A review of research studies on helminth parasites of fish from Austria

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This review describes the history of fish parasitology focusing on endo-helminths in Austria, which commenced with J. G Bremser in the early part of the 18th century and continued by E. Kritscher and M. Rydlo in the 1950's. F. Schiemer subsequently initiated a revival in the subject in the late 1980's by encouraging co-operation with parasitologists worldwide, which resulted in students from Europe, Africa, Asia and South America being trained in aquatic parasitology. This paper, apart from being an overview of fish parasitology over the past decades, provides a comprehensive and up to date host-parasite list and parasite-host list of endo-helminths of freshwater fish from Austria.

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Diese Arbeit beschreibt die Geschichte der Erforschung von Fischparasiten mit dem Fokus auf Endohelminthen in Österreich, die im frühen 18. Jhd. mit J.G. Bremser begann, nach längerer Pause in den 1950ern von E. Kritscher und M. Rydlo weitergeführt wurde und in den späten 1980ern durch F. Schiemer einen deutlichen Aufschwung erlebte. Schiemer konnte durch zahlreiche internationale Forschungskooperationen Studenten aus Europa, Afrika, Asien und Südamerika in dieses Forschungsfeld einführen und ausbilden. Diese Publikation bietet einen Überblick über zahlreiche Untersuchungen von Fischparasiten in Österreich während der letzten Dekaden, sowie eine aktuelle Wirts-Parasiten- und Parasiten-Wirts Liste der Endo-Helminthen von Fischen in Österreich.

Keywords: Austria, fish parasites, helminths, history, host-parasite list, parasite-host list.

Introduction

Helminths are parasitic worms which impact on medical, economic, and ecologic issues. However, until the modern era, the interest on helminth parasites initially focused within the medical or veterinary field. Despite the effects of fish parasites on fish health, yield and population ecology, extant records of fish helminths were not reported until the late 18th century (Bloch 1779, 1792, Goeze 1782). In Austria, research on the helminths of fish commenced with Johann Gottfried Bremser in the early 19th century, who provided extensive lists of helminths of vertebrates including freshwater fish (Schreibers et al. 1811, Sattmann et al. 1999). Further interest in freshwater parasitology evolved from research activities in various Austrian research institutes and included publications on fish parasites, mainly gathered by Erich Kritscher and Manfred Rydlo from different water bodies in Austria (Sattmann et al. 2000, Sattmann & Hörweg 2011, Jagsch 2002). Hitherto the research focus on fish parasites in Austria was mainly faunistic and taxonomic, whereas comprehensive studies on the ecology of fish parasites had previously been undertaken in the 1930's by the Russian parasitologist Vladimir Dogiel, and in the UK from the 1980's onwards by Clive Kennedy (University of Exeter) and John Lewis (Royal Holloway, University of London), together with several authors worldwide. However, many questions including the environmental effects on fish-parasite dynamics remained unanswered (Dogiel 1958, Kennedy 1976, Pike & Lewis 1994). In Austria during the 1980's much research emphasis was placed on the ecology and physiology of freshwater fish and especially on their distribution, feeding habits and growth patterns. Prof. Friedrich (Fritz) Schiemer at the University of Vienna focused on the ecology of fish in the River Danube catchment and pre-alpine lakes (Schiemer & Spindler 1989, Schiemer & Waidbacher 1992, Schiemer & Wieser 1992). In the mid-1980's he coordinated a project funded by the Austrian Science Fund (FWF) on the feeding ecology, optimal foraging and habitat preferences of fish and how these factors influenced their parasite fauna.

Using his network and establishing new contacts, Fritz Schiemer motivated students in the 1980's to commence investigating the ecology of fish parasites in Austria, and his initiative was also supported by Erich Kritscher and Helmut Sattmann (Natural History Museum, Vienna), Horst Aspöck (Medical University Vienna) and Manfred Rydlo (Institute for Aquatic Ecology and Fisheries Management). In addition, John Lewis, who had previously worked in Austria on the parasites of alpine trout in lake sites at Lunz through an exchange program with the British Council and on parasitic diseases of fish (Pike & Lewis 1994), was invited by Fritz Schiemer to supervise a PhD thesis on fish parasites (Konecny 1998), which in turn lead to further advances in fish parasitology in Austria including international courses at the lakes Neusiedler See and Mondsee. Furthermore in the 1990's political changes in Eastern Europe resulted in previous ties being bound again and enabling co-operation to be re-established with institutes in the Czech Republic and Hungary including distinguished taxonomists such as Franticek Moravec, Thomas Scholz, Milan Gelnar and Kalman Molnar (Moravec et al. 1997, Moravec 2001). These productive inputs together with additional international contacts, e.g. Clive Kennedy and Claude Belpaire, resulted in the incorporation of fish parasitology not only in university degree and training courses but also national and international research projects ranging from faunistic documentation to ecological and toxicological analyses. More recently contributions from the "Austrian Barcode of Life initiative" (ABOL) included molecular sequence data and which revealed hidden biodiversity in fish helminths (Reier et al. 2019, 2020). The present review therefore aims to outline the activities of fish helminthologists in Austria and also to provide an up to date list of endo-helminth parasites of fish.

Results

Early history of fish helminthology in Austria – Johann Gottfried Bremser, "Lord of the Worms"

Historically the awareness of helminth parasites in humans and cattle date back to the ancient cultures of Egypt, India and Greece (Hoeppli 1959, Cox 2002), whereas the famous philosopher and naturalist Aristotle reported that parasitic worms in fish, likely to be the plerocercoids of the tapeworm *Ligula intestinalis*, altered the behavior of their fish hosts (Dubinina 1980). Essential systematic records of helminths of freshwater fish were published from the 18^{th} century on (eg. Bloch 1779, 1792, Pallas 1781, Goeze 1782). However, fish helminthology as a research topic in Austria did not appear until the 19th century when the distinguished pioneer of helminthology, the German Karl Asmund Rudolphi (1771–1832), who worked in Greifswald and Berlin, described and named many helminth species from a wide variety of fish hosts. In his helminthological studies, Rudolphi was in close scientific contact with Johann Gottfried Bremser (1767–1827), the founder of helminthology in Austria, who compiled abundant host-parasite lists from over 60,000 dissections of different vertebrates including fish, which he performed with his students between 1806 and 1826 (Sattmann et al. 1999, Sattmann 2000, 2002). This work also included approximately 40 fish species native to Central Europe (Schreibers et al. 1811, Westrumb 1821, Bremser 1824).

In Bremser's first host-parasite list (Schreibers et al. 1811), the authors mentioned that many host specimens originated from the surroundings of Vienna and neighboring regions primarily collected by hunters and fishermen. However, Bremser also acquired fish and avian hosts of uncertain origin from markets and restaurants, but also from a wide network of European naturalists. Unfortunately, published lists and labels of specimens deposited in the Natural History Museum, Vienna provide no information on the origin and localities of individual hosts/parasites so that these early data cannot be assigned for sure as Austrian fauna.

Similarly Carl Moriz Diesing (also: Carl Moritz Diesing) (1800–1867), who succeeded Bremser as Curator in the Viennese Naturaliencabinet/Hofmuseum (currently the Natural History Museum, Vienna), continued to publish extensively in the field of helminthology, including the highly rated "Systema helminthum" (Diesing 1850, 1851), although precise details of origin and geographical location were lacking. Consequently, no reliable data on helminths of fish from Austria prior to the 20th century are available. Furthermore "Austria" prior to 1918, governed by the Austrian-Hungarian monarchy, was a much larger country than in the present-day. Some "Austrian" helminthologists such as Raphaele Molin (1825–1887), Michele Stossich (1857–1906) and Theodor Pintner (1857–1942), also studied fish helminths, but they focused on marine fish primarily from the Adriatic Sea.

Related data from water bodies in neighbouring countries

More precise studies on the parasites of fish were undertaken by researchers in the early 1800's and throughout the 1900's from freshwater bodies in neighbouring countries and those bordering Austria. A monograph on the composition of the parasite and fish fauna in lake Bodensee, situated between present day Germany, Switzerland and Austria was published by Nenning (1834) and further studies in this lake site were carried out by Swiss and German workers (e.g. Zschokke 1933, Zand 1924, Deufel 1956). Fish parasites from the German part of the Danube River had been studied by Reichenbach-Klinke (1962). In Czechoslovakia several parasitological studies on fish from neighbouring rivers Morava and Dyje had been published (Kadlec et al. 1995, Kadlec et al. 2003, Ondračková et al. 2004).

Fish helminthology in the 20th and 21st centuries in Austria

In the first decades of the 20th century Joseph Fiebiger actively studied fish pathogens in Austria, but he focused on fungi, bacteria and protozoans (Fiebiger 1909, 1950, 1951). Extensive studies in the field of fish helminthology were initiated in the mid 1950's by Erich Kritscher (1927–2010), Natural History Museum Vienna, mainly from rivers and lakes in Upper Austria and from the easternmost lake in Austria, the Neusiedler See (Kritscher 1955, 1980, 1983a, 1983b, 1988, 1989, 1990, 1991a, 1991b). A complete publication list of E. Kritscher is provided by Sattmann & Hörweg (2011). During the same period, Manfred Rydlo (1936–2002) commenced studies on the parasites of fish from lakes in

Salzkammergut, mainly in Upper Austria and Salzburg (Rydlo 1988, Rydlo & Jagsch 1993, Jagsch 2002). In the late 1980's, Fritz Schiemer embarked on a project dealing with the ecology and ecophysiology of European cyprinids (Schiemer & Wieser 1992) and this included supervision of a PhD program on the ecology of helminth communities of fish species in the Danube river for comparison with a pre-alpine lake, Wallersee. The thesis was undertaken by Robert Konecny with external supervision by Manfred Rydlo and John Lewis.

In the early 1990's research co-operation and activity continued with parasitologists from the United Kingdom, Czech Republic, Hungary, Italy, Croatia and Germany, establishing new contacts with Marialetizia Fioravanti, Bahram Dezfuli, David Di Cave (Italy), Ivona Mladineo (Croatia) and Bernd Sures (Germany). Students from Europe, Africa, Asia and South America were trained in fish parasitology within the format of an International Workshop and Training Course on Fish Parasites, initiated by John Lewis, Robert Konecny, Alois Herzig and Fritz Schiemer, based at the Biological Station Neusiedler See from 1994–2004. The course was also part of a special module "Fish Parasitology" within the International Post-Graduate Training Course in Limnology (IGPL) from 2006–2009. In the mid 1990's parasitological studies were focused in the Austrian lake districts due to the outbreak of fish mortalities and due to the occurrence of cercarial dermatitis in Wallersee in 1994 (Konecny et al. 2010). Another hot spot occurred in a shallow lake, the Neusiedler See, east of Vienna, where eel populations were found to be infected with the potentially pathogenic nematode *Anguillicola crassus* occurring in the swim bladder of eels (Konecny & Wais 1994).

Master's and PhD theses in the field of fish parasitology were also carried out in Uganda and the Maldives under the supervision of Fritz Schiemer (Akoll et al. 2012, Moravec et al. 2008).

Helminths of barbel

From April to November 1994 investigations of the helminth fauna of the cyprinid barbel, *Barbus barbus* (L.), one of the most abundant fish species of the Danube river basin, were carried out in four localities in Austria, Hungary and the Czech Republic by an international research team. Up to 20 helminth species including three Cestoda, nine Trematoda, five Nematoda and three Acanthocephala were identified and infections with the more frequently occurring species such as *Bathybothrium rectangulum, Proteocephalus torulosus, Diplostomum* sp. larv., *Rhabdochona hellichi, Pomphorhynchus laevis,* and *Neoechinorhynchus rutili* were related to seasonality and maturation / body size of fish hosts. Furthermore, the ecology and composition of helminth parasites in the barbel from the Danube basin in Central Europe were also compared with those from the main European river basins and in other congeneric hosts (Moravec et al. 1997).

Fish parasites as indicators for pollution

Two approaches were used to evaluate the role of fish macroparasites as bioindicators of heavy metal pollution (Schludermann et al. 2003, Laimgruber et al. 2005). Firstly, changes in the diversity and richness of helminths in the barbel were tested relative to heavy metal concentrations occurring in river water at selected stretches of the Danube in Austria. Secondly, the bioaccumulation potential of cadmium, lead and zinc was assessed in the acanthocephalan, *P. laevis* for comparison with muscle, liver and intestinal tissues of its barbel host. Significantly higher levels of heavy metal concentrations, up to 2860 fold, occurred in the tissues of *P. laevis* compared with tissues of barbel (P=0.001). These extremely high levels of heavy metal accumulation in this acanthocephalan species suggest that *P. laevis*, despite variability in its infrapopulation and also host mobility and feeding behaviour, can act as a most sensitive indicator of heavy metals in aquatic ecosystems (Sures et al. 1997, Schludermann et al. 2003). Therefore the role of parasite community patterns relative to heavy metal pollution and its impact on food web dynamics, and the presence/absence of intermediate hosts in polluted waters in Austria will be essential for the assessment of the ecological status as shown in studies undertaken in the UK and elsewhere (Lewis & Hoole 2003, Morley et al. 2003, Sures 2003, Morley & Lewis 2004).

Helminth communities in eels from Neusiedler See

The investigation of the intestinal helminth composition and communities richness and also the prevalence of the swim bladder nematode *A. crassus* represented the first study of a stocked unnatural population of the European eel, *Anguilla anguilla* in a lake site (Schabuss et al. 2005a, 2005b). From the mid-1990's onwards analyses of eel stocks in Neusiedler See, as in many other Central and Eastern European lakes, were based on allochtonous populations, which from 1958 have been maintained by regular massive stocking (Herzig et al. 1994) and hence represents a model for other water bodies in Europe such as Lake Balaton in Hungary, where eels are not naturally occurring. However, the establishment in 1993 of a transboundary national park known as "Nationalpark Neusiedler See–Seewinkel" between Austria and Hungary resulted in eel stocking being prohibited. The eel population was therefore predicted to decline and in turn expected to become extinct within 10 years due to ongoing fishery activities (Herzig et al. 1994). Therefore eel samples were examined from 1994 to 2001 to provide a unique opportunity of comparing the dynamics of intestinal parasite communities in stocked but declining eel populations from Neusiedler See with stable and natural populations from Lough Derg, Ireland (Kennedy & Moriarty 2002) and the River Tiber, Italy (Kennedy et al. 1998).

Helminth communities in eels 1994–2009

An examination of 1044 eels from two sampling sites in Neusiedler See showed low species richness of the intestinal helminth communities similar to those in natural eel populations occurring in the UK and mainland Europe. The component community comprised five species including *Acanthocephalus lucii, Acanthocephalus anguillae, Raphidascaris acus, Proteocephalus macrocephalus and Bothriocephalus claviceps* with a maximum infracommunity richness of four species. Significant differences were observed in the prevalence and abundance values of *A. lucii* and *A. anguillae* in both sites during the entire sampling period. These acanthocephalan species utilize the same crustacean intermediate host (*Asellus aquaticus*) and, although the sampling sites are similar, perch (*Perca fluviatilis*) is the preferred final host of *A. lucii* with *A. anguillae* specifically occurring in eels. In Illmitz, perch initially dominated the fish community resulting in higher levels of *A. lucii* occurring in this site. However, in 2003 the entire reed belt in Illmitz dried out and consequently the entire perch population crashed resulting in disappearance of *A. lucii* from 2004 onwards. The eel population also declined but not as drastically as perch with the occurrence of *A. anguillae* in eels remaining at similar levels of infection as previously observed. Consequently, significant habitat changes rather than interspecific competition had eliminated one dominant species of acanthocephalan from the component helminth community in Neusiedler See (Schabuss et al. 2005a).

Dynamics and predicted decline in *A. crassus* infections

The eel population in Neusiedler See has been maintained by regular massive stocking since 1958, but following the establishment in 1993 of the "National Park Neusiedler See-Seewinkel" stocking was prohibited with the prediction that the eel population would be extinct within a 10 year period. Consequently from 1994 to 2001 a total of 720 eels were examined for *A. crassus*s infections from both lake sites, where prevalence and abundance levels were consistently lower in the spring compared with the summer and autumn with larger/older eels harbouring higher numbers of parasites. Unlike the occurrence of massive eel mortalities in Lake Balaton, Hungary in 1991, 1992 and 1995, significant changes in *A. crassus* infections were not observed in Neusiedler See nor any decline in the eel population despite evidence of illegal stocking.

However it would be interesting if data on the prevalence and abundance values of *A. crassus* in eels from Neusiedler See could be re-evaluated with the view to investigate the impact and interaction of such a dominant nematode species on the component helminth community within the eel population (Schabuss et al. 2005b).

Recent studies by Morley & Lewis (2019) have shown that the prevalence of the eye fluke *Diplostomum* sp. is significantly increased in roach infected with plerocercoids of the cestode *Ligula intestinalis* but eye fluke infections with *Tylodelphys* sp. remain unchanged. Furthermore extreme environmental stress can result in a change in the distribution of eye flukes in roach and perch, which appears to be asymmetrical for *Tylodelphys* sp. during a pre-drought period, but not for *Diplostomum* sp., although this bias is reversed under drought conditions (Morley & Lewis 2020). Therefore, further studies on the impact of thermal stress on host-parasite interactions in a shallow aquatic habitat such as Neusiedler See would be worthwhile (Morley & Lewis 2014).

Recent research on fish parasites in Austria

In co-operation with Christa Frank, who was also working on fish parasites at Neusiedlersee in the 1970ies (Frank 1976) Franz Jirsa developed interest in fish parasitology covering taxonomic and ecologic approaches and focusing on the detection of heavy metal accumulation in several parasite species (Jirsa 2010, Jirsa et al. 2008a, 2008b, 2009, 2010, 2011, Mühlegger et al. 2009a, 2009b).

Pike tapeworm epidemics of *Triaenophorus* sp. in Austria were recorded in Achensee and Grundlsee, which prompted further studies on the potential threat of this parasite species on the economic use of valuable charr and whitefish populations (Achleitner et al. 2009, Schaufler et al. 2014, Schähle et al. 2016).

In the spring of 2004, a massive infection of the whitefish population with *Triaenophorus crassus* was observed in the Austrian lake Achensee. Stomach contents of Arctic charr (*Salvelinus umbla*) and whitefish (*Coregonus lavaretus*) were analysed for food composition and parasitic infections (Schähle et al. 2016). In addition, zooplankton samples were taken to determine the number of crustaceans present and also the prevalence of infected copepods and temporal occurrences of parasites (Anegg et al. 2015).

In 2005, an epidemic of the pike tapeworm *T. crassus* broke out in the Arctic charr stock of lake Grundlsee, which was the first record of an epidemic of this parasite in *S. umbla* (Achleitner et al. 2009). Within 2 years, the prevalence of this cestode species in medium sized Arctic charr increased to almost 100 % leading to the closure of the fishery. High pike populations and the occurrence of specific copepod hosts facilitated the outbreak. Low fishing pressures enabled the development of such a large pike population that served as reservoir hosts for *T. crassus*. To control the epidemic more than 1600 pikes were removed between 2008 and 2013. The prevalence of *T. crassus* in Arctic charr subsequently decreased to 60 % in 2013 (Achleitner et al. 2009, Boufana et al. 2011, Schaufler et al. 2014).

Within the initiative "Austrian Barcode of Life" (ABOL), which is coordinated in the Natural History Museum in Vienna, Susanne Reier studied Acanthocephala from several fish hosts from different rivers in Austria. She provided DNA-barcodes for the ABOL library and unraveled taxonomic ambiguities with integrated morphological-molecular methods and filled some gaps in the knowledge of the acanthocephalan fauna of fish in Austria and Central Europe (Reier et al. 2019, 2020).

Another recent contribution on Acanthocephala from fish hosts was published by Lewisch et al. (2020), who provided new barcoding data of acanthocephalans of 5 fish species from different localities in Austria, combined with records of myxozoa and with pathological observations.

Broad fish tapeworm missing?

Despite historical findings of adults of *Diphyllobothrium latum* (Linnaeus 1758) in humans (Schreibers et al. 1811, Bremser 1819), plerocercoids from fish have not yet been recorded in Austria. One more recent case of adult *D. latum* is from a dog near the city of Krems in association with the consumption of raw fish from the Danube River (Supperer & Wenzel 1967, Auer & Aspöck 2014). Another infection became apparent from Ice bears in the Viennese Zoo around 2005 (pers. com H. Prosl). Furthermore *D. latum* is mentioned from Bodensee by Fiebiger (1947), not stating the fish host species.

Tab. 1: Parasites are arranged in the following main groups (phyla, classes or clades) Cestoda, Trematoda – Digenea, Trematoda – Aspidogastrea, Nematoda and Acanthocephala after Moravec (2001). Monogenea are not included. Authors responsible for the records are listed in chronological order. The list involves records from published scientific literature. – Tab.1: Die Parasiten sind nach den folgenden Hauptgruppen unterteilt (Stämme, Klassen, Kladen) Cestoda, Trematoda – Digenea, Trematoda – Aspidogastrea, Nematoda und Acanthocephala nach Moravec (2001). Monogenea sind nicht inkludiert. Die Autoren sind in chronologischer Reihenfolge der Publikationen angegeben. Die Liste umfasst ausschließlich Daten aus wissenschaftlich publizierten Beiträgen.

Cestoda		
Species of parasite	**Host**	**Reference**
Bathybothrium rectangulum (Bloch, 1782)	*Barbus barbus*	Kritscher 1988, Rydlo 1998
Bothriocephalus acheilognathi Yamaguti, 1934	*Carassius carassius, Cyprinus carpio*	Kritscher 1988, Rydlo 1998
Bothriocephalus claviceps (Goeze, 1782)	*Anguilla anguilla*	Rydlo 1998, Schabuss et al. 2005
Caryophyllaeides fennica (Schneider, 1902)	*Alburnus, alburnus, Rutilus rutilus, Scardinius erythrophthalmus, Squalius cephalus, Vimba vimba*	Kritscher 1988, Rydlo 1998

Caryophyllaeus fimbriceps Annenkova-Khlopina, 1919	*Coregonus wartmanni*	Kritscher 1990
Caryophyllaeus laticeps (Pallas 1781)	Abramis brama, *Chondrostoma nasus, Cyprinus carpio, Gobio gobio, Rutilus rutilus*	Kritscher 1988, Jirsa et al. 2008a, Jirsa 2010
Caryophyllaeus sp.	*Abramis brama, Rutilus meidingeri Rutilus rutilus*	Rydlo 1998, Konecny et al. 2010
Cyathocephalus truncatus (Pallas, 1781)	*Salmo trutta f. fario, Thymallus thymallus*	Rydlo 1998
Eubothrium crassum (Bloch, 1779)	*Anguilla anguilla, Aspius aspius, Coregonus* sp., *Salvelinus umbla*	Kritscher 1990, Stabauer et al. 2017
Eubothrium salvelini (Schrank, 1790)	*Coregonus* sp., *Coregonus wartmanni, Perca fluviatilis, Salvelinus fontinalis , Salvelinus umbla*	Kritscher 1990, Rydlo 1998, Konecny et al. 2010, Stabauer et al. 2017
Khawia coregoni n. sp.	*Coregonus wartmanni*	Kritscher 1990
Ligula intestinalis (Linnaeus, 1758) larv.	*Abramis brama, Blicca björkna, Rutilus rutilus, Sander lucioperca, Scardinius erythrophthalmus, Squalius cephalus*	Frank 1976, Kritscher 1988, Rydlo 1998, Schabuss et al. 2004
Proteocephalus longicollis (Zeder, 1800)	*Coregonus* sp., *Coregonus wartmanni, Oncorhynchus mykiss, Perca fluviatilis, Salmo trutta f. fario*	Kritscher 1990, Rydlo 1998, Konecny et al. 2010, Stabauer et al. 2017
Proteocephalus macrocephalus (Creplin, 1825)	*Anguilla anguilla*	Kritscher 1988, Rydlo 1998, Schabuss et al. 2005
Proteocephalus osculatus (Goeze, 1782)	*Silurus glanis*	Rydlo 1998
Proteocephalus percae (Müller, 1780)	*Perca fluviatilis, Sander lucioperca*	Kritscher 1988, Rydlo 1998, Polin et al. 2002b
Proteocephalus torulosus (Batsch, 1786)	*Alburnus mento, Squalius cephalus, Vimba vimba*	Kritscher 1988, Rydlo 1998, Stabauer et al. 2017
Triaenophorus crassus Forel, 1868 larv.	*Coregonus lavaretus, Coregonus* sp., *Esox Lucius, Oncorhynchus mykiss, Perca fluviatilis, Proterorhinus marmoratus*	Kritscher 1988, Rydlo 1998, Achleitner et al. 2009, Schaufler et al. 2014, Schaele et al. 2016
Triaenophorus nodulosus (Pallas, 1781)	*Alburnus mento , Esox Lucius, Lota lota, Oncorhynchus mykiss, Perca fluviatilis Salvelinus umbla, Vimba vimba*	Kritscher 1988, Rydlo 1998, Polin et al. 2002b, Achleitner et al. 2009, Konecny et al. 2010, Stabauer et al. 2017

Trematoda – Digenea		
Species of parasite	**Host**	**Reference**
Allocreadium isoporum (Looss, 1894)	*Alburnus mento, Rutilus rutilus, Squalius cephalus*	Kritscher 1988, Moravec et al. 1997, Rydlo 1998
Allocreadium transversale (Rudolphi, 1802)	*Misgurnus fossilis*	Kritscher 1983b
Apatemon cobiditis proterorhini (Linstow, 1890)	*Proterorhinus marmoratus*	Kritscher 1988
Asymphylodora tincae (Modeer, 1790)	*Tinca tinca*	Kritscher 1988

Bucephalus polymorphus Baer, 1827	*Neogobius melanostomus*	Mühlegger et al. 2009b, Francova et al. 2011
Bunodera sp.	*Neogobius melanostomus*	Mühlegger et al. 2009a
Bunodera luciopercae (O.F. Müller, 1776)	*Perca fluviatilis*	Stabauer et al. 2017
Crepidostomum farionis (Müller, 1780)	*Oncorhynchus mykiss, Salmo trutta f. fario, Salmo trutta Iacustris, Salvelinus fontinalis, Salvelinus umbla, Thymallus thymallus*	Kritscher 1990, Rydlo 1998
Crepidostomum metoecus Braun, 1900	*Oncorhynchus mykiss, Salmo trutta f. fario, Salvelinus umbla*	Kritscher 1990, Rydlo 1998
Diplostomum spathaceum (Rudolphi, 1819) larv.	*Abramis brama, Alburnus alburnus, Aspius aspius; Esox lucius, Neogobius melanostomus, Oncorhynchus mykiss, Ponticola kessleri, Rutilus rutilus, Sander lucioperca, Scardinius erythrophthalmus*	Kritscher 1983b, Rydlo 1998, Mühlegger et al. 2009a, Konecny et al. 2010, Francova et al. 2011
Ichthyocotylurus sp.	*Alburnus mento, Perca fluviatilis*	Stabauer et al. 2017
Nicolla skrjabini (Iwanitzky, 1928)	*Neogobius melanostomus, Ponticola kessleri*	Mühlegger et al. 2009a, Francova et al. 2011
Nikolla wisniewskii (Slusarski, 1958)	*Salmo trutta f. fario*	Rydlo 1998
Posthodiplostomum brevicaudatum (Nordmann, 1832) larv.	*Gymnocephalus cernuus, Perca fluviatilis*	Polin et al. 2002a
Posthodiplostomum cuticola (Nordmann, 1832) larv.	*Abramis brama, Alburnus alburnus, Aspius aspius, Blicca björkna, Chondrostoma nasus, Cyprinus carpio, Esox lucius, Leucaspius delineatus, Misgurnus fossilis, Phoxinus phoxinus, Rutilus rutilus, Scardinius erythrophthalmus*	Kritscher 1983b, Rydlo 1998
Sphaerostoma bramae (Müller, 1776)	*Abramis brama, Alburnus alburnus, Aspius aspius, Gobio gobio, Rutilus meidingeri, Squalius cephalus, Vimba vimba*	Kritscher 1988, Rydlo 1998, Konecny et al. 2010
Tylodelphis clavata (Nordmann, 1832) larv.	*Abramis brama, Alburnus mento, Gymnocephalus cernuus, Neogobius melanostomus, Perca fluviatilis, Rutilus rutilus*	Polin et al. 2002a, Mühlegger et al. 2009a, Konecny et al. 2010, Francova et al. 2011, Stabauer et al. 2017

Trematoda – Aspidogastrea		
Species of parasite	**Host**	**Reference**
Aspidogaster limacoides Diesing, 1834	*Barbus barbus*	Laimgruber et al. 2005, Schludermann et al. 2005

Nematoda		
Species of parasite	**Host**	**Reference**
Anguillicola crassus (KUWAHARA, NIIMI & ITAGAKI, 1974)	*Anguilla anguilla, Neogobius melanostomus*	RYDLO 1998, SCHABUSS et al. 2005, FRANCOVA et al. 2011
Camallanus lacustris (ZOEGA, 1776)	*Anguilla anguilla, Esox lucius, Sander lucioperca*	KRITSCHER 1983a
Camallanus truncatus (RUDOLPHI, 1814)	*Anguilla anguilla*	KRITSCHER 1983a
Cystidicola farionis (FISCHER, 1798)	*Salmo trutta f. fario*	RYDLO 1998
Eustrongylides excisus JÄGERSKIÖLD, 1909	*Neogobius melanostomus*	FRANCOVA et al. 2011
Hedruris androphora NITSCH, 1821	*Anguilla anguilla*	KRITSCHER 1983a
Philometra ovata (ZEDER, 1803)	*Abramis brama*	KRITSCHER 1983a
Philometra sp.	*Abramis brama*	KONECNY et al. 2010
Pseudocapillaria salvelini (DUJARDIN, 1843)	*Neogobius melanostomus*	FRANCOVA et al. 2011
Raphidascaris acus (BLOCH, 1779)	*Anguilla anguilla, Esox Lucius, Lota Iota, Neogobius melanostomus, Sander Lucioperca*	KRITSCHER 1988, RYDLO 1998, SCHABUSS 2005, FRANCOVA et al. 2011
Rhabdochona denuntata (DUJARDIN, 1845)	*Alburnus alburnus, Chondrostoma nasus, Rutilus rutilus, Salvelinus umbla, Squalius cephalus*	KRITSCHER 1988
Rhabdochona hellichi (SRAMEK, 1901)	*Barbus barbus*	MORAVEC et al. 1995
Rhabdochona sp.	*Barbus barbus*	RYDLO 1998
Schulmanela petruschewskii (SHULMAN, 1948) IVASHKIN, 1964	*Perca fluviatilis*	POLIN et al. 2002b
Streptocara crassicauda (CREPLIN, 1829)	*Neogobius melanostomus*	FRANCOVA et al. 2011

Acanthocephala		
Species of parasite	**Host**	**Reference**
Acanthocephalus anguillae (MÜLLER, 1780)	*Abramis brama, Anguilla anguilla, Misgurnus fossilis, Oncorhynchus mykiss, Scardinius erythrophthalmus, Squalius cephalus, Thymallus thymallus*	KRITSCHER 1988, RYDLO 1998, SCHABUSS et al. 2005, REIER et al. 2020
Acanthocephalus lucii (MÜLLER, 1776)	*Anguilla anguilla, Aspius aspius, Cottus gobio, Cyprinus carpio, Esox lucius, Gymnocephalus cernuus, Lepomis gibbosus, Lota lota, Neogobius melanostomus, Perca fluviatilis, Ponticola kessleri, Proterorhinus marmoratus, Salmo trutta f. fario, Sander lucioperca, Tinca tinca*	KRITSCHER 1988, MORAVEC et al. 1997, RYDLO 1998, POLIN et al. 2002b, SCHLUDERMANN et al. 2003, LAIMGRUBER et al. 2005, SCHABUSS et al. 2005, MÜHLEGGER et al. 2009a, REIER et al. 2020
Echinorhynchus cinctulus PORTA, 1905	*Cottus gobio, Lota lota, Zingel streber*	REIER et al. 2020
Echinorhynchus truttae (SCHRANK, 1788)	*Lota lota, Oncorhynchus mykiss, Salmo trutta f. fario, Salvelinus fontinalis*	RYDLO 1998, LEWISCH et al. 2020

Neoechinorhynchus rutili (Müller, 1780)	*Barbus barbus, Chondrostoma nasus, Oncorhynchus mykiss, Salmo trutta f. fario, Salmo trutta lacustris, Salvelinus umbla, Salvelinus fontinalis, Squalius cephalus*	Kritscher 1954, Kritscher 1988, Rydlo 1998
Pomphorhynchus bosniacus Kiskaroly & Cankovic 1967	*Barbus barbus, Leuciscus idus, Oncorhynchus mykiss, Squalius cephalus*	Reier et al. 2019, 2020
Pomphorhynchus laevis (Müller, 1776)	*Alburnoides bipunctatus, Barbus barbus, Chondrostoma nasus, Cyprinus carpio, Esox lucius, Gobio gobio, Leuciscus idus, Lota lota, Neogobius melanostomus, Oncorhynchus mykiss, Rutilus rutilus, Saldinus fontinalis, Salmo trutta f. fario, Salmo trutta lacustris, Salvelinus umbla, Squalius cephalus, Thymallus thymallus*	Kritscher 1988, Moravec et al. 1997, Rydlo 1998, Schludermann et al. 2003, Laimgruber et al. 2005, Francova et al. 2011, Reier et al. 2019, 2020
Pomphorhynchus tereticollis (Rudolphi, 1809)	*Alburnoides bipunctatus, Alburnus alburnus, Barbus barbus, Barbatula barbatula, Lota lota, Oncorhynchus mykiss, Pseudorasbora parva, Salmo trutta, Squalius cephalus, Zingel streber*	Reier et al. 2019, Lewisch et al. 2020
Pseudoechinorhynchus clavula (Dujardin, 1845)	*Esox lucius, Lota lota*	Rydlo 1998

Host – parasite list

In the host – parasite list, the fish orders and families are arranged systematically following Froese & Pauly 2019. Fish species in each family are arranged alphabetically. Fish names marked with an (*) are introduced fish species not native to Austria. Figure 1 shows four selected helmith parasite species from this list.

Anguilliformes
Fam. Anguillidae
***Anguilla anguilla* (Linnaeus, 1758)**
Eubothrium crassus, Bothriocephalus claviceps, Proteocephalus macrocephalus, Anguillicola crassus, Camallanus lacustris, Camallanus truncatus, Raphidascaris acus, Hedruris androphora, Acanthocepahlus anguillae, Acanthocephalus lucii, Pseudoechinorhynchus clavula

Cypriniformes
Fam. Cyprinidae
***Abramis brama* (Linnaeus, 1758)**
Caryophyllaeus sp., *Caryophyllaeus laticeps, Ligula intestinalis, Sphaerostoma bramae, Diplostomum spathaceum, Tylodelphis clavata, Posthodiplostomum cuticola, Philometra* sp., *Philometra ovata, Acanthocephalus anguillae*
***Alburnus alburnus* (Linnaeus, 1758)**
Caryophyllaeides fennica, Sphaerostoma bramae, Diplostomum spathaceum, Posthodiplostomum cuticola, Rhabdochona denuntata

Alburnus mento **(Heckel, 1837)**
Triaenophorus nodulusus, Proteocepahlus torulosus, Allocreadium isoporum, Ichthyocotylurus sp., *Tylodelphis clavata*
Alburnoides bipunctatus **(Bloch, 1782)**
Pomphorhynchus laevis, Pomphorhynchus tereticollis
Aspius aspius **(Linnaeus, 1758)**
Eubothrium crassum, Sphaerostoma bramae, Diplostomum spathaceum, Posthodiplostomum cuticola, Acanthocephalus lucii
Blicca björkna **(Linnaeus, 1758)**
Posthodiplostomum cuticola, Ligula intestinalis
Barbus barbus **(Linnaeus, 1758)**
Bathybothrium rectangulum, Aspidogaster limacoides, Allocreadium isoporum, Sphaerostoma bramae, Rhabdochona denuntata, Rhabdochona hellichi, Rhabdochona sp., *Pomphorhynchus laevis, Pomphorhynchus bosniacus, Pomphorhynchus tereticollis, Neoechinorhynchus rutili*
Carassius carassius **(Linnaeus, 1758)**
Bothriocephalus acheilognathi
Chondrostoma nasus **(Linnaeus, 1758)**
Caryophyllaeus laticeps, Posthodiplostomum cuticola, Rhabdochona denuntata, Pomphorhynchus laevis, Neoechinorhynchus rutili
Cyprinus carpio **Linnaeus, 1758**
Caryophyllaeus laticeps, Bothriocephalus acheilognathi, Diplostomum spathaceum Posthodiplostomum cuticola, Acanthocephalus lucii, Pomphorhynchus laevis
Gobio gobio **(Linnaeus, 1758)**
Caryophyllaeus laticeps, Sphaerostoma bramae, Pomphorhynchus laevis
Leuciscus idus **(Linnaeus, 1758)**
Pomphorhynchus bosniacus, Pomphorhynchus laevis
Leucaspius delineatus **(Heckel, 1843)**
Posthodiplostomum cuticola
Phoxinus phoxinus **(Linnaeus, 1758)**
Posthodiplostomum cuticola
****Pseudorasbora parva*** **(Temminck & Schlegel, 1846)**
Pomphorhynchus tereticollis
Rutilus meidingeri **(Heckel, 1851)**
Caryophyllaeus sp., *Sphaerostoma bramae*
Rutilus rutilus **(Linnaeus, 1758)**
Caryophyllaeides fennica, Caryophyllaeus laticeps, Caryophyllaeus sp., *Ligula intestinalis, Allocreadium isoporum, Diplostomum spathaceum, Posthodiplostomum cuticola, Tylodelphis clavata, Rhabdochona denuntata, Pomphorhynchus laevis*
Scardinius erythrophthalmus **(Linnaeus, 1758)**
Caryophyllaeides fennica, Ligula intestinalis, Diplostomum spathaceum, Posthodiplostomum cuticola, Acanthocephalus anguillae
Squalius cephalus **(Linnaeus, 1758)**
Caryophyllaeus laticeps, Proteocephalus torulosus, Ligula intestinalis, Allocreadium isoporum, Sphaerostoma bramae, Rhabdochona denuntata, Acanthocephalus anguillae, Pomphorhynchus bosniacus, Pomphorhynchus laevis, Pomphorhynchus tereticollis, Neoechinorhynchus rutili

***Tinca tinca* (Linnaeus, 1758)**
Asymphylodora tincae, Acanthocephalus lucii
***Vimba vimba* (Linnaeus, 1758)**
Triaenophorus nodulosus, Proteocephalus torulosus, Caryophyllaeides fennica, Sphaerostoma bramae
Fam. Cobitidae
***Misgurnus fossilis* (Linnaeus, 1758)**
Allocreadium transversale, Posthodiplostomum cuticola, Acanthocephalus anguillae
Fam. Nemacheilidae
***Barbatula barbatula* (Linnaeus, 1758)**
Pomphorhynchus tereticollis
Esociformes
Fam. Esocidae
***Esox lucius* (Linnaeus, 1758)**
Diplostomum spathaceum, Posthodiplostomum cuticola, Triaenophorus crassus, Triaenophorus nodulosus, Camallanus lacustris, Raphidascaris acus, Pomphorhynchus laevis, Acanthocephalus lucii

Siluriformes
Fam. Siluridae
***Siluris glanis* Linnaeus, 1758**
Proteocephalus osculatus

Salmoniformes
Fam. Salmonidae
***Coregonus lavaretus* (Linnaeus, 1758)**
Triaenophorus crassus
***Coregonus wartmanni* (Bloch, 1782)**
Caryophyllaeus fimbriceps, Khawia coregoni, Eubothrium salvelini, Proteocephalus longicollis
***Coregonus* sp.**
Proteocephalus longicollis, Eubothrium salvelini, Triaenophorus crassus
****Onchorhynchus mykiss* (Walbaum, 1792)**
Proteocephalus longicollis, Triaenophorus crassus, Triaenophorus nodulosus, Crepidostomum farionis, Crepidostomum metoecus, Diplostomum spathaceum, Acanthocephalus anguillae, Echinorhynchus truttae, Neoechinorhynchus rutili, Pomphorhynchus bosniacus, Pomphorhynchus laevis, Pomphorhynchus tereticollis
***Salmo trutta f. fario* Linnaeus, 1758**
Cyathocephalus truncatus, Proteocephalus longicollis, Crepidostomum farionis, Crepidostomum metoecus, Nikolla wiesniewskii, Cystidicola farionis, Acanthocephalus lucii, Echinorhynchus truttae, Neoechinorhynchus rutili, Pomphorhynchus laevis, Pomphorhynchus tereticollis
***Salmo trutta lacustris* Linnaeus, 1758**
Neoechinorhynchus rutili, Pomphorhynchus laevis
****Salvelinus fontinalis* (Mitchill, 1815)**
Eubothrium salvelini, Crepidostomum farionis, Echinorhynchus truttae, Neoechinorhynchus rutili

Salvelinus umbla **(Linnaeus, 1758)**
Eubothrium crassus, Eubothrium salvelini, Triaenophorus crassus, Traienophorus nodulosus, Crepidostomum farionis Crepidostomum metoecus, Rhabdochona denundata, Neoechinorhynchus rutili, Pomphorhynchus laevis

Thymallus thymallus **(Linnaeus, 1758)**
Cyathocephalus truncatus, Crepidostomum farionis, Acanthocephalus anguillae, Pomphorhynchus laevis

Gadiformes
Fam. Lotidae

Lota lota **(Linnaeus, 1758)**
Triaenophorus nodulosus, Acanthocephalus lucii, Echinorhynchus cinctulus, Echinorhynchus truttae, Pomphorhynchus laevis, Pomphorhynchus tereticollis, Pseudoechinorhynchus clavula

Perciformes
Fam. Centrarchidae

****Lepomis gibbosus***
Acanthocephalus lucii

Fam. Percidae

Gymnocephalus cernuus **(Linnaeus, 1758)**
Posthodiplostomum brevicaudatum, Tylodelphis clavata, Acanthocephalus lucii

Sander lucioperca **(Linnaeus, 1758)**
Ligula intestinalis, Proteocephalus percae, Diplostomum spathaceum, Camallanus lacustris, Raphidascaris acus, Acanthocephalus lucii

Perca fluviatilis **(Linnaeus, 1758)**
Triaenophorus crassus, Triaenophorus nodulosus, Eubothrium salvelini, Proteocephalus longicollis, Proteocephalus percae, Diplostomum spathaceum, Bunodera luciopercae, Ichthyocotylurus sp., *Posthodiplostomum brevicaudatum, Tylodelphis clavata, Schulmanela petruschewskii, Acanthocephalus lucii*

Zingel sterber **(Siebold, 1863)**
Echinorhynchus cinctulus, Pomphorhynchus tereticollis

Gobiiformes
Fam. Gobiidae

****Neogobius melanostomus*** **(Pallas, 1814)**
Bucephalus polymorphus, Bunodera sp., *Diplostomum* sp., *Diplostomum spathaceum, Nicolla skrjabini, Tylodelphys clavata, Anguillicola crassus, Eustrongylides excisus, Pseudocapillaria salvelini, Raphidascaris acus, Streptocara crassicauda, Pomphorhynchus laevis, Acanthocephalus lucii*

******Ponticola kessleri*** **(Günther, 1861)**
Diplostomum spathaceum, Nicolla skrjabini, Acanthocephalus lucii

Proterorhinus marmoratus **(Pallas, 1814)**
Triaenophorus crassus, Apatemon cobitidis proterorhini, Acanthocephalus lucii

Scorpeniformes
Fam. Cottidae

Cottus gobio (Linnaeus, 1758)
Acanthocephalus lucii, Echinorhynchus cinctulus

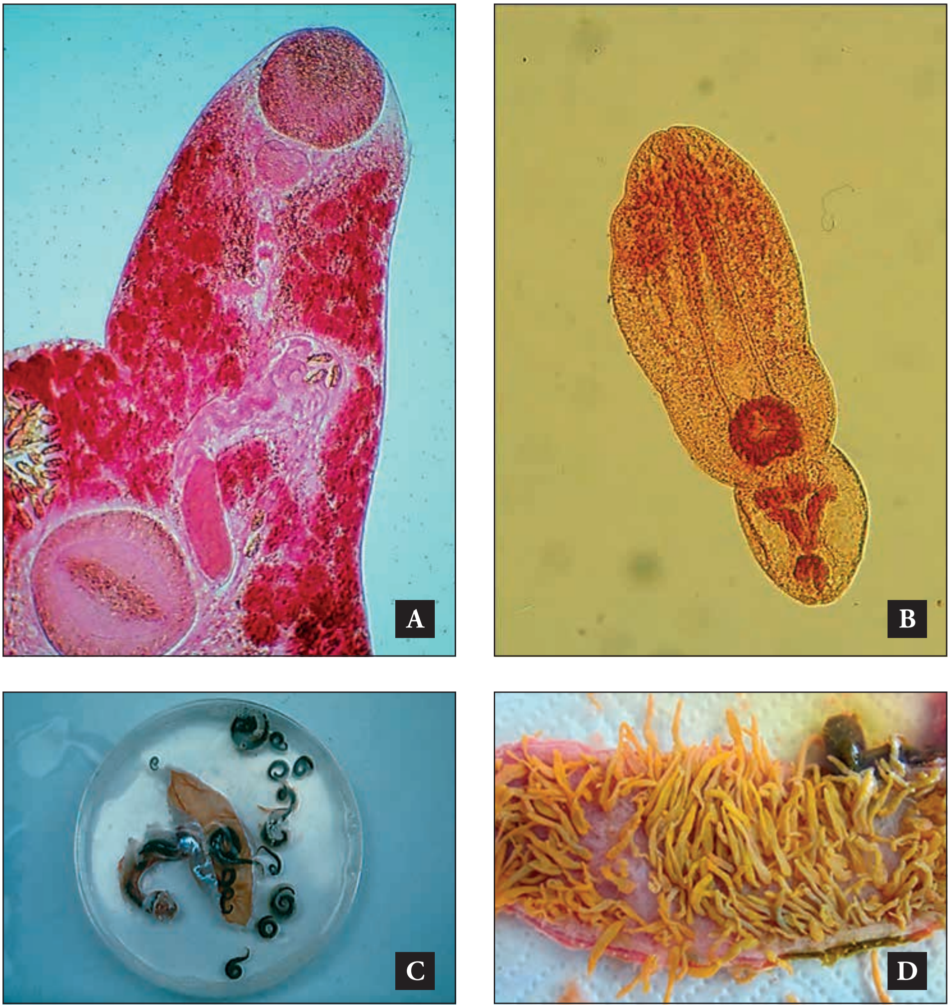

Fig. 1: A: Anterior part of *Sphaerostoma bramae*, Digenea from the intestine of *Abramis brama*, Wallersee 1994, size 0.5 cm, Photo: Rydlo; B: Metacercariae of *Posthodiplostomum cuticola,* Digenea from the integument lens of *Rutilus rutilus*, Wallersee 1994, size 0.7 mm, Photo: Rydlo; C: *Anguillicola crassus,* Nematoda from the swimbladder of eel, Neusiedlersee, size 1.5–2.5 cm mm, Photo: Konecny; D: Acanthocephalan *Pomphorhynchus* sp. in the intestine of barbel, Danube river, Hainburg, size 2–2.8 cm, Photo: Konecny. – Abb. 1: A: Vorderansicht von *Sphaerostoma bramae*, Digenea aus dem Darm von *Abramis brama*, Wallersee 1994, Größe 0.5 cm, Foto: Rydlo; B: Metazerkarie von *Posthodiplostomum cuticola,* Digenea aus dem Integument von *Rutilus rutilus*, Wallersee 1994, Größe 0.7 mm, Foto: Rydlo; C: *Anguillicola crassus*, Nematoda aus der Schwimmblase eines Aales, Neusiedlersee, Größe 1.5–2.5 cm, Foto: Konecny; D: Acanthocephale *Pomphorhynchus* sp. im Darm einer Barbe, Donau bei Hainburg, Größe 2–2.8 cm, Foto: Konecny.

Discussion and conclusions

A total of 61 helminth species from 45 fish species are included in the parasite – host and host – parasite lists. In comparison a checklist of metazoan parasites of fishes of the Czech Republic and the Slovak Republic by Moravec (2001) listed 344 parasite species also including Monogenea, Hirudinea and Crustacea.

The history of fish parasitology in Austria commenced with Bremser and Diesing in the 19th century but a large gap in activity remained until the work of Kritscher and Rydlo beginning in the 1950's. Their reports gave a sound basis for further studies initiated by Fritz Schiemer in the 1980's. He achieved a revival of the subject and initiated co-operation with parasitologists from the United Kingdom, Czech Republic, Hungary, Italy, Croatia, and Germany. In association with Czech and Hungarian researchers, a large-scale study of barbel parasites contributed to our knowledge of the helminth fauna of this common river fish in central Europe (Morevec et al. 1997). Students from various Austrian universities and research institutes extended the knowledge of the parasite fauna of Austrian fish in different waters. A focus on the ecology of fish parasites also included a long-term study in the lake Neusiedler See (Schabuss 2005) on an allochthon eel population which revealed a remarkable alteration in the helminth community over 10 years. Another Austrian working group analyzed the ecology of tapeworms from gourmet fish in Austrian lakes and showed not only that fishery management influences the parasite epidemiology (Schaufler et al. 2014, Anegg et al. 2015), but also proved the economic input of parasitology for wild fish populations. Projects also included environmental studies on helminths as heavy metal accumulators and indicators (Schludermann et al. 2003, Jirsa et al. 2008b), which complemented and confirmed similar studies in Germany (Sures et al. 1997, Sures 2003).

New data were also obtained within the Austrian Barcode of Life initiative (ABOL) especially for Acanthocephala. The study by Reier et al. (2019) revealed the occurrence of two additional *Pomphorhynchus* species in Austria by combining morphological and molecular genetic methods. *P. tereticollis* and *P. bosniacus* were identified in addition to *P. laevis,* an acanthocephalan which was commonly reported from various fish species in different locations in Austria (Kritscher 1985, Rydlo 1998). Furthermore Reier et al. (2020) found indications for cryptic species within *E. cinctulus* whereas one sample of *Acanthocephalus* from *A. anguilla*, which was not assigned to any known species, is likely to represent a new species.

At the present time students from different Austrian universities continue to pursue MSc and PhD studies, which have incorporated current techniques in molecular biology, biochemistry, genetics, epidemiology and evolutionary biology to increase our understanding of aquatic parasitology. Besides medical and economic interests, research in fish parasitology is still essential for biogeography and ecology as well as for evolutionary science. Hence efforts should be made to promote and strengthen research on fish parasites in Austria.

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