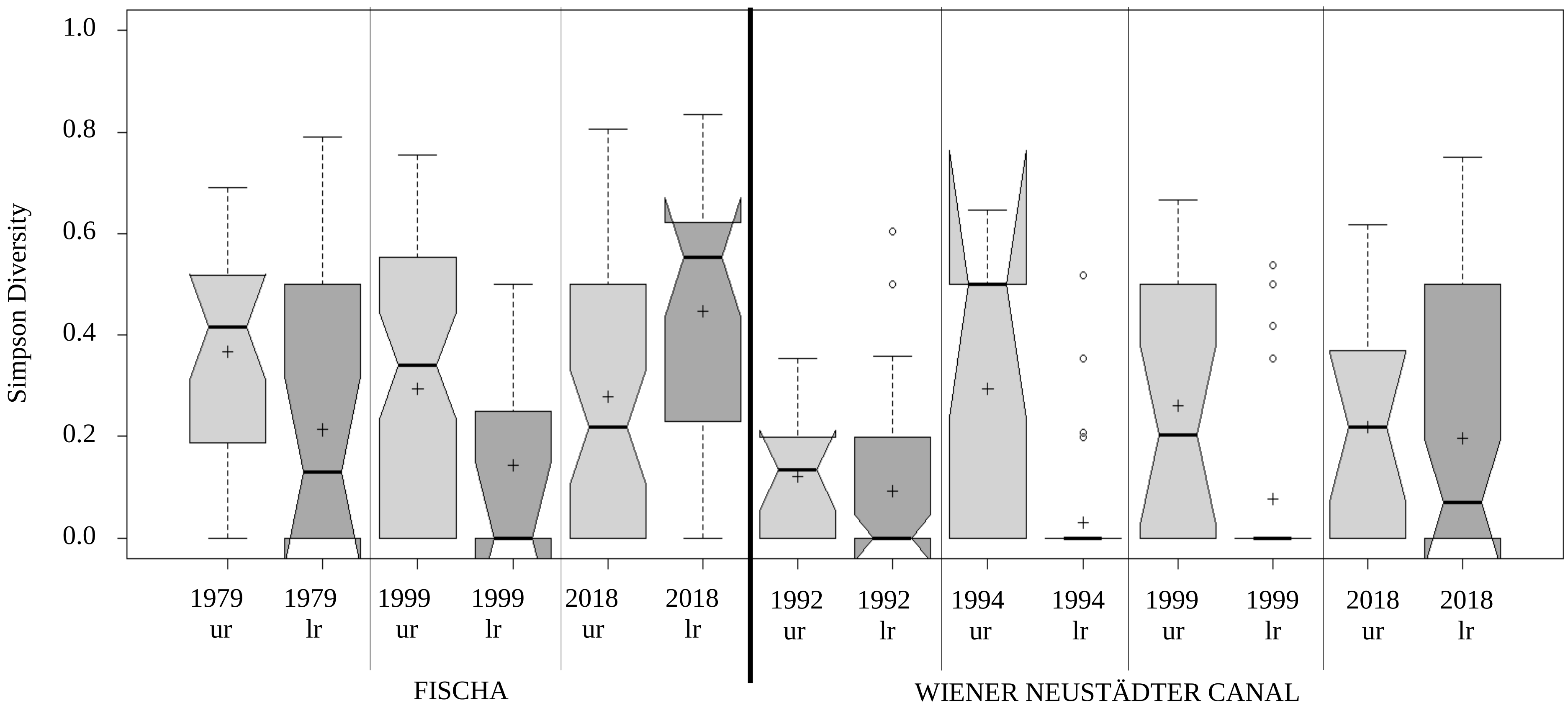


Fig.20: River Fischa and WNC: Notched Box-Plot of the Simpson Diversity Index. Left: Fischa (1979, 1999, 2018), Right: Wiener Neustädter Canal (1992, 1994, 1999, 2018), ur…upper reach, lr…lower reach. Indicated are median (central horizontal line), mean (+), interquartile range, limits (whiskers) and outliers (○).

Diversity values of the survey units in the upper reach of River Fischa show comparable means over all surveyed years. They do not differ significantly from the diversity values of the lower reach (Tab.11). Looking at the whole length of River Fischa in different survey years, there are no significant differences in Simpson diversity as well.

In Wiener Neustädter Canal we face another situation: diversity differs significantly in the upper and lower reach (Tab.11), as the upper one shows a higher value. Comparing all four years of recording, it reveals that there are also some significant differences between the individual surveys.

Overall the diversity median values of all survey units are significantly higher in River Fischa than in the Wiener Neustädter Canal (Fig.20, Tab.8, $p < 0.0001$).

7. Discussion

River Fischa and Wiener Neustädter Canal (WNC) are two waterbodies located south of Vienna in the region of the 'Viennese Basin' (Fig.1). Although flowing through the same landscape and facing the same climatic conditions, they feature very different environmental backgrounds for macrophyte growth.

The rather natural River Fischa is in contrast to the artificial Wiener Neustädter Canal. They not only differ in course formation, but also in hydromorphology and physical-chemical characteristics. Even within the individual running waters, differences in upper and lower reaches are existent.

To investigate similarities a comparison based on multivariate statistics was carried out for the two sections of each waterbody, respectively, and additionally for all survey campaigns mentioned in Tab. 3. Results confirm the hypothesis that the different environmental conditions in the river sections, as well as the historical progression lead to identifiable differences in the local macrophyte species composition.

Spatial distribution of species. As expected in the hypothesis, there are significant differences between the two waterbodies concerning their macrophyte species composition. In general, River Fischa contains more than twice as many species as Wiener Neustädter Canal. This goes well together with the fact that minimal species numbers often are correlated with very homogenous environmental conditions (Gasteiner, 2001) like they are present in artificial canals. In contrast, in more dynamic and heterogeneous systems species numbers are often enhanced, because of the higher spatial heterogeneity or diversity of habitats (Townsend et al. 1997; Baattrup-Pedersen & Riis 1999). But, following up on the investigations of Janauer et al.

(1993), species diversity alone is no distinct sign of nearly natural conditions in a river, but rather a suggestion for further analysis. According to Hrivnák et al. (2014) the historic origin of water bodies did not prove to be a solid predictor of the species richness of macrophytes, as even man-made habitats, like canals, also can provide appropriate ecological conditions for the survival of aquatic plants under particular conditions and proper management (Sipos et al. 2003; Jursa & Othahel'ová 2005; Dorotovičová 2013).

River Fischa still retains a lot of its original lowland river character, although it shows some substantial anthropogenic interventions too. The results of this study though, support the universal, but controversial Intermediate disturbance hypothesis (introduced by Connell 1978). Willby et al. (2001) took up that point and found evidence that an intermediate disturbance gradient seems to be appropriate for the conservation of species-rich aquatic vegetation. Following Townsend et al. (1997), disturbances in streams often take the form of bed movements during periods of high discharge, while stable sediment is mostly one of the key parameters for macrophyte growth. The moderate frequency and intensity of disturbances, like natural flood events could prevent the prevalence of specific adapted species and promote the development of a wide spectrum of coexisting species with different habitat requirements, as new microhabitats could establish. Even human interventions such as biologically treated sewage runoff, modification of hydrological regimes, dam and dike construction, alteration of riparian vegetation and canal realignment are just some of anthropogenic pressures, which can significantly affect the structure and functioning of macrophyte communities and indirectly also other organisms as well as ecosystems as a whole (Knehtl & Germ, 2017).

Floating-leaf plants are completely missing in the species spectrum of River Fischa, caused by the relatively high flow velocity. In comparison, Othahel'ová et al. (2007) recorded extensive distribution of *Nuphar lutea* in the slow flowing and groundwater-fed River Klatovske rameno (Slovakia). These conditions are comparable to the ones in Wiener Neustädter Canal, where the distribution of *Persicaria amphibia* is possible.

Indicator species analysis (ISA). Conducting an indicator species analysis for the survey of 2018 reveals the highest number of indicator species in the upper reach of River Fischa (Tab.8). This circumstance may have its reason in the quite homogenous and special environmental conditions of this section, most suitable for appropriately adapted species. One of them, *Groenlandia densa*, is a typical indicator for groundwater influenced systems (Janauer 1981) and is found solely upstream of the confluence with River Piesting and is categorized as "endangered" in the Austrian Red List of Species according to Niklfeld H., Schratt-Ehrendorfer L. (1999).

In the lower reach of River Fischa, downriver of the Piesting River mouth, another species turns out to be characteristic: *Ranunculus trichophyllus*. Janauer 1981 reported this species as widely spread and ubiquistic. Over the last decades, this species was in steep decline. In the years 1999 (Drofenik 2002) and 2018 only small populations could be recorded in the lower reach of the river. As the occurrence of pollution-tolerant species often increases with growing distance from the source of a river (Hrivnák et al. 2007), this species may have been one, which profited from the elevated nutrient loads in the water body before the situation of wastewater plants was improved.

In overview of the entire River Fischa three species end up being characteristic: *Berula erecta*, *Veronica anagallis-aquatica* and *Veronica beccabunga*.

Berula erecta can tolerate high percentages of shading in relatively clear river sections (Janauer 1981). It occurs extensively in the head reach of River Fischa, which is embedded in dense forest and even hardly showed any seasonal variation in biomass (Drofenik 2002). In addition to its occurrence in the clean groundwater of the upper reach, however, it can also be found under moderate eutrophic conditions (Kohler & Janauer 1995, Schweinitz et al. 2012) in the lower reach.

Riis et al. 2004 suggest *V. anagallis-aquatica* to have a high rate of biomass production and strong dispersal capacities. Because its competitiveness it is able to colonize the river in its whole length in short time span after disturbances. This applies also to *V. beccabunga*, which is mainly dispersed by plant fragments during high water flow (Les et al. 1985).

E. canadensis is one of the few species, which colonizes the very beginning of Wiener Neustädter Canal – the "triangle", a section with strong anthropogenic influence. The success of this species in this extremely unattractive section may be due to the possible trend in heavily modified water bodies towards a relatively greater abundance of species with high dispersal capacity (Sand-Jensen et al., 2000) and, like *E. canadensis*, a high amplitude in nutrient loads (Janauer 1981). In the last surveys this widespread adventive species maintained its sites of occurrence (Gasteiner 2001), but may profit from increasing temperatures in the future, as it enhances growth in warmer conditions (Zhang et al. 2015). It is commonly recorded in different waterbodies of Central Europe (Baattrup-Pedersen & Riis 1999; Othahel'ová et al. 2007; Hrivnák et al. 2009; Hrivnák et al. 2013, Kočić et al. 2014), even though there are indications of replacement by the more competitive species *Elodea nuttallii* (Simpson 1990, Barrat-Segretain 2001; Kočić et al. 2014).

The characteristic species of the lower reach of WNC is *Myriophyllum spicatum*, which is again a typical example of an ubiquistic species with wide ranging disturbance tolerance to eutrophic waters (Aiken et al. 1979; Hrivnák et al. 2007). It is one of the species, which was recorded during all conducted surveys in both waterbodies and is generally a very widespread species in Europe. For example, it was also found extensively (together with *S. pectinata*) in the Marchfeld Canal northeast of Vienna, another artificially constructed canal (Ernegger et al. 1998) and different canals in Slovakia (Dorotovičová 2013). Even though this species is mostly known from still-standing or slow-flowing water bodies, in WNC and Marchfeld Canal alike this species was also found in free flowing sections directly below weirs or locks (Ernegger et al. 1998).

Considering the entire length of Wiener Neustädter Canal only one species (*Stuckenia pectinata*) turned out to be representative for this artificial waterbody. Despite of often occurring in slow-flowing conditions (Janauer et al. 2010), it is also known as fast-growing species typical of eutrophic, disturbed environments (Janauer 1981, Sand-Jensen et al., 2000). It is able to adjust its reproductive strategy in running- and standing-water habitats (Ganie et al. 2016) and can be found globally (Kaplan 2008; Mebane et al. 2014), mainly in the lower reaches of waterbodies (Holmes & Whitton 1977, Kohler et al. 2000, Jäger 2013; Janauer et al. 2015).

Based on the occurring species the waterbodies match the EU Freshwater Habitat Group C1.2b (Mesotrophic to eutrophic waterbodies with angiosperms – European Red List of Habitats) and Group C2.3 (Permanent non-tidal, smooth-flowing watercourse – European Red List of Habitats). Both habitat types reach the qualification of 'Near Threatened' in Europe, due to their strong reduction in quality by human activities over the last decades (European Red List of Habitats 2016 – European Commission).

Historical development. Based on the data set of 2018 and some previous separate surveys (Janauer 1981; Janauer np. 1992; Janauer np. 1994; Gasteiner 2001; Drofenik 2002), a historical comparison was possible, covering a period of 39 years.

The most common species in all surveyed years were: *Elodea canadensis*, *Myriophyllum spicatum*, *Potamogeton crispus* and *Stuckenia pectinata* – all common species in Central Europa (Bubíková & Hrivnák 2018).

The graphical overview of spatial distribution of species (Fig.7-13) shows some changes in species composition over the years and along the course of the running waters. While some species maintained their "patchy" and restricted occurrence, like *Groenlandia densa,* others stayed consistently at their inhabited sites (i.a. *Myriophyllum spicatum)* or even expanded their occupied area (i.a. *Berula erecta*).

As already indicated in the distribution diagrams, the most common species of the survey in 2018 in River Fischa is *Berula erecta* (Fig.7). Janauer 1981 and Drofenik 2002 also recorded this species as very dominant. Following its MMT and MMO values (Fig.14) it was the only species that seems to have some (even if minor) influence on the river's vegetation character. A typical example of extremely aggregated growth pattern is *Groenlandia densa*, which grows in dense swaths, develops high biomass locally, but occurs at restricted few survey units only (Fig.7,9,10). Parallel to this observation is the quite low value of relative abundance and regarding MMT (Fig.14).

The occurrence of specific species, like stoneworts (*Characeae*) and the endangered species *Groenlandia densa* in the upper reach of River Fischa indicate relatively oligotrophic and pristine conditions. This cannot be expected for groundwater influenced rivers per se: Othahel'ová et al. 2007 reported several eutraphent species, like *Stuckenia pectinata*, *Zannichellia palustris* and even the alien species *Elodea canadensis* in the upper region of the groundwater fed River Klatovske rameno (Slovakia). They pointed out the indication of anthropogenic disturbance in this natural ecosystem.

In general, most of the recorded species were rare in the whole water body and additionally were not even able to build up a considerable amount of plant mass at their sites. The existence of macrophytes was detected in more than 90% (Fischa) and almost 80% (WNC) of the surveyed units, but in relatively low abundance. This is similar to the findings of Janauer et al. (2015) described for the River Danube,

Of particular note is that the lower reach of River Fischa showed hardly any vegetation in the survey of 1999 (Fig.10). Drofenik 2002 explained this situation by extremely strong turbidity of water after confluence with River Piesting. Particle load of water strongly limits light transmission and therefore causes low macrophyte abundances in turbid sites (Mebane et al. 2014; Son et al. 2018).

Enhanced turbidity in the lower reach of River Fischa may be caused by (1) heavy construction activities in the catchment of River Piesting. For instance, the cycle track “Piestingtal Radweg” was opened in June 1999 after four years of construction (APA-OTS 2020). The path runs from Gutenstein to Sollenau and follows the course of River Piesting. Maybe this and other building activities caused some short-term disturbance of sediments and resulted in enhanced turbidity of water. Other conceivable scenarios are (2) heavy rainfalls in the catchment area, that may have led to erosion of banks and accumulation of suspended particles, as well as (3) changes in landuse along the river, which also enhances surface runoff from open soils and loose material. As Drofenik 2002 mentioned, the visibility of plants was heavily restricted. Possibly plants were still existing, but could not be seen from the banks.

In WNC most of the species are infrequently distributed, but do reach some great amounts of biomass locally. *Potamogeton crispus* was regionally highly developed in the years of 1992 and 1994 (Janauer np.), which can be shown in Fig.11 and Fig.12, but still did not reach RPM > 5% (Fig.17). The temporal species turnover was quite low: vegetation cover was dominated by the same three species throughout the years: *Stuckenia pectinata*, *Elodea canadensis* and *Myriophyllum spicatum* (Fig.17). This matches the observation by Jursa & Othahel’ová (2005) of continuous type of species distribution in canalised systems in river-arms of the Danube River (Slovakia).

Non-metric multidimensional scaling. This study also deals with the differences in species composition of the two waterbodies over the timespan of all conducted surveys (Fig.18 and Fig.19).

For River Fischa considerable changes in species abundances are recognized over the last years. Pairwise comparison of the surveyed years resulted in significant changes of the years 1979 vs. 2018 and 1999 vs. 2018 (Tab.9). In support of the differences shown in the distribution diagrams the centroids indicate some ongoing process of change in species composition. Over the course of the last 39 years some species lost their importance in River Fischa (i.a. *Ranunculus trichophyllus*), whereas some new others came up and quickly built up a considerable amount of plant mass (i.a. *Veronica beccabunga*).

This progress may be caused by a series of changes in the surrounding conditions, we can suspect: (1) with regard to the improvement of water quality over the last decades (Tab.1), this shift may be related to succession to a less eutrophic ecosystem. Because plants need some time for recovery and adaption changes to their environment are often detected many years after their occurrence or implementation (Drofenik 1999, Schmidt et al. 2018). Some may react faster to changes in nutrient enrichment than others, as they have different nutritive strategies (Melzer 1999). (2) Many species, have become rare, vulnerable, endangered or even extinct in the European lowland streams, due to heavy construction activity in the last decades. This leads to lower diversity of macrophyte species and unification of communities (Janauer et al., 2018). (3) Species dispersal capacity is driven by species-specific demographic dynamics combined with a set of habitat characteristics (Demars & Harper 2002).

We can also see some progress in species composition at Wiener Neustädter Canal. There are significant changes over some years detected (Tab.10). This stepwise shifts in community composition may be explained, inter alia, by modified hydraulic conditions. As the water quality in the canal more or less stayed stable for a long time (Tab.2), this can be assumed to be more reasonable than pollution or clean-up. Therefore one could conclude that one of these changes is the progressive closing of power plants and the removal of the lock gates in the last decades. This reduction of impoundments continued until 2013, when the last gate of lock #34 was eliminated (Tinhofer 2017). Even though lock gates are removed nowadays, due to the strongly constricted channel passage in the lock chamber the water is dammed up and produces an impoundment. Also, regular maintenance works, like the draining and clearing every autumn, certainly have some impact on the occurring species composition. For some species there is evidence that they may respond to cutting through enhanced regrowth (Sand-Jensen et al., 2000), in other cases overall declining numbers in abundance are reported, even though long-term studies are still missing (Baczyk et al. 2018). For sure, different species will react variously to mechanical weed control measures (Sipos et al. 2003).

The long timespan in between the studies makes it difficult to state some clear incidents that explain the present results most probably. It is quite likely that the change in species composition is a synergy of anthropogenic and natural hydrological events combined with random dispersal of species (Demars & Harper 2002)

A successful application of NMDS to detect changes in species distribution is shown by Schmidt et al. (2018). They conducted similar analysis for three river sections of the Austrian Danube over the timespan of only nine years (1995-2004), which is much shorter than the one of this study. They spotted significant differences in macrophyte species composition and could trace them back to the impact of the Danube flood event in 2002.

For scientific verification of one or the other assumption, more detailed and specially designed studies are necessary, that also include extensive analysis of environmental parameters (landuse change, bank-side construction activities, precipitation quantity in the catchment area etc.). This historical changes are quite likely to play a key role in the species composition of the aquatic vegetation today. The natural dynamics of macrophyte populations, even without changes in the environmental factors, like trophic status and disturbance, can only be assessed by detailed long-term investigations (Wiegleb et al., 2016).

Species diversity. Contrary to the expectation, that the confluence with River Piesting may influence species diversity per se, the calculation of the Simpson Diversity Index gives numerical evidence that the number of occurring species in the two reaches of River Fischa did not differ significantly (Fig.20). Nevertheless there was a turnover in the floristic composition. In the upper reach of River Fischa, discharge, low turbidity and nutrient situations seem to be quite consistent and especially allowed the dispersal of species in mostly oligotrophic (Tab.1), clear and slow-flowing conditions, like *Characeae* (Krause 1976; Kohler & Janauer 1995; Kufel & Kufel 2002) and also *Groenlandia densa* (LANUV-Arbeitsblatt 30) – an indicator of groundwater (Janauer 1981).

The more dynamic and fluctuating background conditions may stimulate the growth of other specific plants downriver of the confluence. Even though the flood protection structure downriver of Fischamend controls extreme water levels, a high level of discharge fluctuations are obtained (Fig.2), which have to be withstand by the plants.

At River Wiener Neustädter Canal we face another situation. According to the Mann-Whitney test (Tab.8) diversity in the sections of the upper reach was significantly higher than of the lower reach (Fig.20). Again, coming back to the hypothesis of intermediate disturbances, we could explain that the upper reach, without the serial impoundments, but almost constant environmental conditions seems to provide quite good habitats for long-term plant cover. The short intervals between the locks in the lower reach generate too many and too intense disruptions in turbulence, flow velocity (Mebane et al. 2014) and consequently destabilisation of bed sediment (Riis et al. 2004) for dense vegetation cover. Only some adapted species that are tolerant towards traction were able to build up considerable biomass. Hrivnák et al. (2014) stated that diverse species richness patterns are closely associated with the hydrological mode, utilization, land use or human impacts of canals, and though reinforces the theory that canals as man-made aquatic habitats are able to host a number of macrophytes including highly threatened plant species.

The backwater of the locks in the lower reach causes suspended sediments to sink down and cover the ground with fine material, well suitable for macrophyte growth, analogous with large-scale impoundments in River Danube (Pall & Janauer 2003). Some meters downstream, right behind the outflow of the lock, drift is very rapid and torrential, which is not favoured by most of higher aquatic plant species, as water currents are among the strongest environmental variables determining the occurrence and/or abundance of aquatic plants (Janauer et al. 2010).

Analysis of the Simpson Diversity Index based on all vegetated sections of years resulted in significant differences between River Fischa and the WNC (Tab.8, Mann-Whitney test, $p > 0.001$). Similarly to the findings of Hrivnák et al. 2009, who recorded species at River Turiec (Slovakia) repetitively after a timespan of seven years, species diversity of River Fischa did not change significantly over the surveyed years, although differences in abundance and spatial distribution were clearly evident.

In comparison to the Austrian section of River Danube, River Fischa showed similar index values. In both rivers they ranged from 0.1 to 0.5 (Schmidt et al. 2018) and may be caused by the direct connection of the two at the confluence in Fischamend. The WNC showed clearly lower range of diversity medians (0.1 to 0.3), matching the theory of Townsend et al. (1997) that species diversity would be higher in heterogeneous environments. Baattrup-Pedersen & Riis (1999) and Jursa & Othahel'ová (2005) also confirmed the assumption of positive correlation between substratum heterogeneity and macrophyte heterogeneity in Danish and Slovakian streams. Conversely, Dorotovičová et al. (2013) reported remarkably high diversity values in different canals of Slovakia and stated their dependence on management type and flow age. Similar examples for Hungarian canals were reported by Sipos et al. (2003).

Conclusion. This only occasionally applied comparison of the macrophyte species inventory of two fundamentally different waterbodies, as well as their different sections, documented clear differences in species composition, indicator species and diversity.

Species number and diversity was significantly higher in River Fischa than in the artificial Wiener Neustädter Canal, according to expectations due to a more diverse environmental background (Baattrup-Pedersen & Riis 1999; Jursa & Othahel'ová 2005). Nevertheless there are also many other examples that show contrary results (Sipos et al. 2003; Dorotovičová et al. 2013). The implementation of NMDS revealed significant differences in species composition based on the campaign periods. This indicates changes in both waterbodies, which may be caused by environmental changes over the last decades.

This comparative and time-related study on two closely located waterbodies of clearly different character provides an exclusive overview of the changes and trends in species composition of the two waterbodies. It could be shown that macrophyte species composition had undergone some changes over the past decades. As the timespan in between the survey campaigns was quite long, a clear deduction of environmental triggers is not possible. To go further, the identification of structural patterns and habitat factors behind the species distribution would enable speculation on the underlying mechanisms generating these patterns, from which experimental designs and concepts could then emerge (Demars & Harper 2002). Increasing knowledge of dispersal characteristics of different species (Riis et al. 2004) and the effects of pressures and pressure combinations on macrophyte communities are some of the key requirements for introducing effective measures to improve the ecological status and sustainable management of riverine ecosystems (Knehtl & Germ 2017). Stream rehabilitation projects should take into consideration the importance of the physical stream environment for macrophyte communities (Demars & Harper 2002) and aim at providing diverse physical stream environments to encourage and support the establishment and growth of diverse macrophyte communities (Baatrupp-Pedersen & Riis 1999). The protection and maintenance of ground-water fed oligotrophic rivers is an important tool to prevent the extinction of endangered macrophytes species, like *Groenlandia densa* (Schweinitz et al. 2012).

Another important issue in the future will be the spreading of introduced, and possibly invasive, species in waterbodies of this area (Sipos et al. 2003), often benefiting from rising temperatures (Zhang et al. 2015). As native aquatic habitats in Central Europe are gradually disappearing, secondary habitats, like canals can create suitable conditions for aquatic organisms (Dorotovičová 2013; Jäger 2013; Neuhold et al. 2018).

Long term monitoring of stream conditions combined with regular field surveys of macrophyte development will help to unravel the underlying abiotic mechanisms of plant distribution (Demars & Harper 2002). This survey of August 2018 was part of a year-round investigation, which may examine the seasonal variation in plant biomass in further analysis.

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10. Register of figures and tables

Table 9: River Fischa: Pairwise permutational multivariate analysis of variance (PERMANOVA).

Table 10: Wiener Neustädter Canal: Pairwise permutational multivariate analysis of variance (PERMANOVA).

Table 11: River Fischa and WNC: Mann-Whitney two-sample test of Simpson diversities.

Formula 1. Melzer 1986; Janauer et al. 1993; Janauer & Heindl 1998

Formula 2. Pall & Janauer 1995

Formula 3. Janauer et al. 1993

Formula 4. McCune & Grace, 2002

11. Appendix
11.1 Survey units

<u>FISCHA</u>

Survey Unit Number 1978	Survey Unit Number 1999	Survey Unit Number 2018	Lenght [m]	description
1	1	1	135	origin Fischa - junction with 2nd headstream
	2	2	180	junction with 2nd headstream - measuring bridge
2	3	3	205	measuring bridge - footbridge
	4	4	610	footbridge - approach at farm road
	5	5	750	approach at farm road - building on right side
3	6	6	65	building on right side - bridge (Großmittler Straße)
4	7	7	50	bridge (Großmittler Straße) - 50m downstream bridge (Großmittler Straße)
	nk	nk	410	50m downstream bridge (Großmittler Straße) - Am Fischafeld 7c
	9	9	65	Am Fischafeld 7c - bridge (Kirchengasse)
	10	10	50	bridge (Kirchengasse) - 50m downstream
	nk, 12	nk	265	50m downstream - former milk storage (Dorfstraße)
5	13	12	115	former milk storage (Dorfstraße) - memorial
	14	nk	335	memorial - bridge between Haschendorf and Siegersdorf
6	15-16	14	760	bridge between Haschendorf and Siegersdorf - bridge Tomawerk 1
7	nk	15	45	bridge Tomawerk 1 - bridge (Anton Mach Straße)
	18	16	115	bridge (Anton Mach Straße) - bridge (Pottendorfer Straße)
	19	17	95	bridge (Pottendorfer Straße) - junction with side arm
	20	18	180	junctionwith side arm - bridge (fire department)
	21	19	210	bridge (fire department) - bridge (church)
	22	20	145	bridge (church) - Nytzienweg
	23	21	220	Nytzienweg - bridge (Pottendorfer Straße)
8	nk	nk	575	bridge (Pottendorfer Straße) - approach at Mühlgasse
	25	23	125	approach at Mühlgasse - Heißmühle
9	nk, 26-28	nk	2040	Heißmühle - 25m upstream bridge (Badener Straße)
	29	25	50	25m upstream bridge (Badener Straße) - 25m downstream bridge (Badener Straße)
10	30	26	815	25m downstream bridge (Badener Straße) - 25m upstream bridge farm road
	31	27	50	25m upstream bridge farm road - 25m downstream bridge farm road
11	32-33	nk	580	25m downstream bridge farm road - junction Alte + Neue Fischa

nk	34-36	nk	845	branch-off Neue Fischa - bend at Badener Straße
	37	30	125	river bend at Badener Straße - small bridge (junction farm path and Badener Straße)
	38	31	110	small bridge (junction farm path and Badener Straße) - high voltage power line
	39	32	465	high voltage power line - footbridge Schlosspark Pottendorf
	nk	33	650	footbridge beginning Schlosspark Pottendorf - footbridge end Schlosspark Pottendorf
	41	34	20	footbridge end Schlosspark Pottendorf - bridge (Wiener Straße)
	42	35	120	bridge (Wiener Straße) - bridge (Hans Koller Wegerl)
	43-45	nk	1045	bridge (Hans Koller Wegerl) - 25m upstream bridge farm road
	46	37	50	25m upstream bridge farm road - 25m downstream bridge farm road
	47	38	255	25m downstream bridge farm road - sign gas pipe
	48	39	30	sign gas pipe - 30m downstream sign gas pipe
	48-49	nk	95	30m downstream sign gas pipe - 25m upstream bridge (Wiener Straße)
	50	41	50	25m upstream bridge (Wiener Straße) - 25m downstream bridge (Wiener Straße)
	51-52	nk	1040	25m downstream bridge (Wiener Straße) - junction Alte + Neue Fischa
11-12	53	43	275	junction Alte + Neue Fischa - bridge highway (A3)
	54	44	155	bridge highway (A3) - high voltage power line
	55	45	115	high voltage power line - Fischagut
	nk, 57, nk	nk	1355	Fischagut - transition forest/ field
13	59	47	170	transition forest/ field - bridge farm road
14	60	48	430	bridge farm road - farm road bend
	61	49	595	farm road bend - barrage
	62	50	285	barrage - bridge (Wiener Straße)
	nk	nk	25	bridge (Wiener Straße) - barrage
	63	52	40	barrage - footbridge
	64	nk	330	footbridge - bridge (Lagerhausstraße)
15	nk	54	50	bridge (Lagerhausstraße) - rail bridge
16	66	55	375	rail bridge - junction side arm
nk	67-68	56	405	junction side arm - 150m upstream branch-off side arm
nk	69	57	150	150m upstream branch-off side arm - branch-off side arm
19	70	58	425	branch-off side arm - barrage
20-21	nk	nk	800	barrage - bridge (Lindenallee)
nk	72	60	175	bridge (Lindenallee) - sill
	73-74	nk	560	sill - junction right side arm
nk	75	62	515	junction right side arm - junction left side arm
nk	76	63	175	junction left side arm - footbridge
nk	77	64	225	footbridge - barrage

	78	65	110	barrage - backyards (brick built banks)
26	79	66	135	backyards (brick built banks) - bridge (Mühlstraße)
27-28	80-82	nk	2585	bridge (Mühlstraße) - branch-off side arm
29	83	68	260	branch-off side arm - 140m upstream bridge (Sportplatzstraße)
	84	69	140	140m upstream bridge (Sportplatzstraße) -bridge (Sportplatzstraße)
	85	70	375	bridge (Sportplatzstraße) - bridge (Lagerstraße)
30	86	71	190	bridge (Lagerstraße) - footbridge (Philipp Haas Gasse)
31	87	nk	90	footbridge (Philipp Haas Gasse) - Dammweg
	88	73	525	Dammweg
32	89	74	175	Dammweg - gardencenter (Zur Fischa)
nk	90	75	520	gardencenter (Zur Fischa) - sign gas pipe
34	91	76	275	sign gas pipe - hedgerow left side
	92	77	215	hedgerow left side - former water gauge
35	93	78	270	former water gauge - measuring bridge
36	94	79	420	measuring bridge - farm road bend
37-38	nk, 96	nk	950	farm road bend - junction side arm
	97	81	165	junction side arm - measuring bridge
	98	82	265	measuring bridge - beginning woodland
39	99	nk	500	beginning woodland - rail bridge
40	100	84	790	rail bridge - former rail bridge
41	nk	85	1060	former rail bridge - bridge (Mannersdorfer Straße)
42	102	nk	565	bridge (Mannersdorfer Straße) - junction side arm
		87	680	junction side arm - transition forest/ field
43	103	88	365	transition forest/ field - bridge farm road (Knappenbühel)
44	104	89	905	bridge farm road (Knappenbühel) - barrage (Führbach)
45	105	90	600	barrage (Führbach) - bridge (Seegasse)
46-47	106-107	nk	3820	bridge (Seegasse) - barrage (Trafo Schwadorf)
48	nk	92	620	barrage (Trafo Schwadorf) - mill Schwadorf
	109	93	185	mill Schwadorf - bridge (Brucker Straße)
49	110	94	585	bridge (Brucker Straße) - rail bridge
nk, 51	111, nk	nk	1530	rail bridge - bridge (Mühlstraße)
52	113	96	620	bridge (Mühlstraße) - footbridge (Enzersdorfer Weg)
53	114	nk	340	footbridge (Enzersdorfer Weg) - bridge (Kirchenplatz)
54	115	98	165	bridge (Kirchenplatz) - bridge (Schulgasse)
55	116	99	505	bridge (Schulgasse) - wastewater treatment plant
56	117	100	190	wastewater treatment plant - junction side arm
57	118	101	100	junction side arm - footbridge
58	119	102	790	footbridge - power suppyl line (Kote 156)
59	120	103	520	power supply line (Kote 156) - branch-off side arm (Kleine Au)
60	121	104	1190	branch-off side arm (Kleine Au) - footbridge
	122	105	440	footbridge - bridge (Fehrgasse)
61	123	106	115	bridge (Fehrgasse) - footbridge (Fischapromenade)

62	124	107	165	footbridge (Fischapromenade) - bridge (Hainburger Straße)
63	125	108	675	bridge (Hainburger Straße) - bridge (Donaustraße)
nk	nk	nk	5100	bridge (Donaustraße) - junction River Danube

WIENER NEUSTÄDTER CANAL

Survey Unit Number 1992	Survey Unit Number 1994	Survey Unit Number 1999	Survey Unit Number 2018	Lenght [m]	description
37	nk	90	nk	30	outset of Wr. Neustädter Canal - outset of triangle
36	nk	89	2	730	outset of triangle - Wolfgang Amadeus Mozart Gasse
35	nk	88	3	960	Wolfgang Amadeus Mozart Gasse - Johann Strauß Gasse
34		87	4	175	Johann Strauß Gasse - aqueduct triangle (Kehrbach)
33	nk	86	5	440	aqueduct triangle (Kehrbach) - bridge (Pottendorfer Straße)
	nk	85	nk	560	bridge (Pottendorfer Straße) - footbridge (Pioniersteg)
		84	7	575	footbridge (Pioniersteg) - rail bridge
32	nk	83	8	1075	rail bridge - bridge (Gutensteiner Straße)
	nk	82	9	730	bridge (Gutensteiner Straße) - fence military area
31		81	10	605	fence military area - bridge (Tritolstraße)
30	nk	80	11	905	bridge (Tritolstraße) - woodland right side
	nk	79	12	1235	woodland right side - bridge gravel plant
	nk	78	13	765	bridge gravel plant - bridge (Waldgasse)
29		77	14	1310	bridge (Waldgasse) - bridge (Großmittelstraße)
28	44	76	nk	960	bridge (Großmittelstraße) - bridge (Blumauerstraße)
nk	43	75	16	805	bridge (Blumauerstraße) - aqueduct (Piesting, Kalter Gang)
	42	74	17	500	aqueduct (Piesting, Kalter Gang) - bridge (Industriestraße)
	41	73	18	330	bridge (Industriestraße) - rail bridge
26		72	19	140	rail bridge - bridge (Industriestraße Nord)

25	40	71	20	735	bridge (Industriestraße Nord) - bridge (Sollenauer Straße)
	39	70	21	1230	bridge (Sollenauer Straße) - aqueduct (Triesting)
	38	69	22	240	aqueduct (Triesting) - bend
		68	23	335	bend - bend
		67	24	520	bend - aqueduct (Triesting)
24		66	25	225	aqueduct (Triesting) - bridge (Hainfelder Straße)
23	37	65	26	660	bridge (Hainfelder Straße) - bridge (Josef Pürrer Straße)
22	36	64	27	125	bridge (Josef Pürrer Straße) - former lock
21	35	63	28	225	former lock - former lock
20	34	62	29	165	former lock - former lock
	33	61	30	70	former lock - bridge (Renngasse)
		60	31	75	bridge (Renngasse) - bridge (Parkallee)
		59	32	145	bridge (Parkallee) - bridge (Schloßallee)
	32	58	33	65	bridge (Schloßallee) - former lock
		57	34	130	former lock - former lock
		56	35	185	former lock - former lock
		55	36	220	former lock - former lock
19		54	37	195	former lock - bridge (Flugfeldstraße)
18	31	53	38	190	bridge (Flugfeldstraße) - former lock
	30	52	39	375	former lock - former lock
nk		51	40	350	former lock - bridge (Flugfeldstraße)
	29	50	41	325	bridge (Flugfeldstraße) - former lock
		49	42	230	former lock - former lock
	28	48	43	135	former lock - bridge
		47	44	110	bridge - former lock
		46	45	185	former lock - former lock
16		45	46	60	former lock - bridge highway (A2)
	27	44	47	165	bridge highway (A2) - former lock
		43	48	195	former lock - former lock
		42	49	390	former lock - bridge
15	26	41	50	845	bridge - former lock
14		40	nk	355	former lock - bridge (Haidhofstraße)
13	25	39	52	415	bridge (Haidhofstraße) - bridge (Badener Straße)
	24	38	53	65	bridge (Badener Straße) - bridge (Baden)
		37	54	275	bridge (Baden) - aqueduct (Schwechat)
	23	36	55	145	aqueduct (Schwechat) - former lock
12		35	56	100	former lock - bridge (Waltersdorfer Straße)

		34	57	720	bridge (Waltersdorfer Straße) - former lock
11	22	33	58	230	former lock - rail bridge
	21	32	nk	380	rail bridge - former lock
		31	60	460	former lock – former lock
10		30	61	210	former lock - bridge (Badenerstraße)
	20	29	62	225	bridge (Badenerstraße) - former lock
		28	63	285	former lock - former lock
		27	64	165	former lock - former lock
9		26	65	80	former lock - former lock (Doktor Josef Folk Gasse)
	19	25	66	100	former lock (Doktor Josef Folk Gasse) - former lock
	18	24	67	560	former lock - former lock (Eugen Dahm Straße)
8	17	23	68	370	former lock (Eugen Dahm Straße) - bridge (Houskaweg)
	16	22	69	590	bridge (Houskaweg) - former lock
	15	21	70	215	former lock - bridge (Rosalienweg)
7		20	71	290	bridge (Rosalienweg) - bridge (Wiener Straße)
	14	19	72	205	bridge (Wiener Straße) - former lock
		18	73	290	former lock - former lock
		17	74	490	former lock - bend
6		16	75	320	bend - bridge (B17)
	13	nk	nk	465	bridge (B17) - bridge (Hauptstraße)
		14	77	240	bridge (Hauptstraße) - footbridge
nk	12	nk	nk	220	footbridge - rail bridge
		12	79	325	rail bridge - former lock
	11	11	80	400	former lock - footbridge
	10	10	81	325	footbrige - footbridge
4	9	9	82	250	footbridge - bridge (Neudorferstraße)
3	8	8	83	525	bridge (Neudorferstraße) - former lock
	nk	7	84	420	former lock - bridge (IZ NÖ Süd)
	nk	6	85	105	bridge (IZ NÖ Süd) - roundabout
	nk	nk	nk	1345	roundabout - bridge (Neudorfer Straße)
2	2	3	87	715	bridge (Neudorfer Straße) - bridge (Laxenburg)
1	1	2	88	480	bridge (Laxenburg) - bend
		1	89	55	bend - mouth (River Mödling)

11.2 Pictures

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River Fischa – upper reach (Haschendorf)

River Fischa – lower reach (Fischamend)

Wiener Neustädter Canal – upper reach (Großmittel)

Wiener Neustädter Canal – lower reach (Bad Vöslau, former power station and bypass channel)