Parasites of round goby, *Neogobius melanostomus*, currently invading the Elbe River

by

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Abstract

The round goby, *Neogobius melanostomus*, is a Ponto-Caspian fish species currently found in many parts of Europe, including the North Sea riverine deltas. The objective of this study was to examine the parasite community of fish caught in the lower Elbe (Süderelbe – tidal zone; Geesthacht – non-tidal) in Germany and compare it with published data from the upper Elbe (Ústí nad Labem) in the Czech Republic. Twelve parasite taxa were recorded in the lower Elbe, six in the Süderelbe and nine near the city of Geesthacht. Süderelbe fish were mainly infected with *Angullicola crassus* larvae, while gobies from Geesthacht – with glochidia and sporadically occurring *Pomphorhynchus laevis*, and the opposite situation was observed at Ústí nad Labem. It appears that a large tidal weir at Geesthacht significantly contributes to the division of the round goby population, with the Geesthacht parasite community being more similar to that at Ústí nad Labem than the one from the Süderelbe, thus increasing the likelihood that shipping from Hamburg was the introduction vector to Ústí nad Labem. We also recorded *Acanthocephalus rhinensis* in the Elbe for the first time, and in a new host – the round goby. Thus, round gobies may represent a new vector for the introduction of this parasite along the Elbe.

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Introduction

The round goby, *Neogobius melanostomus* (Pallas, 1814) (Actinopterygii: Gobiidae), is a Ponto-Caspian brackish water fish species, with its natural range in the Black and Caspian seas and in the lower reaches of connecting rivers (Kottelat, Freyhof 2007). Since the late 1980s, however, the species has become one of the most successful fish invaders in Europe and North America (Corkum et al. 2004; Roche et al. 2013). At present, the westernmost European range of this species reaches the North Sea basin, where it is widespread in different parts of the Rhine Basin (Manné et al. 2013), as well as in the lower reaches and tidal zones of the Schelde, the Weser and the Elbe in the north (Verreycken et al. 2011; Brunken et al. 2012; Hempel, Thiel 2013). More recently it has been recorded in the Midland Canal (German: Mittellandkanal) in Northern Germany (Matteikat et al. 2016).

Artificial water courses, such as navigation and irrigation canals, have been shown to facilitate the distribution of a number of Ponto-Caspian aquatic species in Europe (bij de Vaate et al. 2002), with three main invasion routes (corridors) described: 1) the Northern Corridor that connects the Caspian Sea with the Baltic Sea via the river basins of the Volga and the Neva (also connecting the basin of the Sea of Azov with the Volga River via the Don river system); 2) the Central Corridor that connects the Black Sea with the Baltic Sea via the drainage basins of the Dnieper and the Vistula (further connecting the Baltic basin with the North Sea via a series of canals and smalls rivers); and 3) the Southern Corridor that connects the Black Sea with the North Sea via the drainage basins of the Danube, the Main and the Rhine (see Roche et al. 2013). The North Sea is the final meeting point of the two invasion routes: the Central and Southern Corridors. The North Sea riverine estuaries and deltas have specific ecological conditions, including unstable
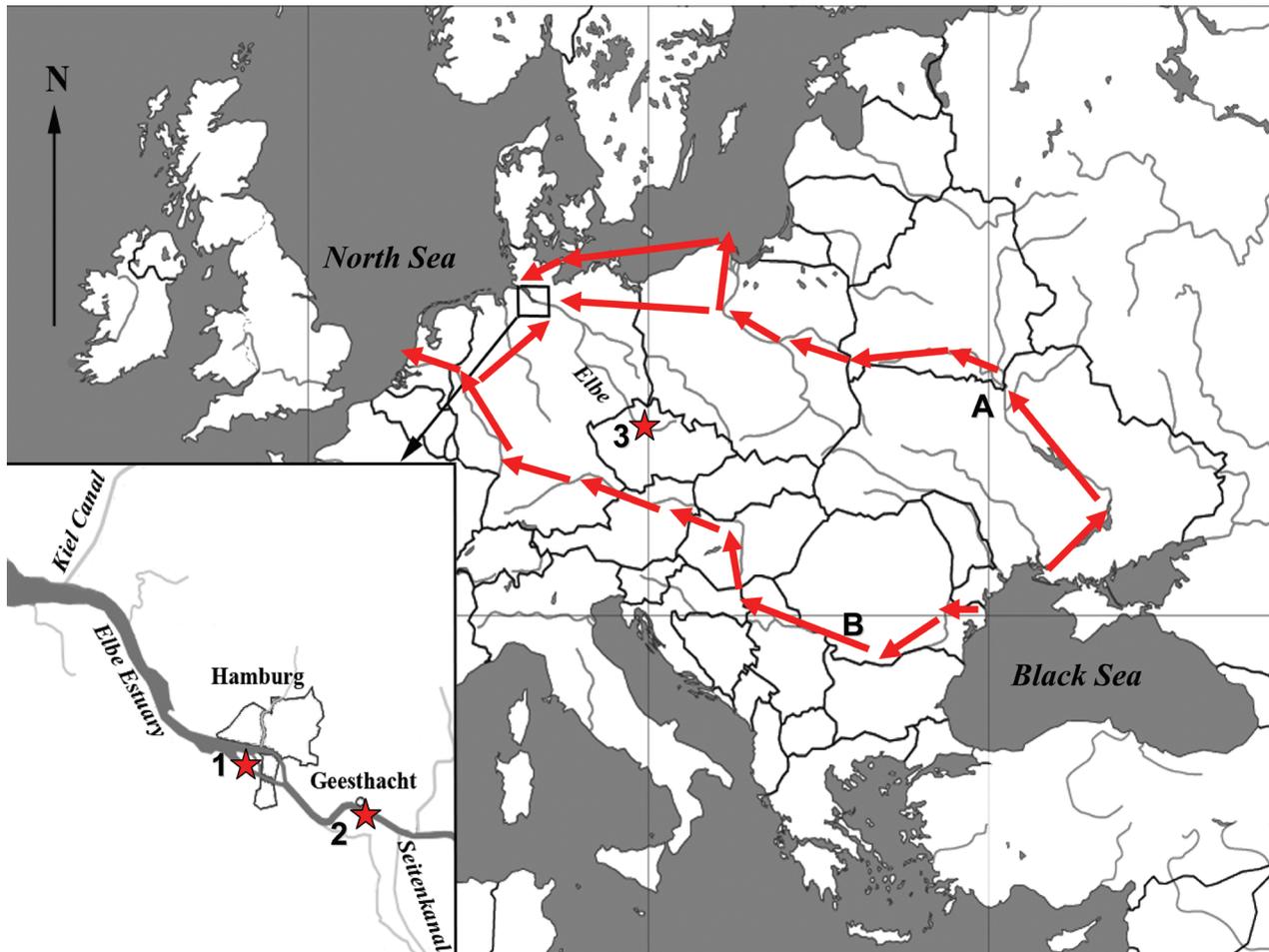
Figure 1

Map of the sampling area in the Elbe River with the Aquatic Invasion corridors: A – Central Corridor, B – Southern Corridor. Sampling localities are marked by stars: 1 – the Süderelbe, 2 – Geesthacht, 3 – Ústí nad Labem

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salinity and water levels that change rapidly due to intensive tides (van Rijn 2011). The tidal zone of the Elbe Estuary runs from its mouth at the town of Cuxhaven to the city of Geesthacht, 140 km from the river mouth, where a large weir was built to protect navigation against the tides. Salinity intrusion is observed up to 65 km from the river mouth, with salinity reaching 0.5 PSU in the limnetic zone around the city of Hamburg (Hofmann et al. 2005).

Although Ponto-Caspian gobiids inhabit mainly brackish water in their natural range (Miller 1986), the so-called neolimnetic species occur mainly in freshwater, even though they come from brackish water (Kvach, Kutsokon 2017). Since the Black Sea is an enclosed water body and has no tidal zones, the native Ponto-Caspian gobiids are not well adapted to extreme ecological conditions such as diel changes in salinity and water levels. Round and monkey gobies, *Neogobius fluviatilis* (Pallas, 1814), two of the most adaptive species, can be found in both fresh and marine waters (up to 37 PSU), but prefer salinities of up to 18 PSU (Smirnov 1986). Furthermore, gobiids inhabiting brackish waters tend to be more tolerant to salinity than those from freshwater populations. For example, round gobies in the Kiel Canal (Germany) survive in 30 PSU seawater without any problem (Hempel, Thiel 2015), while 100% of gobies introduced to 30 PSU water from a freshwater population in the Detroit River (Canada) died within 48 h (Ellis, MacIsaac 2009).

According to the theory of invasion, the primary colonization success of certain species could be caused by a temporary release from native parasites and pathogens in a new habitat (Torchin et al. 2003). This is an important part of the "enemy release hypothesis" put forward by Keane and Crawley (2002). On the other hand, invasive species can be a source of new parasitic components that could parasitize indigenous local fauna (Mack et al. 2000). For example, a number of studies reported invasive gobiids carrying the Ponto-Caspian monogenean *Gyrodactylus proterorhini* Ergens, 1964 (Mierzejewska et al. 2011; Ondračková 2016). Another parasite species, the acanthocephalan *Pomphorhynchus laevis* (Zoega, 1776), is probably invasive in Western Europe and spreads together with its host, the round goby (David et al. 2018; Hohenadler et al. 2018). Finally, following the successful introduction, exotic host species can be infected with local parasites that naturally infest ecologically similar species. An example of these processes is the case of invasive gobiids using the Central Invasion Corridor, which appear to have partially escaped from their native parasites but continues to accumulate local parasite species (Kvach et al. 2014). Over time,

parasitization in the invasive population will therefore increase until it reaches a level comparable with indigenous species. However, this process can take a long time, as shown by the example of round gobies in North America, which after 20 years still host fewer parasites than local fishes (Gendron et al. 2012).

In this study, we examined the parasite fauna of round gobies in the lower tidal and non-tidal zone of the Elbe River (Germany) and compared the obtained results with previously published results for parasites recently found on round gobies occurring lately in the upper Czech stretch of the Elbe, paying particular attention to diverse environmental conditions affecting gobies along the river profile, from the estuary to upper reaches, and their impact on the parasite communities.

Materials and methods

Round gobies were sampled by angling in the warm season (July 2017) at two localities along the lower German Elbe, i.e. the Süderelbe (53°28.266'N, 9°59.133'E) and Geesthacht (53°25.643'N, 10°21.905'E) (Fig. 1). The Süderelbe is a tidal branch in the estuarine zone of the Elbe, while the second locality is situated near the city of Geesthacht, where the river is protected from the tides by a large weir. Both salinity and conductivity were measured under laboratory conditions. Forty three fish were transported to the field laboratory live in aerated containers containing water from the sampling localities, where the fish were humanely dispatched. Prior to dissection using the standard methodology (see Kvach et al. 2016), the standard and total lengths (SL, TL) were measured and the sex of each fish was determined (Table 1).

Parasites were preserved in hot 4% formaldehyde (digeneans, nematodes) or 70% ethanol (acanthocephalans, mites, glochidia). Cystacanths of *Pomphorhynchus* sp. were identified using molecular analysis due to the ambiguity of morphological characteristics (David et al. 2018; Hohenadler

Table 1

The number of fish examined (n) with mean standard (SL, mm) and total (TL, mm) length (means and standard deviation)

	Süderelbe	Geesthacht	Ústí nad Labem
n	23	20	53
SL	70.8 ± 9.4	101.0 ± 8.3	69.7 ± 6.5
TL	84.2 ± 10.3	118.1 ± 9.1	82.5 ± 7.6

et al. 2018). For the molecular identification of *Pomphorhynchus* species, the fragment of internal transcribed spacer 1 (ITS1) of nuclear ribosomal DNA (rDNA) was analyzed. The total genomic DNA was extracted from four ethanol-fixed specimens using the DNeasy® Blood & Tissue Kit (Qiagen, Hilden, Germany) following the manufacturer's instructions. Partial ITS1 was amplified using primers BD1 (5´-GTCGTAACAAGGTTTCCGTA-3´; forward) (Kráľová-Hromadová et al. 2003) and AC/ITS1 (5´-TTGCGAGCCAAGTGATTCAC-3´; reverse) (Franceschi et al. 2008). The polymerase chain reaction (PCR) was performed according to the protocol described in Franceschi et al. (2008). PCR amplicons were purified using ExoSAP-IT™ (Affymetrix Inc., Santa Clara, USA) and sequenced directly from both strands using PCR primers. DNA sequencing was carried out using the BigDye® Terminator v3.1 Cycle Sequencing Kit (Applied Biosystem by Thermo Fisher Scientific, Praha, Czech Republic) and the Applied Biosystems 3130 Genetic Analyzer (Applied Biosystems). The Obtained DNA sequences were assembled and edited using the Sequencher software (Gene Codes Corp., Ann Arbor, MI, USA). The consensus ITS1 sequence was compared with the NCBI diabase using the nucleotide basic local alignment search tool (BLASTn). The obtained ITS1 sequence was 320 bp long and shared the highest degree of sequence identity with *P. laevis* (96–99%). The presence of microparasites and their number were recorded under a light microscope without sampling. Parasitological terminology and the indices used were in accordance with Bush et al. (1997). The results were then compared with recently published data from the upper Elbe, near Ústí nad Labem (50°39.629'N, 14°2.442'E; Kvach et al. 2017; Fig. 1).

Mann–Whitney *U* tests were used to compare fish length, while the Sørensen index (SI; Sørensen 1948) was used to compare parasite communities. Differences in the composition of the parasite community were tested using permutational multiple analysis of variance (PERMANOVA; Anderson 2001) with P values obtained with 999 permutations and visualized on the first two axes of a non-metric multidimensional scale (NMDS). Both PERMANOVA and NMDS were based on community dissimilarity matrices calculated using Jaccard (binary) and Bray-Curtis (quantitative) dissimilarity measures. Since differences in fish size could have affected the total parasite abundance results, the Bray-Curtis dissimilarity was calculated on standardized data, i.e. the abundance of each parasite was expressed as a percentage (integer values from 0 to 100) of the total parasite abundance for each fish. Differences in fish abundance and species richness were tested using generalized linear models (GLM; using "quasipoisson" distribution, i.e. a distribution correcting Poisson distribution for over- and under-dispersion, which were detected in abundance and richness data, respectively) with fish size included in the model as a covariate (due to a possible relationship between fish size and parasite abundance). The analyses were conducted using R statistical software v 3.2.4 (R Core Team 2015).

Results

Salinity in the Süderelbe stretch was 0.5 PSU and conductivity – 1083 µS cm^{-1}, while salinity near Geesthacht was 0.2 PSU and conductivity – 440 µS cm^{-1}. Gobies caught at Geesthacht were significantly larger than those from both the Süderelbe and Ústí nad Labem (Mann–Whitney tests, n = 43 and 73, both $p < 0.001$), with no difference between the latter two localities (Mann–Whitney test, n = 76, $p = 0.738$).

In total, twelve parasite taxa were collected along the lower Elbe, six from the Süderelbe and nine from Geesthacht (Table 2). Four taxa were represented by microparasites (unidentified microsporidia and myxosporea, two ciliate species), including two taxa (*Microsporidium* sp. and *Trichodina* spp.) occurring at both localities. Five species were represented by larval stages: metacercariae (1 sp.), the third larval stage of nematodes (2 spp.), cystacanths (1 sp.) and glochidia (1 sp.). Two species of acanthocephalans (*Acanthocephalus lucii* and *A. rhinensis*), both present in the gut as adults. The presence of a mite (*Hydrachna* sp.) on the gills represents a case of pseudoparasitism. The digenean, acanthocephalans, the mite and glochidia were all recorded near Geesthacht, but not in the Süderelbe.

Although the composition of parasite communities from the three study localities was comparable (Süderelbe – Geesthacht SI 40%, Süderelbe – Ústí nad Labem SI 46.2%, Geesthacht – Ústí nad Labem SI 50%; *Unio* sp. and *Anodonta* sp. presented as the same taxa, glochidia), they differed significantly in terms of abundance between the three localities (PERMANOVA, df = 1 and 41, 1 and 74, 1 and 71, respectively; all $p < 0.001$; Fig. 2). Fish from the Süderelbe were mostly infected with *Anguillicola crassus* larvae, which were almost absent in fish from the two other localities (Table 2; Fig. 2). By comparison, gobies from Geesthacht were mainly infected with glochidia larvae, with *Pomporhynchus laevis* occurring sporadically, while the opposite pattern was observed at Ústí nad Labem. Both taxa were absent in Süderelbe fish (Table 2; Fig. 2). Infracommunity species richness did not differ significantly between the three localities (GLM,

Table 2

Parasite community of round goby (*Neogobius melanostomus*) from the Elbe River, showing prevalence (P, %), mean intensity (MI±SD), intensity range (min.–max) and mean abundance (A)

Parasite species	Site	Süderelbe			Geesthacht			Ústí nad Labem*		
		P	MI ± SD (min.–max)	A	P	MI ± SD (min.–max)	A	P	MI ± SD (min.–max)	A
Microsporidia										
Microsporidium sp.	mesentery	13.0	4.3 ± 1.5 (3–6)	0.6	20.0	3.5 ± 2.1 (1–6)	0.7			
Oligohymenophorea										
Trichodina spp.	gills	4.3	10.0	0.4	10.0	50.5 ± 70.0 (1–100)	5.1	1.9	1.0	0.02
Ichthyophthirius multifiliis Fouquet, 1876	gills	4.3	1.0	0.04				1.9	1.0	0.02
Myxozoa										
Myxosporea cl. spp.	gills	4.3	1.0	0.04						
Digenea										
Diplostomum spp. metacercariae	eye				5.0	1.0	0.1	11.3	1.7 ± 1.0 (1–3)	0.2
Acanthocephala										
Acanthocephalus lucii (Müller, 1776)	intestine				5.0	1.0	0.1			
Acanthocephalus rhinensis Amin et al., 2008	intestine				5.0	1.0	0.1			
Pomphorhynchus laevis (Zoega, 1776) cystacanths	mesentery				20.0	1.0 ± 0.0	0.2	96.2	21.5 ± 21.6 (1–82)	20.7
Nematoda										
Anguillicola crassus (Kuwahara et al., 1974) larvae	mesentery gut walls	56.5	3.6 ± 2.9 (1–10)	2.0				3.8	1.0 ± 0.0 (1)	0.04
Raphidascaris acus (Bloch, 1779) larvae	mesentery liver	43.5	1.5 ± 0.5 (1–2)	0.7	15.0	1.3 ± 0.6 (1–2)	0.2			
Contracaecum rudolphii Hartwich, 1964 larvae	mesentery							1.9	1.0	0.02
Arachnida										
Hydrachna sp. nymph	gills				5.0	1.0	0.1			
Bivalvia										
Anodonta sp. glochidia								23.3	1.4 ± 0.8 (1–3)	0.3
Unio sp. glochidia	gills				30.0	3.0 ± 0.9 (2–4)	0.9			

* Kvach et al. (2017)
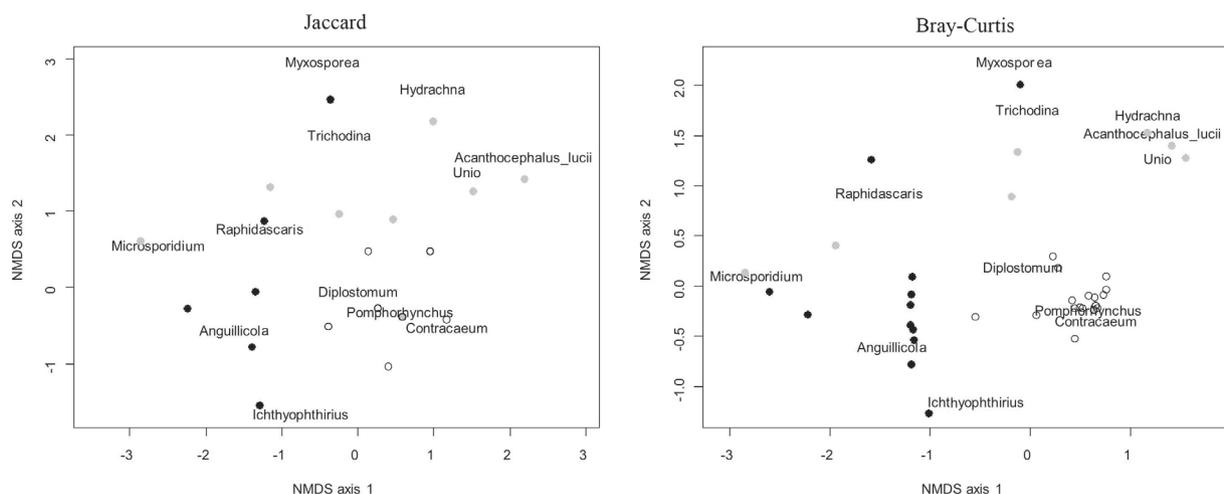
Figure 2

Non-metric multidimensional scaling (NMDS) based on Jaccard and Bray-Curtis dissimilarities in parasite communities found in round goby (*Neogobius melanostomus*) from the Süderelbe (black points), Geesthacht (gray points) and Ústí nad Labem (open points). Fish with parasite assemblages too distant from all other fish are not presented (i.e. fish with no parasites or with only one specimen not present in any other fish)

df = 2 and 92, P = 0.38), being generally low with mean values reaching 0.75 in Süderelbe fish (range 0–3), 1.09 in Geesthacht fish (range 0–3) and 0.54 in fish from Ústí nad Labem (range 0–2). Parasite abundance did not differ significantly between Süderelbe and Geesthacht (GLM, df = 1 and 40, P = 0.85), with both German localities hosting significantly fewer parasites compared to fish from Ústí nad Labem (GLM, df = 1 and 73, 1 and 70, both *p* < 0.001; Fig. 3).

both the Baltic Sea and the Rhine (Kvach, Winkler 2011; Ondračková et al. 2015) and native populations in the Black Sea (Kvach 2004b; Kvach et al. 2014). The Geesthacht weir appears to play a significant role in dividing the round goby population, resulting in clear differences in parasite communities. As a result, the parasite community from Geesthacht is more similar to that from Ústí nad Labem than the one from the Süderelbe, with limnetic parasites, such as
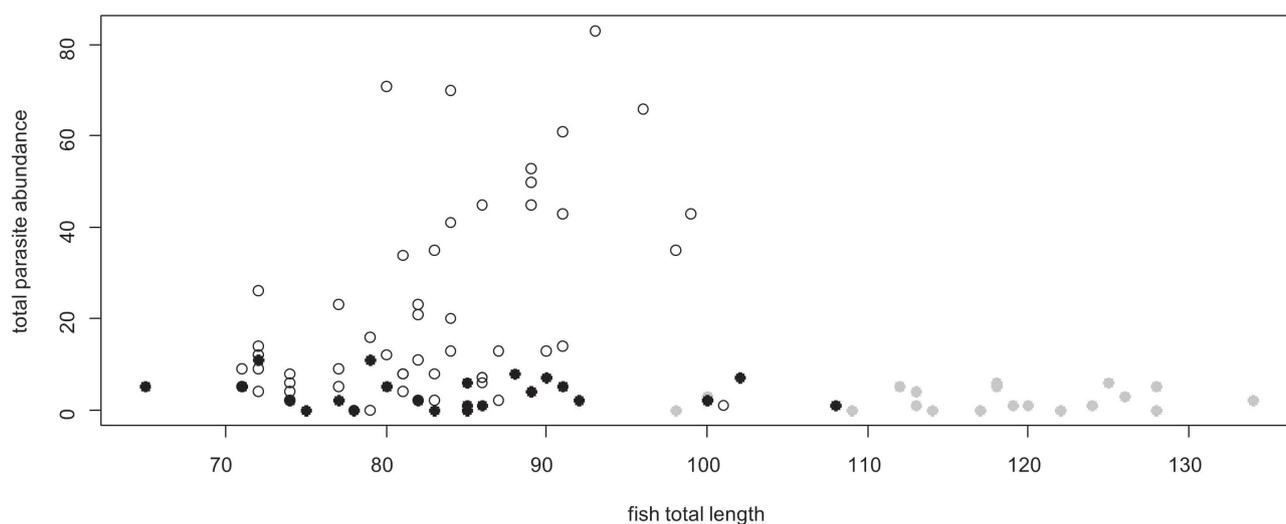
Figure 3

Total parasite abundance in round goby from the Süderelbe (black points), Geesthacht (gray points) and Ústí nad Labem (open points) in relation to fish size

Discussion

In general, parasite communities of round gobies in both the upper and lower Elbe comprised limnetic or euryhaline species with no marine or brackish-water parasites (see Table 2; Kvach et al. 2017). Marine/brackish-water parasites were previously observed in round gobies from estuarine zones, with brackish-water *Cryptocotyle concava* (Creplin, 1825) and marine *Telosentis exiguus* (von Linstow, 1901) recorded in round gobies from the oligohaline stretches of the Dniester and Dnieper estuaries (Kvach 2004b; Kvach et al. 2014). As these fish are known to have migrated from the sea into the estuarine zones (typical for round goby; Smirnov 1986), our results would suggest that migration between the brackish-water and freshwater part of the Elbe is not common.

In general, the Elbe parasite community was characterized by a small abundance of parasites with birds as definitive hosts, which form the majority of parasite communities in invasive populations in

metacercariae of *Diplostomum* sp., acanthocephalans, aquatic mites (*Hydrachna* sp.) and glochidia, absent at the tidal locality. Although *Diplostomum* metacercariae occurred in small numbers in the upper Elbe and were recorded once near Geesthacht, they were totally absent in the tidal Elbe (see Table 2; Kvach et al. 2017).

The substrate of the habitat also appears to have played an important role in shaping different parasite communities. Although both localities at the Süderelbe and Geesthacht are located near ship's mooring lines, for example the rocky bottom at the Süderelbe is an unsuitable habitat for unionids, hence the presence of *Hydrachna* sp. mites, a parasite of unionids, is only possible at Geesthacht with a muddy bottom. Similarly, *Diplostomum* sp. metacercariae were recorded in the lower Elbe near Geesthacht and the upper Elbe but were absent in the tidal Elbe, the difference was caused by the lack of an intermediate host, i.e. limnetic pulmonate bladder snails of the Lymnaeidae family (Selbach et al. 2015).

The nematode, *Anguillicola crassus*, was the most abundant helminth in the lower Elbe, but was

only found in fish from the Süderelbe (Table 2). This parasite, introduced from the Far East, is usually found in the swim bladder of eels (*Anguilla anguilla* L., 1758) and is currently recorded in various localities around Europe (Moravec 2013). The round goby has recently been reported as a paratenic host of this nematode (see Emde et al. 2014; Ondračková et al. 2015 and references therein) and the parasite was found in gobies from the upper Elbe, though in small numbers (mean 0.04; Kvach et al. 2017). According to Emde et al. (2014), the abundance of *A. crassus* found in round gobies from the non-tidal stretch of the Rhine (near Düsseldorf) was on average 1.0, hence they do not appear to play a very important role in the life cycle of this nematode in non-tidal waters. In the tidal Elbe, however, the species was twice as abundant (2.0), making it a borderline satellite/secondary species (Zander et al. 2000). As such, round gobies in the tidal Elbe are likely to play a more important role in the life cycle of *A. crassus*. On the other hand, this nematode was not recorded in the lower Elbe near Geesthacht, and was rarely found in the upper Elbe (see Kvach et al. 2017). Once again, however, differences in the habitats could explain this anomaly as the locality near Geesthacht was more lotic compared to the harbor in the Süderelbe. Since planktonic cyclopoids, the first intermediate host of *A. crassus* (Moravec 2013), are usually more numerous in lentic waters, the flow rate may explain the difference in the abundance of plankton (and thus parasite infection) at the two localities.

Acanthocephalus lucii is an acanthocephalan species recorded in the lower Elbe near Geesthacht and native to the Elbe river basin. This common parasite of European freshwater fish previously recorded in the round goby (Kvach 2004a) was rarely recorded in our study. The second acanthocephalan, *P. laevis*, is a common parasite of many fish species in Europe (Perrot-Minnot et al. 2018). Morphologically, it is very similar to *Pomphorhynchus tereticollis* (Rudolphi, 1809), therefore it is difficult or impossible to distinguish correctly these two species based only on morphological characteristics (Franceschi et al. 2008). The identification of the species based on morphology (see Špakulová et al. 2011) probably resulted in an erroneous report on *P. tereticollis* in round gobies from the upper Elbe in the Czech Republic (Kvach et al. 2017) and the Lower Rhine (Emde et al. 2014). According to Hohenadler et al. (2018), *P. laevis* is probably an invasive species in the North Sea basin, introduced and distributed with its first intermediate host – the killer shrimp, *Dikerogammarus villosus* (Sowinsky, 1894), and the paratenic host – the round goby. The fish host becomes infected through the consumption of

gammarids, which are now present in both the lower and upper Elbe (Nehring 2006; Buřič et al. 2009). The third acanthocephalan parasite recorded in this study, *Acanthocephalus rhinensis*, known to parasitize eels, was previously recorded only in the middle Rhine and the Po river drainage basin (Amin et al. 2008; Dezfuli et al. 2012). As such, this represents the first record of this parasite in the Elbe and, furthermore, in the new host species – the round goby. Since previous parasitological studies on eels from the Elbe have not reported the presence of this acanthocephalan (Jakob et al. 2016), round gobies may represent a possible vector for the introduction of this parasite into the Elbe.

The presence of *A. rhinensis*, a parasite common in the middle Rhine (Amin et al. 2008), and also *P. laevis*, which is numerous in the lower Rhine (Emde et al. 2014; Ondračková et al. 2015), would tend to support the hypothesis of Midland Canal as a possible route for the introduction of the round goby into the Elbe. Midland Canal (and Seitenkanal) connects the Rhine, the Weser and the Elbe, joining the Elbe near the city of Lauenburg, above the weir at Geesthacht (see Fig. 1). The additional presence of introduced Ponto-Caspian bighead gobies, *Ponticola kessleri* (Günther, 1861), in the lower Elbe, again above the Geesthacht weir (Thiel et al. 2017), also supports the hypothesis about this route. Like the round goby, the bighead goby is now common throughout the Rhine basin, having been introduced from the Black Sea basin via the Southern Corridor (Borcherding et al. 2011; Kalchhauser et al. 2013). The second possible route for the introduction of round goby to the Elbe is via the Kiel Canal (Nord-Ostsee-Kanal), which connects the Baltic Sea with the North Sea (see Fig. 1), and this hypothesis is supported by recent genetic data (Janáč et al. 2017). This canal, which is part of the Central Corridor (bij de Vaate et al. 2002), opens into the mesohaline zone of the Elbe Estuary and has already served as an introduction route for many non-native fish species (Hofmann et al. 2005; Gollasch, Rosenthal 2006). It should be noted, however, that the round goby parasite community in the canal is rather poor, comprising only three species: unidentified microsporidia, *Cosmocephalus obvelatus* (Creplin, 1825) and *Paracuaria adunca* (Creplin, 1846), with both nematode species occurring rarely (Kvach, Winkler 2011). Contrary to nematodes, unidentified microsporidians were recorded in the Elbe Estuary (and in native gobiids from the Baltic Sea; see Kvach, Winkler 2011; Table 2).

In general, the similarity of parasite communities in gobies from the upper and lower (non-tidal) Elbe seems to confirm the hypothesis of Roche et al. (2015) that round gobies were introduced into the upper

Elbe at Ústí nad Labem via ship navigation from Hamburg. Furthermore, there is strong evidence that the Elbe acts as part of both the Central and Southern introduction corridors. Finally, the presence of previously unrecorded parasites (usually found only in eels) suggests that round gobies act as a new vector for the introduction of parasites into the Elbe. We therefore suggest that further research is needed to monitor the role of round goby as a new vector and particularly as regards parasitization within the Elbe eel population.

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