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Parasite community and heavy metal contents of roach (*Rutilus rutilus* L.) from different freshwater habitats in North Rhine-Westphalia, Germany

Parasitengemeinschaft und Schwermetallbelastung von Rotaugen (*Rutilus rutilus* L.) aus unterschiedlichen Süßwasserhabitaten in Nordrhein-Westfalen

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Summary: The parasite fauna and heavy metal contents of roach, *Rutilus rutilus* L., was studied from four different freshwater habitats in North Rhine-Westphalia. A total of 115 roach were sampled from Lake Dörpfeld, Lake Masuren, River Ruhr and Diergardt's side canal from April to August 2007, revealing 19 generalistic parasite species belonging to the *Trichodina* (2), Sporozoa (1), Myxozoa (3), Digenea (2), Monogenea (2), Cestoda (2), Nematoda (3), Acanthocephala (2) and Crustacea (2). The most diverse component community was found in the River Ruhr (twelve species) and the lowest in Lake Masuren (seven species). The infracommunity was highest in the River Ruhr (3.7) and lowest in the Diergardt's side canal (2.1). The two helminths *Diplostomum spathaceum* (Rudolphi, 1819) (Digenea) and *Dactylogyrus* sp. (Monogenea) were the only ubiquitary species. Acanthocephalans were recorded only from the River Ruhr, while the cestodes and the nematode *Philometra rischta* (Skrjabin, 1917) occurred only in the lakes. Ten roach from each sampling site were analysed for their heavy metal contents in muscles and kidney. Highest values in muscles were recorded from the River Ruhr and lowest from Lake Dörpfeld. The heavy metal concentration in the kidney was, in most cases, higher compared to that of the muscle. Especially high nickel contents were found in the muscle of fishes from River Ruhr and high cadmium contents in the kidney from Lake Masuren. A positive correlation was found between the heavy metal content and the level of infestation with trichodinid ectoparasites. Similarly, the size of the water bodies and the connectivity to nearby lakes and rivers enforced a higher level of infestation with the recorded fish parasites.

Key words: Bioindicators, freshwater habitats, heavy metals, roach, *Rutilus rutilus*, Germany, North Rhine-Westphalia

Zusammenfassung: Rotaugen (*Rutilus rutilus* L.) aus vier unterschiedlichen Süßwasserhabitaten in Nordrhein-Westfalen wurden hinsichtlich ihrer Parasitenfauna und der Schwermetallbelastung untersucht. Insgesamt wurden 115 Rotaugen aus den Gewässern Dörpfeldsee, Masurensee, der Ruhr und dem Diergardt'schen Seitenkanal im Zeitraum zwischen April und August 2007 beprobt. Dabei konnten 19 generalistische Parasitenarten der Taxa *Trichodina* (2), Sporozoa (1), Myxozoa (3), Digenea (2), Monogenea (2), Cestoda (2), Nematoda (3), Acanthocephala (2) und Crustacea (2) nachgewiesen werden. Die größte Artenvielfalt konnte in den Fischen der Ruhr (zwölf Arten) und die niedrigste im Masurensee (sieben Arten) festgestellt werden. Die Infragemeinschaft der Rotaugen der Ruhr war am höchsten (3,7), die niedrigste konnte für die Fische des Diergardt'schen Seitenkanals (2,1) berechnet werden. Die Helminthenarten *Diplostomum spathaceum* und *Dactylogyrus* sp. waren in allen Gewässern vertreten. Die Acanthocephalen kamen nur in der Ruhr vor, während die Cestoden und Nematoden wie *Philometra rischta* nur aus den beprobten Seen isoliert werden konnten. Darüber hinaus wurden zehn Rotaugen aus jedem Beprobungsgebiet auf ihre Schwermetallbelastung in der Muskulatur und der Niere untersucht. Die stärkste Belastung in der Muskulatur konnte in der Ruhr, die niedrigste im Dörpfeldsee festgestellt werden. Die Belastung der Niere war überwiegend höher. Die höchste Belastung der Muskulatur wurde in den Fischen der Ruhr durch Nickel verursacht. In der Niere der Fische aus dem Masurensee wurden die höchsten Cadmium-Konzentrationen berechnet. Die Schwermetallbelastung war positiv korreliert mit dem Befall von trichodinen Ektoparasiten. Auch die Gewässergröße und die Vernetzung mit anderen Seen und Flußhabitaten verstärkt die Parasitierung der Fische.

Schlüsselwörter: Bioindikation, Süßwasserhabitat, Schwermetalle, Rotauge, *Rutilus rutilus*, Deutschland, Nordrhein-Westfalen

1. Introduction

Parasitic organisms occur in almost every habitat and animal taxon, including zoonotic parasites that infect humans (Rohde 1993, Palm & Klimpel 2007, Klimpel & Palm 2011). They represent the most frequent life form on earth, and are able to attack nearly every host organ (Grabda 1991). Parasites have developed elaborate transmission pathways within the terrestrial and aquatic habitats. Palm (2011) estimated the existence of up to 120,000 fish parasite species, including protozoans and metazoans. Margolis & Arthur (1979) and McDonald & Margolis (1995) recorded 925 different fish parasites on 292 marine and freshwater fish species from Canadian waters, including protozoans and metazoans (3.2 parasite species/fish species). Palm et al. (1999) reported 191 different metazoan parasite species from another northern habitat, the coastal waters of Germany. A total of 62 wild fish species from the North and Baltic Sea coast harboured an average of 3.1 metazoan parasite species per fish species. Especially omnivorous and widely distributed fish species can accumulate a high number of parasite species. Roach (*Rutilus rutilus*) is one of the most abundant and widely distributed freshwater fish in central Europe. Previous parasitological studies have recorded a total of 180 parasite species for roach, including 19 protozoans and 161 metazoans. Most studies were carried out in freshwater habitats in Great Britain, Finland, and the Czech Republic (e.g. Kennedy 1974, Valtonen & Koskivaara 1989, Simkova et al. 2000). In Germany, Knopf et al. (2007) examined fishes from Lake Dölln near Berlin. Mellin & Stremmer-Bretthauer (1993) studied *R. rutilus* from a dam ecosystem (Kerspe dam) and Taraschewski (1988) from Lake Ruhr in Bochum, both located in North Rhine-Westphalia (NRW). Rückert et al. (2007) collected data in northern Germany, from Lake Diek and an artificial water body, the brackish water Kiel Canal that connects the North and the Baltic Sea. So far, 70 of the 151 roach parasite species have been reported from Germany, 41 of them from North Rhine-Westphalia.

The high species diversity and a number of different life cycle stages allow fish parasites to be used as biological indicators for a range of different applications. Palm (2011) distinguished biological indicators for the host ecology (Palm 1999) and phylogeny, accumulation indicators to detect pollutants, impact indicators to describe the relationship between e.g. pollution or eutrophication and the parasite (Palm & Dobberstein 1999, Palm et al. 2011), and finally systemic indicators that provide information on the health status of the environment. While ectoparasites can be directly affected by polluted environmental conditions, heteroxenous (multihost life cycle) parasites can be linked to the number of intermediate hosts at the studied sites (Xianghua 1987, Overstreet et al. 1996). The intermediate hosts may be more sensitive to environmental changes than the parasite, which in the case of endoparasites is buffered from the environment by the host physiology (Paperna & Overstreet 1981). Consequently, fish parasitological investigations combined with pollution studies can provide valuable information on aquatic environmental health, allowing assessment and even monitoring studies in changing environments (Palm 2011, Kleinertz et al. in press).

The omnipresence of roach in many European countries and also in German freshwater ecosystems, the high diversity of recorded parasites and its resilience to adverse environmental conditions may allow this fish species and its parasites to be used as a biological indicator model for freshwater environments. This might allow the integration of fish parasites and health aspects of their hosts into the European Water Framework Directive that so far relies on other biological parameters but not includes fish health. The present study was carried out in order to analyse the parasite fauna of roach from four different freshwater habitats in North Rhine-Westphalia, Lake Dörpfeld, Lake Masuren, River Ruhr and Diergardt's side canal (DSC). The heavy metal contents were analysed in order to link these contaminants with the recorded parasite infracommunities. The potential to utilise fish parasites of roach as biological indicators in German freshwater environments is discussed.

2. Material and methods

A total of 115 *Rutilus rutilus* from four freshwater habitats in North Rhine-Westphalia were studied for fish parasites (fig. 1). Lake Dörpfeld (51° 10' N, 6° 55' O) with a surface area of 0.07 km² was the most isolated water body. Lake Masuren (51° 23' N, 6° 47' O) with an area of 0.3 km² belongs to the Sechs-Seen-Platte, a large lake system in Duisburg. Riverine ecosystems were represented by the River Ruhr (51° 28' N, 7° 13' O), a large river of 221 km length and up to 70 m width at the sampling site. Diergardt's side canal (in the following: DSC) (51° 15' N, 6° 10' O) is 4.725 m long and 6-8 m wide. The DSC is

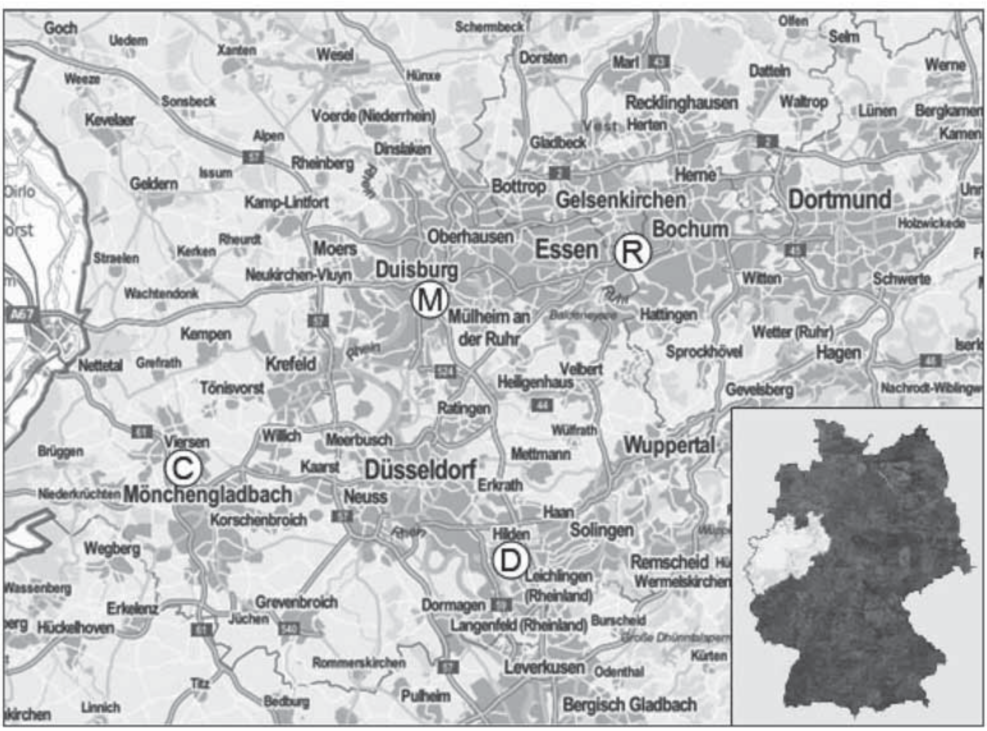


Fig. 1: Map of the area of investigation. Map according to the Federal Agency for Cartography and Geodesy 2012, modified. *C* = Diergardt's side canal, D = Lake Dörpfeld, M = Lake Masuren, R = River Ruhr.
Abb. 1: Karte der Untersuchungsgebiete, verändert nach dem Bundesamt für Kartographie und Geodäsie 2012. C = Diergardt'scher Seitenkanal, D = Dörpfeldsee, M = Masurensee, R = Ruhr.

connected to the River Schwalm. The channel diverts from this river and flows into it again. Diergardt's side canal can be considered as a small, slowly moving water body that tends to desiccate during summer.

A total of 35 roach from each habitat were obtained from April to August 2006 with the help of local fishermen, except for Lake Masuren, where only ten roach were caught. Smears were taken from the gills and the skin directly after catch to record the infection of protozoan parasite species (except for fishes from DSC). For the heavy metal survey, tissue samples of the kidney and the muscles (ridge) were sampled and deep frozen at -80 °C. The fishes were kept deep frozen at -20 °C for subsequent investigation. In the laboratory, the following measurements were taken: total fish length (TL, to 1.0 cm), total body weight (BW, to 1.0 g) and the slaughter weight (SW, to the nearest 1.0 g). The condition factor was calculated according to the Fulton formula (Bagenal 1978), where higher k-values (condition factor) correlate with better health condition of the fish.

$$k = \frac{\text{slaughter weight SW (g) x 100}}{\text{total fish length TL (cm)}^3}$$

Fish were examined via stereo-microscope. The body surface (fins, operculi, mouth and skin) was studied for ectoparasites. The internal organs such as the digestive tract, gall bladder, gonads, heart, kidney, liver, spleen, and swim bladder were separated and transferred into saline. The smears from the gills and opercula were stained by using silver nitrate impregnation after Klein (1926, 1958). Metazoan parasites and protozoans belonging to the Myxosporidia, Peritrichida and Sporozoa were quantified. All isolated parasites were fixed in ethanol (70 %) with 4 % glycerine. Parasite identification followed standard literature and original descriptions (Golvan 1969, Lom & Dykova 1992, Khalil et al. 1994, Moravec 1994).

The ecological terms follow Margolis et al. (1982) and Bush et al. (1997): Prevalence (P) is the number of infected fish with one or more individuals of a particular parasite species (or taxonomic group) divided by the number of hosts examined (expressed as a percentage). Intensity (of infection, I) is the number of individuals of a particular parasite species in a single infected host (expressed as a numerical range); and mean intensity (of infection, mI) is the average intensity or the total number of parasites of a particular species found in a sample divided by the number of infected hosts. For protozoan parasites, the density of infection (number of parasites per cm^2 of gill scraping or tissue) was calculated. The diversity of the endoparasite fauna was estimated by using the Shannon-Wiener diversity index (H'(en)) and the evenness index (E (en)) of Pielou [H'(en)) = -∑_Pi x lnPi]; [E (en) = H'(en)/ lnS], with H'(en) being the diversity index, Pi the proportion of the individual species to the total and S the total number of species in the community (species richness), see Magurran (1988). Both indices were calculated only for metazoan endoparasites, assessing the diversity of intermediate hosts in the surrounding ecosystem. The infracommunity (IC) is the average number of parasite species in each fish. Species with prevalence above 60 % are considered as core species (CS). Additionally, the ratio of ecto- to endoparasites (E/E ratio) was calculated (Palm & Rückert 2009). Species groups (such as Nematoda indet.) that could not be further identified were not included in these calculations.

For examination of the heavy metal contamination, the tissue samples of kidney and musculature were analysed. Anatomic absorption spectroscopy (5100 PC) was used in order to quantify cadmium, copper, lead, mercury and nickel, respectively. The tissue was prepared in 65 % nitric acid. After removing water and organic substances by heating, each heavy metal was evaporated by its specific temperature. The content of the containing heavy metals could be measured via photometric absorption. The limit of detection was 0.001 mg/kg BW for cadmium, lead, mercury and nickel, and 0.002 mg/kg BW for copper.

3. Results

3.1. Parasites

Nineteen different parasite species, belonging to the Sporozoa, Ciliata, Myxozoa, Digenea, Monogenea, Cestoda, Nematoda, Acanthocephala and Crustacea, were found, all of them generalists. Two species have an allogenic life cycle, while 17 species complete the entire life cycle inside the aquatic habitat (autogenic). Seven species had a monoxenous and 12 a heteroxenous life cycle. The highest species richness was observed in the riverine ecosystem Ruhr (12 species) compared with the two sampled lakes (seven species in Lake Masuren, ten species in Lake Dörpfeld). The highest number of parasites was recorded from Lake Dörpfeld (3759 individuals), the lowest from the DSC (1541 individuals). Prevalence, intensity and site of infection are summarised in table 1, recorded parasites are illustrated in figures 2 and 3.

3.1.1. Protozoan parasites

The gills of a single roach obtained from the River Ruhr were infested by a sporozoan belonging to the genus *Octosporella* Ray & Raghavachari, 1942 (Sporozoa, ord. Eucoccidiorida, fam. Eimeriidae (fig. 2C)). *Trichodina* sp. and *Paratrichodina incissa* (Lom, 1959) (fig. 2A), both belonging to the Ciliata, ord. Peritrichida (fam. Trichodinidae), were found on the gills and opercula of the fish. The fishes from River Ruhr were infested with *P. incissa* at a prevalence of 25.7 % and a density of 3.7 (1-8) (tab. 1). *Trichodina* sp. was isolated from Lake Dörpfeld at a prevalence of 8.5 % and a mean density of 1.3 (1-2). Both species were absent in fishes from Lake Masuren and the DSC.

3.1.2. Metazoan parasites

Myxozoa: Three species of myxozoans could be identified, *Myxobolus diversicapsularis* Slukhai, 1966 (fig. 2B), *Myxobolus muelleri* Bütschli, 1882 and *Myxobolus* sp. *M. diversicapsularis* occurred in the gills of the fishes from Lake Dörpfeld and River Ruhr, at a prevalence of 17 % and 40 % (tab. 1), respectively. The mean intensity was highest in River Ruhr with 74.2 (1-426) recorded xenoma and lowest in Lake Dörpfeld with 1.5 (1-2). *M. muelleri* was found in the gills of roach from the DSC (14.3 %), with an intensity of 4.4 (1-13). *Myxobolus* sp. was recorded only in Lake Masuren with a prevalence of 30 % and an intensity of 1-17 (mean 11.0). The highest infection of Myxozoa occurred in roach from the River Ruhr, the DSC showed the lowest myxozoan load.

Monogenea: Two species of monogeneans were found on the gills of *Rutilus rutilus*, *Dactylogyrus* sp. (fig. 2E) and *Diplozoon paradoxum* Nordmann, 1832. *Dactylogyrus* spp. occurred in each sampling site, with the highest prevalence in Lake Masuren (100 %). Highest mean intensity (49.6) occurred in the DSC. Fishes from lake Dörpfeld showed the lowest infection. *D. paradoxum* was most abundant on fishes from Lake Masuren (90 %) with a mean intensity of 3.2 (1-8), and was also present in the River Ruhr and the DSC, while absent in Lake Dörpfeld.

Digenea: Digenean trematodes were most abundant. Especially *Diplostomum spathaceum* was recorded as a core species in the eyes of the examined fish. The larvae of *D. spathaceum* were isolated from all studied localities, with the highest prevalence in the River Ruhr (91.4 %) with an intensity of 1-119 (mean 52.4). This parasite was less frequent in roach from Lake Masuren (30 %) and the DSC (25.7 %). Almost half of the fishes from Lake Dörpfeld (54.3 %) were infected with an intensity of 3-79 (mean 16.7). Metacercariae of *Rhipidocotyle campanula* (Dujardin, 1845) (fig. 2D) with a low intensity were found in the gills of roach from three sampling locations except Lake Masuren. Highest prevalence was found in River Ruhr (11.4 %, intensity 1-3, mean intensity 1.5), only a single specimen each was recorded from Lake Dörpfeld and the DSC.

Cestoda: Almost every roach from the sampled lakes was infected with cysts on liver and mesenteries of the cyclophyllid Cestoda *Paradilepis scolecina* (Rudolphi, 1819) (fig. 3A-B; Lake Masuren 90 %, Lake Dörpfeld 94.3 %). Another not further identified Cestoda occurred with a

		Lake Dörpfeld (n=35)		Lake Masuren (n=10)		Ruhr (n = 35)		DSC (n=35)		Infection site
Parasites	kind ec/en	P %	I (mI) D (mD)	P %	I (mI) D (mD)	P %	I (mI) D (mD)	P %	I (mI) D (mD)	
Sporozoa										
Octosporella sp.	-	-	-	-	-	2.9	1 (1.0)	-	-	g
Myxozoa				-					-	
Myxobolus diversicapsularis	en	17.1	1-2 (1.5)	-	-	40.0	1-426 (74.2)	-		g
Myxobolus muelleri	en	-	-	-	-	-	-	14.3	1-13 (4.4)	g
Myxobolus sp.	en	-	-	30.0	1-17 (11.0)	-	-	-	-	g
Ciliata										
Paratrichodina incissa	ec	-	-	-	-	25.7	1-8 (3.7)	-	-	g
Trichodina sp.	ec	8.5	1-2 (1.3)	-	-	-	-	-	-	g
Digenea										
Diplostomum spathaceum	en	54.3	3-79 (16.7)	30.0	2-6 (3.6)	91.4	1-119 (52.4)	25.7	1-7 (3.6)	e
Rhipidocotyle campanula	ec	2.9	1 (1.0)	-	-	11.4	1-3 (1.5)	2.9	1 (1.0)	g
Monogenea										
Dactylogyrus spp.	ec	42.9	1-38 (8.5)	100.0	1-30 (2.7)	88.5	1-93 (29.1)	82.9	1-324 (49.6)	g
Diplozoon paradoxum	ec	-	-	90.0	1-8 (3.2)	37.1	1-7 (2.8)	20.0	1-7 (3.9)	g
Cestoda										
Paradilepis scolecina	en	94.3	5-436 (99.5)	90.0	1-316 (93.3)	-	-	-	-	l, m
Cestoda indet.	en	11.4	1-3 (1.8)	-	-	-	-	-	-	i
Nematoda										
Philometra rischta	en	2.9	6 (6.0)	10.0	3 (3.0)	-	-	-	-	f, o, s
Pseudocapillaria tomentosa	en	-	-	-	-	5.7	1-2 (1.5)	-	-	i
Nematoda indet.		-	-	-	-	17.1	1 (1.0)	34.2	1-7 (2.5)	i
Acanthocephala		-								
Acanthocephalus anguillae	en	-	-	-	-	45.7	1-7 (2.6)	-	-	i
Pomphorhynchus laevis	en	-	-	-	-	42.8	1-7 (2.4)	20.0	1-3 (1.3)	i
Crustacea										
Argulus foliacens	ec	5.7	1 (1.0)	-	-	-	-	2.9	1 (1.0)	g
Ergasilus sieboldi	ec	5.7	1 (1.0)	10.0	1 (1.0)	2.9	1 (1.0)	-	-	s

Tab. 1: Parasite infection of *Rutilus rutilus* from four freshwater habitats in North Rhine-Westphalia. D = density, DSC = Diergardt's side canal, e = eyes, ec = ectoparasite, en = endoparasite, f = fins, g = gills, I = intensity, i = intestine, l = liver, m = mesenteries, mD = mean density, mI = mean intensity, o = opercula, P % = prevalence, s = skin.

Tab. 1: Parasitenbefall bei *Rutilus rutilus* aus vier Süßwasserhabitaten in Nordrhein-Westfalen. D = Dichte, DSC = Diergardt'scher Seitenkanal, e = Augen, ec = Ektoparasit, en = Endoparasit, f = Flossen, g = Kiemen, I = Intensität, i = Darm, l = Leber, m = Mesenterien, mD = mittlere Dichte, mI = mittlere Intensität, o = Opercula, P % = Prävalenz, s = Haut.

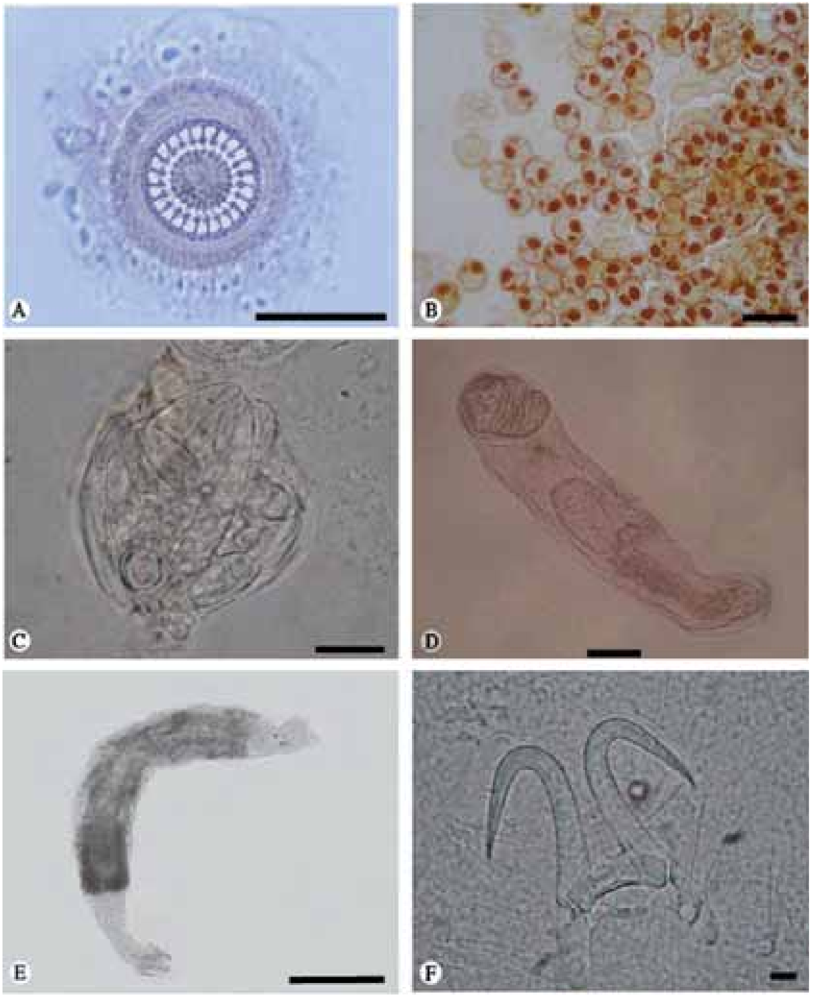


Fig. 2 A-F: A Habitus of *Paratrichodina incissa*. Scale bar = 20 µm. **B** Habitus of several specimens of *Myxobolus diversicapsularis*, silver nitrate staining. Scale bar = 10 µm. **C** Oocyte and sporocyst of *Octosporella* sp. Scale bar = 20 µm. **D** View to the ventral side of *Rhipidocotyle campanula*. Scale bar = 100 µm. **E** Habitus of *Dactylogyrus* sp. Scale bar = 100 µm. **F** Hooks of *Dactylogyrus* sp. Scale bar = 20 µm.

Abb. 2 A-F: A Habitus von *Paratrichodina incissa.* Skala = 20 µm. **B** Habitus mehrerer Exemplare von *Myxobolus diversicapsularis,* gefärbt mit Silbernitrat. Skala = 10 µm. **C** Oocyste und Sporocyste von *Octosporella* sp. Skala = 20 µm. **D** Ventralansicht von *Rhipidocotyle campanula*. Skala = 100 µm. **E** Habitus von *Dactylogyrus* sp. Skala = 100 µm. **F** Detailaufnahme der Haken von *Dactylogyrus* sp. Skala = 20 µm.

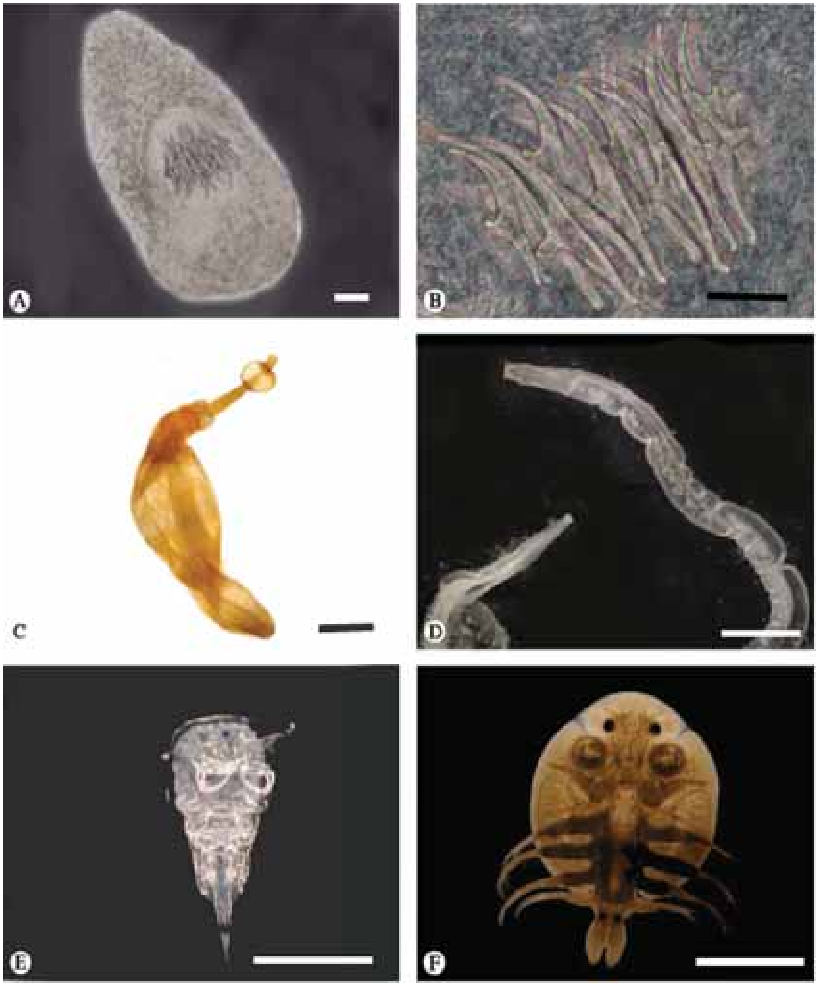


Fig. 3 A-F: A Plerocercus of *Paradilepis scolecina*. Scale bar = 50 µm**. B** Hooks of *P. scolecina* in detail. Scale bar = 100 µm. **C** Habitus of *Pomphorhynchus laevis*. Scale bar = 1.000 µm. **D** Female of *Philometra rischta*. Scale bar = 500 µm. **E** Habitus of *Ergasilus sieboldi*. Scale bar = 500 µm. **F** Adult of *Argulus foliaceus*. Scale bar = 2.0 mm. **Abb. 3 A-F: A** Plerocercus von *Paradilepis scolecina*. Skala = 50 µm. **B** Detailaufnahme der Haken von *P. scolecina*. Skala = 100 µm. **C** Habitus von *Pomphorhynchus laevis.* Skala = 1.000 µm. **D** *Philometra rischta*, weibliches Exemplar. Skala = 500 µm. **E** Habitus von *Ergasilus sieboldi.* Skala = 500 µm. **F** *Argulus foliaceus*, adultes Exemplar. Skala = 2,0 mm.

prevalence of 11.4 % in the intestine of the fish from Lake Dörpfeld. No cestode could be detected in fishes from the riverine ecosystems.

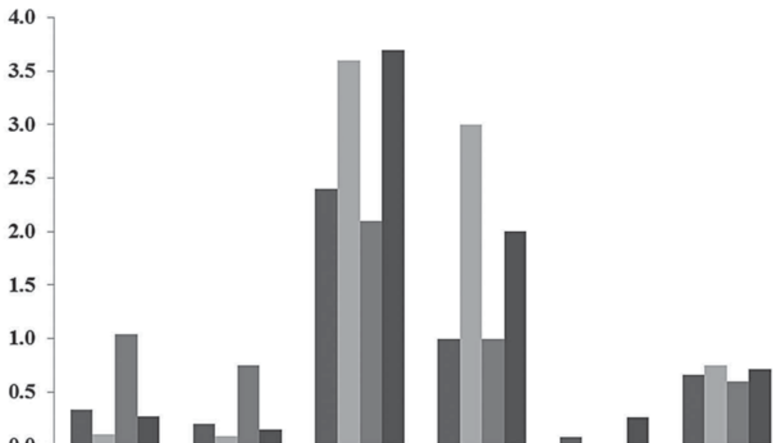
Nematoda: The Nematoda were represented by adults of the species *Philometra rischta* (fig. 3D) and *Pseudocapillaria tomentosa* (Dujardin, 1843). In the riverine ecosystems one further nematode species was found, that could not be identified to the species level. *P. rischta* was isolated from both lakes. They occurred in the skin with low prevalences of 2.9 % and 10 % respectively and reached intensities of 6 and 3. *P. tomentosa* was found in River Ruhr but only in the intestine of few fishes (6 %) with an intensity of 1-2 (mean 1.5). Nematoda indet. was recorded from the DSC and River Ruhr with prevalences of 17.1 % and 34.2 % and an intensity of 1 and 1-7 (mean 2.5), respectively.

Acanthocephala: Adult Acanthocephala were found in River Ruhr and the DSC, but were absent in the lakes. The acanthocephalans were located in the intestine and were identified as *Pomphorhynchus laevis* (Zoega in Müller, 1776) (fig. 3C) and *A. anguillae* (Müller, 1780). *P. laevis* had a prevalence of 42.8 % in the River Ruhr, but only 20.0 % of roach were infected in the DSC. The intensity of infection was 1-7 (mean 2.4) in River Ruhr and 1-3 (mean 1.3) in the DSC. *A. anguillae* was only recorded from River Ruhr with a prevalence of 45.7 % and an intensity of 1-7 (mean 2.6).

Crustacea: Two different crustacean species, *Argulus foliaceus* (Linnaeus, 1758) (fig. 3F) and *Ergasilus sieboldi* Nordmann, 1832 (fig. 3E), were found on the gills and the surface. Roach from all sampling sites except the DSC were infected with single specimens of *E. sieboldi* with prevalences of 5.7 % (Lake Dörpfeld), 10 % (Lake Masuren) and 2.9 % (River Ruhr). Three specimens of *A. foliaceus* were found on two roach from Lake Dörpfeld and a single roach from the DSC.

3.2. Ecological parameters

Ecological indices have been calculated in order to compare the different sampling localities, as illustrated in figure 4. The endoparasite diversity was the highest in the DSC (1.04) and comparatively low in the other sampled water bodies (0.1-0.27). The evenness was also highest in the DSC (0.75) and comparatively low in the other freshwater systems (0.09-0.20). The average parasite species load (IC) in the fishes ranged from 2.1 to 3.7. Most species were found in the large water bodies lake Masuren and river Ruhr. The highest number of core species was also recorded from lake Masuren (3). Trichodinid



	H` (en)	E (en)	IC	CS	p Trichodina	E/E R
Dörpfeldsee	0.33	0.2	2.4	1	0.08	0.66
Masurensee	0.1	0.09	3.6	3	0	0.75
DSC	1.04	0.75	2.1	1	0	0.6
Ruhr	0.27	0.15	3.7	2	0.26	0.71

Fig. 4: Comparison of different indices in the four freshwater systems. CS = core species, DSC = Diergardt's side canal, E/E ratio = Ecto-/Endoparasite ratio, H'(en) = Shannon-Wiener Index (metazoan endoparasites), IC = infracommunity, E (en) = evenness (metazoan endoparasites), p= prevalence/100.

Abb. 4: Vergleich von verschiedenen Indices in vier unterschiedlichen Süßwassersystemen. CS = Kernarten, DSC = Diergardt'scher Seitenkanal, E/E ratio = Ekto-/Endoparasiten-Verhältniss, H'(en) = Shannon-Wiener-Index (metazoischer Endoparasiten), IC = Infragemeinschaft, E (en) = Dominanzindex (metazoischer Endoparasiten), p = Prävalenz/100.

ciliates were found only in lake Dörpfeld (8.5 %) and River Ruhr (25.7 %). The E/E ratio differed from 0.60 to 0.75 and was similar among the sampling locations.

3.2.1. Heavy metals

The heavy metal contamination in the kidney was higher than in the muscle (tab. 2-3). The mercury load was highest in the fish muscles from DSC with an average of 0.29 mg/kg BW. In contrast the kidney samples of specimens from Lake Masuren reached the highest load with 1.22 mg/kg BW. The lowest mercury contamination (0.12 mg/kg BW) was found in muscles of roach from the River Ruhr. The lowest concentration in the kidney with 0.39 mg/kg BW was found in fishes from Lake Dörpfeld. Highest concentration of lead in the muscles, mean of 0.09 mg/kg BW, occurred in fishes of the River Ruhr and in the kidney with 7.59 mg/kg BW in the specimens from Lake Masuren. The mean values of lead in the muscles of roach from Lake Dörpfeld and Lake Masuren were very low (0.02 mg/kg BW); the kidney tissues obtained lowest concentrations in Lake Dörpfeld with 1.62 mg/kg BW. Mean values of nickel were highest in the fish muscles from the River Ruhr (2.15 mg/kg BW) and highest with 11.63 mg/kg BW in the kidney from the DSC. In lake Masuren the lowest concentration was measured in the muscles with a mean of 0.02 mg/kg BW; in the kidney, roach from Lake Dörpfeld showed the lowest contamination with 1.99 mg/kg BW. The lowest cadmium load has been found in the muscles of roach from Lake Dörpfeld and the DSC with 0.02 mg/kg BW, respectively. These

Tab. 2: Heavy metal contaminations (mean, standard variance) in the muscles of *Rutilus rutilus* from the different sampling sites. Concentrations are given in mg/kg total body weight (BW). DSC = Diergardt's side canal.
Tab. 2: Schwermetallbelastung (Mittelwert, Standardabweichung) in der Muskulatur von *Rutilus rutilus* von unterschiedlichen Probestellen. Die Konzentrationen sind in mg/kg Körpergewicht angegeben. DSC = Diergardt'scher Seitenkanal.

	cadmium	copper	lead	mercury	nickel
Lake Dörpfeld	0.02 ± 0.01	0.64 ± 0.49	0.02 ± 0.02	0.24 ± 0.08	0.06 ± 0.05
Lake Masuren	0.03 ± 0.05	0.78 ± 0.43	0.02 ± 0.03	0.16 ±0.07	0.02 ± 0.01
Ruhr	0.03 ± 0.01	1.23 ± 0.39	0.09 ± 0.13	0.12 ± 0.09	2.15 ± 6.28
DSC	0.02 ± 0.01	0.65 ± 0.21	0.05 ± 0.09	0.29 ± 0.12	0.05 ± 0.09

Tab. 3: Heavy metal contaminations (mean, standard variance) in the kidney of *Rutilus rutilus* from the different sampling sites. Concentrations are given in mg/kg total body weight (BW). DSC = Diergardt's side canal.
Tab. 3: Schwermetallbelastung (Mittelwert, Standardabweichung) in den Nieren von *Rutlis rutilus* an den unterschiedlichen Probestellen. Die Konzentrationen sind in mg/kg Körpergewicht angegeben. DSC = Diergardt'scher Seitenkanal.

	cadmium	lead	mercury	nickel
Lake Dörpfeld	7.69 ± 2.44	1.62 ± 0.53	0.39 ± 0.11	1.99 ± 1.91
Lake Masuren	112.54 ± 123.18	7.59 ± 13.03	1.22 ± 1.01	5.97 ± 6.02
Ruhr	17.77 ± 20.07	4.13 ± 5.63	0.13 ± 0.13	4.37 ± 5.57
DSC	11.69 ± 14.44	4.61 ± 8.17	0.74 ± 1.03	11.63 ± 13.13

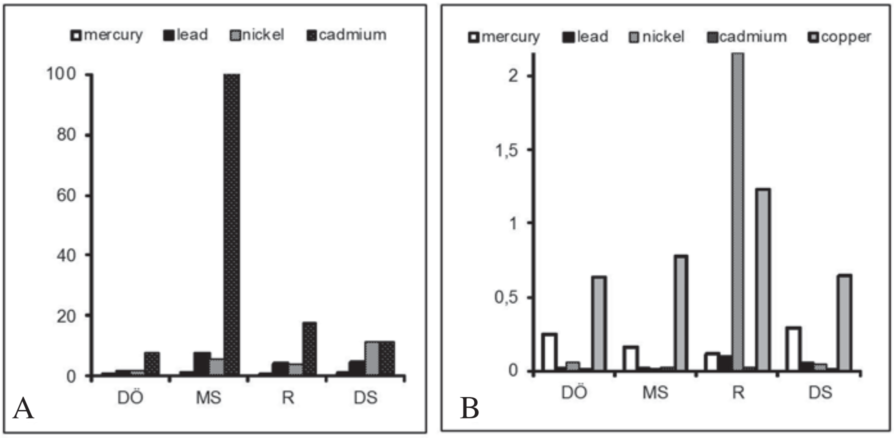


Fig. 5 A, B: Mean values of heavy metal contaminations in the muscles (**A**) and kidney (**B**) of *R. rutilus* in the four sampling sites. Values are given in mg/kg total body weight (BW). DÖ = Lake Dörpfeld, DSC = Diergardt's side canal, MS = Lake Masuren, R = River Ruhr.
Abb. 5 A, B: Die durchschnittlichen Schwermetallgehalte in der Muskulatur (**A**) und den Nieren (**B**) von *R. rutilus* der vier Probestellen. Die Werte sind in mg/kg Körpergewicht angegeben DÖ = Dörpfeldsee, DSC = Diergardt'scher Seitenkanal, MS = Masurensee, R = Ruhr.

values are similar to those of Lake Masuren and the River Ruhr (0.03 mg/kg BW, respectively). The mean values of cadmium in the kidney of the fishes from Lake Masuren are considerably higher (112.54 mg/kg BW) than those from Lake Dörpfeld (7.69 mg/kg BW). The copper contamination in the muscles of fishes from the River Ruhr showed the highest mean values. With 1.23 mg/kg BW the load was twice as high as of the fishes from Lake Dörpfeld (0.64 mg/kg BW) and the DSC (0.65 mg/kg BW).

4. Discussion

4.1. Parasites

Rutilus rutilus from the four sampled water bodies in North Rhine-Westphalia displayed a diverse parasite fauna. In total, 19 parasite species were found, all of them generalists that can infect a variety of different host species. Two species have an allogenic life cycle, including birds as final host, while 17 species complete the entire life cycle inside the aquatic habitat (autogenic). Seven species had a monoxenous and 12 a heteroxenous life cycle, involving more than a single host. Highest parasite load was recorded from the River Ruhr with 12 species and lowest from the Lake Masuren (seven species).

River Ruhr: The highest parasite load was found in the River Ruhr. The examined roach harboured especially monoxen parasite species. The sampling locality can be characterised by an average depth of 1.75 and a width of 30-40 m, with a medium velocity of about 0.4 m/sec. According to the Ministry for Climate Protection, Environment, Agriculture, Nature Conservation and Consumer Protection of North Rhine-Westphalia (2004) the water quality class of the River Ruhr is II-III, the most polluted of the four examined water bodies. Protozoan parasites were almost exclusively detected at this sampling site. Ciliates such as trichodinid ciliates feed on algae and bacteria, especially under eutrophic conditions (Palm & Dobberstein 1999). In addition, the intermediate host of the recorded myxozoan parasite species, *Tubifex* sp., occurs mostly in slow flowing and slightly polluted water bodies (Coulibaly 2007). This might explain the infestation with different myxozoan parasites in the River Ruhr. According to Schäperclaus (1990) heavy infestation of Myxozoa can be also caused by a decreased health status of the fish.

The Digenea has been the predominant taxon in this study. The two isolated species have been detected most abundant in the River Ruhr. The dense vegetation of the river provides diversified habitats for the molluscs that serve as first intermediate hosts for the digeneans (Glör 2002). The nematode *Pseudocapillaria tomentosa* also occurred in the river Ruhr, a species that has been introduced with ornamental fishes. *Tubifex* sp. is suggested as a possible intermediate host for this species (Moravec 1994). Cestoda were absent, but acanthocephalans occurred in high numbers. *Acanthocephalus anguillae* and *Pomphorhynchus laevis* were only recorded from the Ruhr and the DSC. The acanthocephalan *P. laevis* is restricted to riverine ecosystems due to the distribution of the intermediate hosts, rheophil gammarids such as *Gammarus pulex* or *G. roeseli* (Schwab 1995, Lagrue et al. 2007). *Acanthocephalus anguillae* uses the isopode *Asellus aquaticus* as intermediate host (Crompton & Nickol 1985). This invertebrate prefers smooth habitats in a river with a high load of deadwood and an increased level of eutrophication. *Acanthocephalus anguillae* was found only in the river Ruhr, a system which is notably nutrient-rich.

The parasite fauna of *Rutilus rutilus* has not been studied so far from the river Ruhr. Other authors investigated the parasite fauna of chub, eel, grayling, ruff and perch (e.g. Taraschewski 1985, Taraschewski 1989, Taraschewski et al. 1995). Mainly acanthocephalans (*A. anguillae*/*P. laevis*) were found, comparable to the parasite fauna of roach in the present study.

Lake Masuren: Roach from Lake Masuren were infected by seven parasite species, three of them at the level of a core species. The load of myxozoans (*Myxobolus* sp.) was nearly as high as in the River Ruhr, resulting from the mesotrophic conditions in the lake and a high density of the fish. The monogenean *Dactylogyrus* spp. infested all sampled roach. According to Koskivaara et al. (1991) the prevalence and intensity of monogeneans depends on the fish density and the flow velocity, because these factors support fish to fish transmission resulting from the direct parasite life cycle. Bagge et al. (2004) claimed that the distribution of Monogenea depends on the size of the host population. This could not be confirmed. The only Cestoda was *Paradilepis scolecina*. The Lake Masuren constitutes an ideal ecosystem for birds, the definitive host for this parasite. Cyclophyllid Cestoda of birds are typical parasites of fishes from standing water bodies because most of the copepods that transfer the cestodes as intermediate hosts, e.g. *Eudiaptomus gracilis* (Scholz et al. 2004), only occur in such lakes (Schwab 1995). The present study is the first parasitological investigation from Lake Masuren, which belongs to a large lake system in NRW. Endoparasites can proliferate especially in a structural divers and stable ecosystem. However, the low number of sampled fishes from Lake Masuren doesn‘t allow detailed comments on the underlying environmental factors in this lake, and can possibly explain the lower number of observed parasite species.

Lake Dörpfeld: This first parasitological study from Lake Dörpfeld revealed ten different parasite species. The Monogenea *Dactylogyrus* spp. is common at sampling sites with a high density of roach (Koskivaara et al. 1991) and also in this lake. However, *Diplozoon paradoxum*, that was recorded from the other three locations, did not occur in Lake Dörpfeld. In this isolated lake, no stocking activities took place for more than 30 years. This might have prevented the transfer of this larger sized monogenean into the lake. Similar to Lake Masuren, the nematode *Philometra rischta* could be detected in Lake Dörpfeld. According to Moravec (1980), the copepod intermediate hosts are a common component of the zooplankton community, enabling transmission of the parasite. With *Argulus foliaceus* and *Ergasilus sieboldi* two widely distributed Crustacea were found. Both have a direct life cycle without an enduring life cycle stage (Halisch 1939). However, compared with the River Ruhr, Lake Dörpfeld is a small and more isolated system, demonstrating more limited parasite infections of the sampled roach.

Diergardt's side canal: The highest parasite diversity load was found in the adjacent backwater DSC. A significant characteristic of the DSC is the annual desiccation during summer. This periodical event leads to a lack of intermediate hosts and transmission pathways for the fish that regularly migrate into the small channel during summer. They must have acquired their parasites returning back into the deeper parts of the connected River Schwalm. The backwater accumulates fish parasites, when it doesn't desiccate. The connection to the larger River Schwalm can explain why *Pomphorhynchus laevis* was found in the DSC. The intermediate hosts have a wide tolerance concerning temperature and pH-value (Limno-Plan GbR 2001). Low oxygen levels limit the occurrence of the gammarids (Amann 2003). Our samplings took place from April to August 2006. The observed generalistic parasite species might have recolonised the DSC from the deeper and more stable river system during autumn and winter, where such habitats are regularly used as resting sites for the fish from the rivers.

4.2. Ecological parameters

In order to demonstrate that the recorded parasite fauna can be used to characterise the sampled freshwater system, several different ecological indices were calculated (fig. 4). The highest endoparasite diversity was detected in roach from DSC, resulting from the ability of adjacent backwaters to serve as a parasite reservoir. The fact that fishes retire in smooth and densely overcrowded regions of a riverine system makes it possible to complete the entire life cycle within this small water body. This leads to the assumption, that the small flowing, densely overgrown backwaters harbour a diverse intermediate host fauna. Endoparasites have often complicated life cycles and are transferred via the food web (Overstreet et al. 1996). The evenness showed the most equal distribution of fish parasites in the DCS. A predominance of a single parasite species would allude to an absence of diverse intermediate hosts. Although the DSC tends to desiccate in summer, the fauna of invertebrates is diverse. Because of the short reproduction time, the adjacent backwater can be recolonized rapidly after desiccation by generalistic fish parasites. Although the infracommunity was lowest in the DSC, this is an indication of the instability of such a small system. However, the presence of a high number of monogeneans indicates that the fish density in the channel can be high, as common for fish refuges during the winter season.

The Shannon-Wiener Index for Lake Dörpfeld was low; the low evenness is caused by the predominant bird cestode *Paradilepis scolecina*. This can be explained by the small size of the lake, lacking fish stocking and the only possible parasite introduction events taking place through migrating birds. It must be questioned if this situation is typical for this small lake system, with low diversity and evenness lasting for a long period of time. According to Dogiel et al. (1958), the parasite fauna of isolated lakes can be described as randomly distributed. Rare species such as *Philometra rischta* can be even recorded from isolated lakes while more frequent and widely distributed species such as *Diplozoon paradoxum* are absent. This could be the case also for Lake Dörpfeld. The larger Lake Masuren harboured the lowest parasite richness and parasite diversity. The lowest evenness results from the predominance of the monogeneans *Dactylogyrus* spp. and *D. paradoxum*. The calculated ecto-/endoparasite ratio was high. This leads to the assumption, that ecosystem health is affected in Lake Masuren. Endohelminths cannot complete their life cycles because of the lack of the required intermediate hosts. However, the low number of sampled fish must be kept in mind, with the real parasite numbers possibly being higher.

Highest species richness was detected in the River Ruhr. The endoparasite diversity and the evenness were lower in the River Ruhr than in the DSC. This corroborates the theory that adjacent backwaters can harbour a high endoparasite load. The infracommunity, however, was highest in the River Ruhr, because of the predominant species *Dactylogyrus* spp. and *Diplostomum spathaceum*. The stable ecosystem Ruhr harbours a high number of parasites. The River Ruhr is a large riverine ecosystem in a densely populated area. The ecological factors like eutrophication, current velocity and vegetation determine the parasite fauna of the examined roach. The stable ecosystem provides a high number of niches for the parasites (macro- and microhabitats in the sense of ROHDE 1982) and the possibility for the fish to reach different habitats, within the river as well as in the adjacent water systems. Typical river parasites such as *Acanthocephalus anguillae* and *Pomphorhynchus laevis* were found in the Ruhr, while the bird cestode *P. scolecina* was absent. This is caused by the presence of the suitable first intermediate hosts in the former and the lack of the parasite transmitting birds in the latter. Only the generalistic helminths *Diplostomum spathaceum* and *Dactylogyrus* spp. were recorded from all four sampling sites.

With the lack of long term data sets it is difficult to affiliate the observed parasite fauna to environmental stability or conditions such as eutrophication or pollution. However, the trichodinid ciliates in the River Ruhr are commensals, they act as bioindicators for bacterial load and eutrophication (PALM & DOBBERSTEIN 1999, OGUT & PALM 2005, RÜCKERT et al. 2009). The prevalence of 26 % displays distinct eutrophication and nutrient load, as also determined through the critical water quality status II-III.

4.3. Heavy metal contamination

The heavy metal contamination in the muscles was highest in roach from the River Ruhr. In the kidneys, the lake Masuren was charged most. Especially the load of nickel (2.15 mg/kg BW), copper (1.23 mg/kg BW) and lead (0.09 mg/kg BW) was much higher than in fishes from the other sampling sites. This could be explained by high industrial and agricultural influence. Highest concentrations of cadmium were found in the kidneys of roach from Lake Masuren (112.54 mg/kg BW). This is much higher than comparative data from BARAK & MASON (1990) for inner organs (0.05-0.07 mg/kg BW). The cadmium concentration in the muscles was 0.06 mg/kg BW and corresponds to the average (BARAK & MASON 1990). The lowest heavy metal contamination was found in fishes from the more isolated Lake Dörpfeld. The lead concentration (0.02 mg/kg BW) was similar to the data by WEBER (1985, 0.05-0.08 mg/kg BW). The comparative data from BARAK & MASON (1990) for mercury were between 0.05-0.08 mg/kg BW in the muscles and 0.45-0.82 mg/kg BW in the inner organs. The results for muscle tissue in the present study exceeded this value. These differences might be explained by the small number of examined fishes (WACHS 1996). In addition the heavy metal contamination in the kidney was much higher than in the muscles. The maximum allowed level of heavy metal in the muscles of fishes is regulated by the Commission Regulation (EC) 46/2001 amended by the Commission Regulation (EC) 75/2005 for cadmium, lead and mercury. In every examined sample, the concentrations were below these maximum levels, with no negative implications for the fish consumers.

Heavy metals can accumulate in the fish and their parasites. Some species such as *Pomphorhynchus laevis* are able to accumulate a higher heavy metal concentration than in the host tissue, allowing their use as accumulation indicators (SURES et al. 1994, SURES & TARASCHEWSKI 1995, SURES & SIDDAL 2003, PALM 2011). Only a minor correlation between the heavy metal concentration in the fish and the ectoparasite load was recognised within the present study. The high prevalence of trichodinid parasites coincides with the highest heavy metal pollution in roach from the River Ruhr.

4.4. Conclusions

We could demonstrate that the fish parasite fauna of common roach was able to characterise four freshwater systems in NRW. Fish parasites have been already used to characterise their environment, because they play a key role in aquatic ecosystems (OVERSTREET et al. 1996). Since the 1980s fish parasites have been tested for the utilisation as biological indicators to display the health status of aquatic ecosystems with inconsistent results (LAFFERTY 1997, VIDAL-MARTÍNEZ et al. 2009, DZIKA & WYZLIC 2010). The habitat structure with the number of available niches, the level of isolation and the function as a reservoir during winter season was decisive for the observed parasite fauna in the Diergardt's side canal, lakes Dörpfeld, Masuren and River Ruhr. This allows roach parasites to be used as biological indicators for the freshwater habitat structure and function for the fish. We could affiliate the observed ectoparasite fauna, e.g. trichodinid ciliates in the River Ruhr, to the observed heavy metal pollution as well as contamination in the fish. Trichodinids react on eutrophic or bacteria enriched environments. PALM & DOBBERSTEIN (1999) and PALM (2011) illustrated a positive trend for trichodinids and heavy metals in field studies. Still, there is a lack of appropriate evaluation systems that allow fish parasites to be used as biological indicators for the health status of their fish hosts as well as the environment (PALM 2011). The introduced indices could be an approach to solve the problem.

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