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Alien aquatic plants in a thermally abnormal river and their assembly to neophyte-dominated macrophyte stands (River Erft, Northrhine-Westphalia)

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Abstract

Floristic surveys, vegetation mapping, and detailed transect analyses rendered a macrophyte flora of 14 native and five alien taxa of flowering plants in the River Erft, a contributory of the River Rhine in Northrhine-Westphalia. Water temperatures of this river do not fall below 10 °C all the year round, for reasons of geothermically heated water discharged from nearby opencast mining areas. Macrophyte stand structures, composed of the neophytes *Azolla filiculoides* and *Lemna minuta* (floating) and *Myriophyllum aquaticum*, *Egeria densa*, and *Vallisneria spiralis* (rooted in the muddy or sandy ground of the river) are described and the ecological requirements of these taxa are characterized. The alien species can be seen as elements that increase the α-diversity of the aquatic vegetation of the River Erft. They do not replace any of the native species, even if shifts in the competition dynamics occur. The colonization by neophytes of the abnormally warmed River Erft can be appreciated as paradigmatic for trends in the macrophyte vegetation of medium-sized rivers in Central Europe when climate-related or discharge-based heating of the waterbody occurs and propagules of alien plants imported by waterfowl or – more important – plants from aquarium waste will find suitable places of existence and spread.

Keywords: Biodiversity; *Vallisneria spiralis*; *Egeria densa*; *Myriophyllum aquaticum*; Competition

Introduction

Most running waters provide a variety of habitats enabling niches for heterogenous plant growth and animal life (French & Chambers, 1996). Aquatic macrophytes in running waters usually occur in distinct groups of a mosaic structure. In particular, medium-sized rivers frequently provide ideal conditions for a highly variable hydrophyte vegetation (Meilinger, 2003). The occurrence of the different species is influenced by water depth, light, temperature, availability of nutrients and flow rate of the running water (Barko, Hardin, & Matthews, 1982; Wegener, 1982; Remy, 1993a–c; Zucchi, 1993; French & Chambers, 1996; Fernandez-Alaez, Fernandez-Alaez, & Becares, 1999; van de Weyer, 1999; Janauer, 2001; Schneider & Melzer, 2003). Normally more or less stable gradients exist of light conditions and the average current velocity, but water chemistry and temperature can change in rivers even over small distances.

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The availability of heterogeneous niches permits also for alien plants possibilities of establishment. Brought in by waterfowl even over larger distances and, perhaps more important, from aquarium waste, such non-indigenous taxa may occupy growing space that alternatively would be filled by native plants. On the other hand, establishment of alien plants can also increase species diversity without serious impacts on the autochthonous flora. In particular running waters have their own dynamics, where locally interspecific competition is low so that extraordinary conditions are provided for the settlement of neophytic macrophytes (Lohmeyer & Sukopp, 1992).

Discharge of cooling water from power plants and other industrial sources and of geothermically warmed water drained from deep reaching opencast mining areas can raise water temperatures of the receiving water bodies. In this case, the outfall river will be particularly susceptible for warmth demanding macrophytes native from low latitude waters and discharged from aquarium wastewaters.

Paying special attention to the occurrence of neophytic plants we investigated such a situation along the lower part of the River Erft/Northrhine-Westphalia, Germany, where geothermically warmed water makes up considerable amounts of the whole water discharge of the river. Floristic reports from the last two decades (Diekjobst, 1983, 1984; Wolff, 1991; Diekjobst & Wolff, 1995) indicated the establishment in this river of several exotic plants not registered during the first vegetation survey of the Erft river by Friedrich (1973). He reported on 11 native plant species in the River Erft in the 1970s (Table 1). We hypothesized that due to a year-round elevated water temperature the alien taxa might come in stronger competition with native ones and a co-existence of them must lead to floristically quite particular stands of aquatic macrophytes.

Table 1. List of all macrophytes, which Friedrich reported in the 1970s (Friedrich, 1973)

Lemna gibba L.
Lemna minor L.
Lemna trisulca L.
Nuphar lutea L.
Potamogeton crispus L.
Potamogeton natans L.
Potamogeton pectinatus L.
Ranunculus fluitans Lam.
Sparganium emersum Rehmann
Sparganium erectum L.
Spirodela polyrhiza (L.) Schleiden

Materials and methods

Study region

The River Erft starts at 540 m a.s.l. to the South-West of Bad Münstereifel (50°30′N, 6°42′E) and terminates after 105 km as a contributory of the River Rhine in the vicinity of the city of Neuss (see Fig. 1 or the inset in Figs. 2–4). Downstream from the town of Kerpen the natural run-off regime of the River Erft is completely changed. At some different river points processed wastewater of the nearby lignite opencast mining area is added to the river. This massive input of processed wastewater has started in 1950s. The natural flowing-off of about 5 m^3/s is actually doubled to a current flowing-off to about 10 m^3/s (Erftverband 2002). The MHQ/MNQ ratio is about 3 (MHQ~17.5 m^3/s; MNQ~5.8 m^3/s) and the naturally high water run-off is reduced in addition by retention ponds (Rose, pers. comm.). Most water is discharged in the river upstream the region of Bergheim but there are some additional discharging points in the study area too (Fig. 1). The added water has a temperature of about 20 °C throughout the whole year. By this, even during the winter months the temperature of the River Erft below the town of Bergheim is rarely below 10 °C (Friedrich, 1966, 1973, 2000). Friedrich (1973) considers this type of river as a "warm course of the water" in the temperate regions.

In the study area the pH-value is about 7 in the river near Bedburg and increases to about 7.7 in the river near Neuss. NO_3–N ranged between 0.84 and 2.67 mg/l in the river near Bedburg and between 3.17 and 5.64 mg/l in the river near Neuss. Values of these two and other limnological parameters [total organic carbon (TOC), conductivity and total phosphorus (P_{tot})] are shown in Table 2 (data provided by Erftverband).

Macrophyte mapping

In 2003 the aquatic macrophytes of the River Erft were surveyed once during the main vegetation period from the end of May to the beginning of September. The river section downstream from Bergheim was divided into 52 mapping sections of different lengths (Fig. 1). The individual sections of the research area were deliminated following practical aspects of accessibility, secondly based on the uniformity of morphological characteristics, substrate conditions, flow velocity or homogeneity of vegetation as suggested by Kohler (1978), Kohler, Vollrath, & Beisl (1971) and Kohler & Janauer (1995). Within each section the quantity of species was estimated, according to the five degree scale from Kohler (1978). The relationship between the five groups and the actual

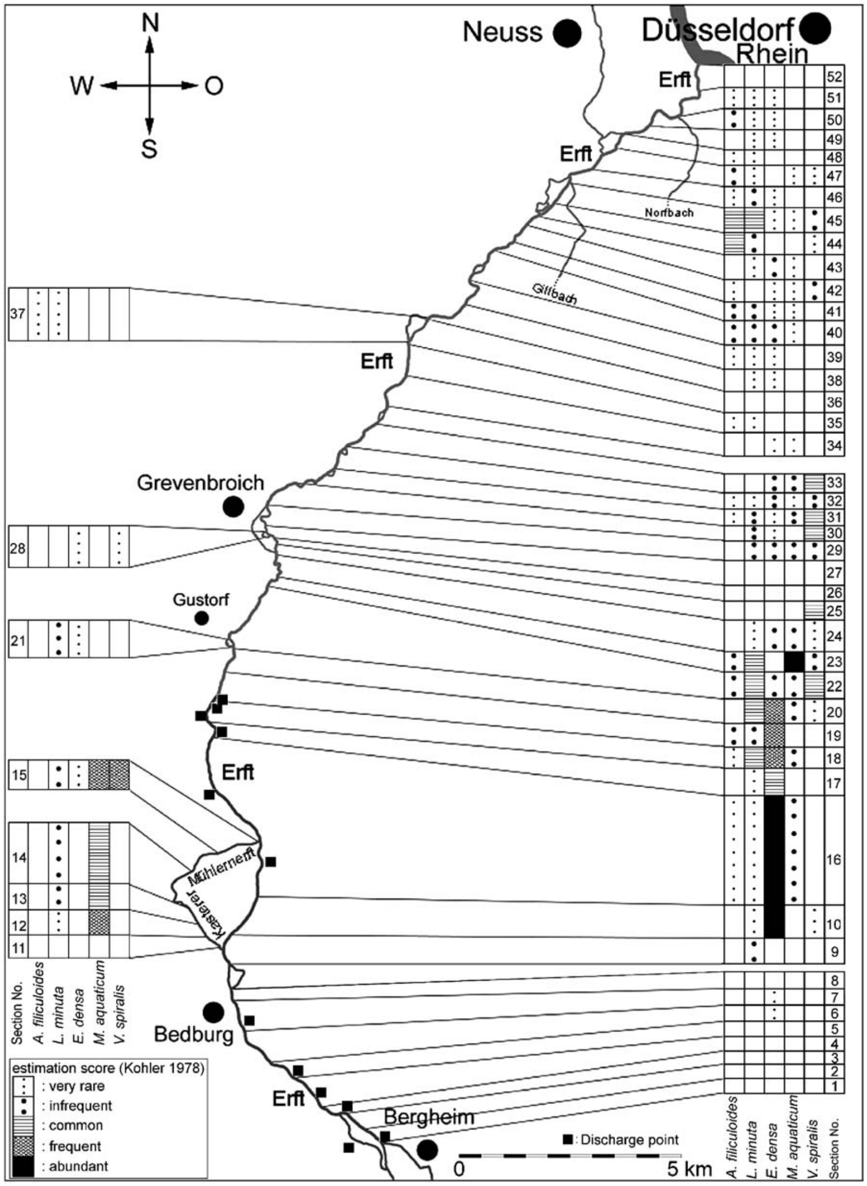

Fig. 1. Occurrence of alien aquatic plants documented for the river sections between Bergheim and mouth of the River Erft.

quantity of the submerged macrophytes is nonlinear, with a third power relationship between score number and plant mass (Kohler & Janauer, 1995; Janauer & Heindl, 1998).

The actual current velocities of the mapping sites were measured with a MiniAir2 (Schiltknecht Messtechnik AG). The instrument indicates a mean value of 6 s measurements. They were taken of a depth of 10 cm below the water surface. In deeper parts of the river (> 50 cm), additional measurements were taken 10 cm above the ground, but not deeper than 1 m. The current velocities of all sections were classified by a four degree scale according to Janauer (2003) (see Table 3). The current velocities at the transects are noted in the Tables 7–9 and in Figs. 2–4.

Transects

In addition to the mapping, transects were examined at several locations along the river to obtain exact values of amounts and habitat quality of the different species. Apart from the quantity of species (according to Braun-Blanquet, 1964), the parameters river depth, current velocity (compare Table 3) and substrate type according to Janauer (2003; see Table 4) were investigated and classified. Furthermore the turbidity was scored into three classes of low, medium and high turbidness. The investigations were carried out when the river had medium water levels. These results permitted to relate the association of different plants with an exact characterization

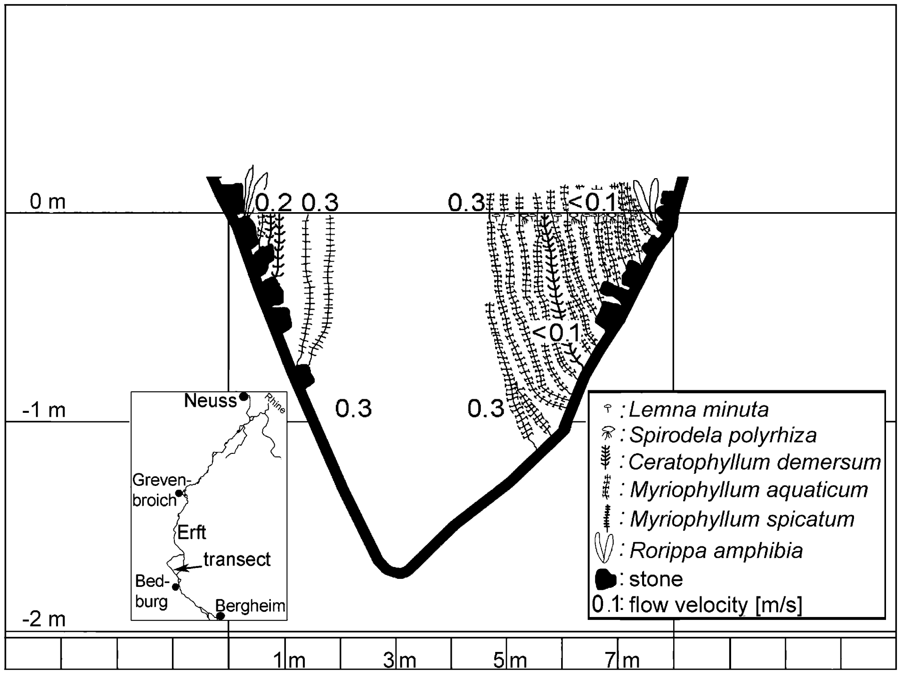

Fig. 2. Transect, Kasterer Mühlenerft near Kaster. Medium water level, high turbidity.

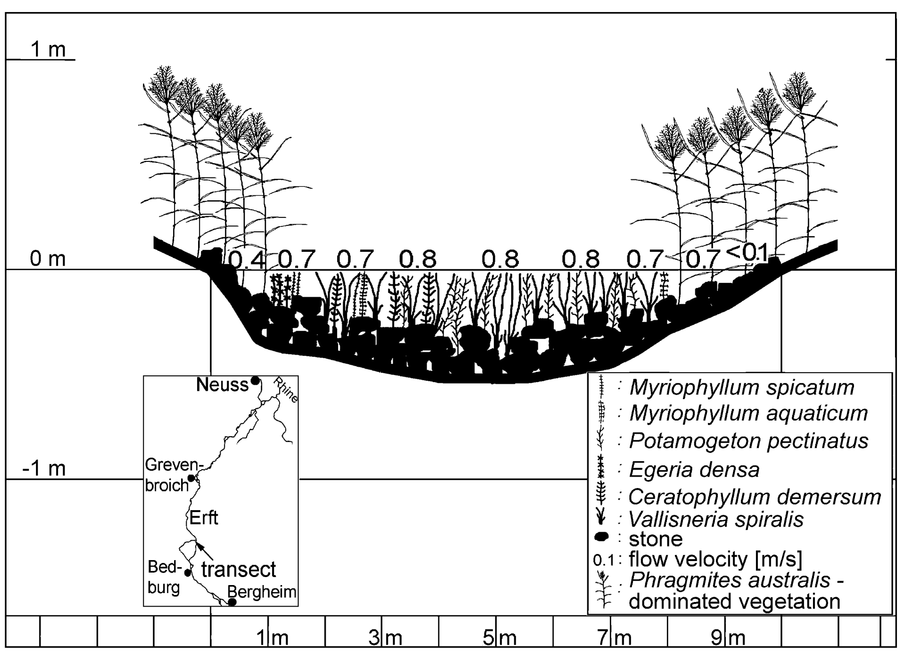

Fig. 3. Transect, upper region of Kasterer Mühlenerft. Medium water level, low turbidity.

of the particular locations (Wahrenburg, van de Weyer, & Wiegleb, 1991; Kohler & Janauer, 1995; van de Weyer, 1999).

The presented transects document situations, which are widespread in the river and characteristic for different stretches of comparable environmental conditions at the river.

The alien plant species of the River Erft

In the River Erft five alien plant species were found. In addition to the two floating neophytes *Azolla filicuoides* and *Lemna minuta*, which are widespread in Germany, three further neophytic plant species were recorded, which have only a few more occurrences in Germany.

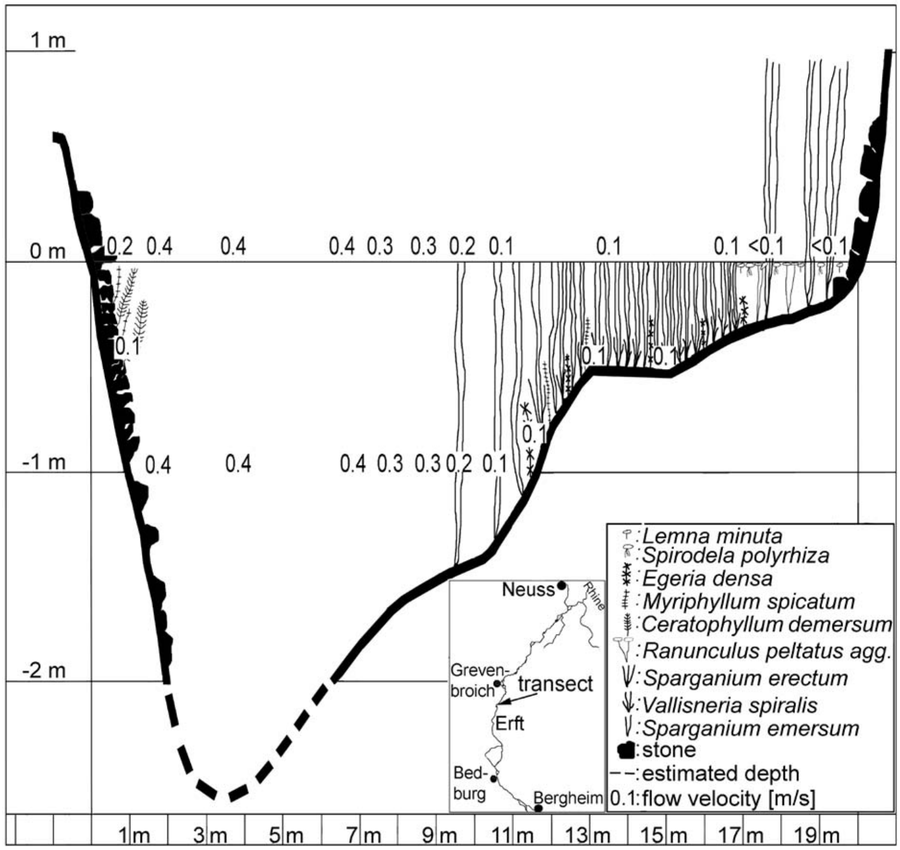

Fig. 4. Transect, Erft 100 m downstream Gustorf mill, medium water level, medium turbidity.

Table 2. Values of some limnological parameters at two different points of the River Erft (compare Fig. 1)

	pH	TOC (mg/l)	NO_3–N (mg/l)	P_{tot} (mg/l)	Conductivity (μs/cm)
Erft near Bedburg					
Min.	6.9	2.88	0.84	0.11	715
Max.	7.2	5.62	2.67	0.34	802
Mean	7.0	3.62	1.77	0.22	758
Erft near Neuss					
Min.	7.5	3.17	1.50	0.10	720
Max.	8.0	5.64	3.50	0.26	834
Mean	7.7	4.19	2.13	0.17	787

Azolla filiculoides Lamk. (Azollaceae)

This species is an up to 2.5 (10) cm large floating plant. It is native in warm temperate and subtropical America (Casper & Krausch, 1980; Lumpkin & Plucknett, 1980). It is distributed throughout the whole world and found in South-, Central- and North-America, Europe, Asia, Australia and South Afrika (Janes, 1998a, b; Hill & Cilliers, 1999). This red water fern can be found occasionally but widespread in Germany (Bernhardt, 1991; Kohler, 1995). In the River Erft *Azolla filiculoides* has been observed in changing frequencies since 1991 (Diekjobst & Wolff, 1995).

Lemna minuta Kunth (Lemnaceae)

The Least Duckweed is native to America and was found for the first time in Germany in 1960 in the River Rhine upstream Basel/Weil am Rhein. In addition,

Table 3. Flow velocity classes according to Janauer (2003)

No flow, stagnant
Low flow velocity, from just visible to ca. 30 cm/s
Medium flow velocity, ca. 35–65 cm/s
High flow velocity, >70 cm/s

Table 4. Sediment classes according to Janauer (2003)

Solid rock or Mega-, Macro- and Mesolithal (>6.3 cm)
Gravel (Microlithal and Akal, 0.2–6.3 cm)
Sand (Psammal, 0.063–0.2 cm)
Fine predominantly inorganic substrate (Pelal, <0.063 cm)
Artificial material (concrete, asphalt, etc.)
Detritus or other organic material

duckweed was also found at the same time in other countries, e.g. in Switzerland, Great Britain and France (Diekjobst, 1983). In the River Erft *Lemna minuta* was documented for the first time in 1981 (Diekjobst, 1983; Diekjobst & Wolff, 1995).

Egeria densa Planchon (Hydrocharitaceae)

This species is a submerged or floating, substantially branched plant, and is native to South Africa. Shoots reach lengths of up to 3 m and in optimal conditions form dense populations and spread explosively (Countryman, 1970; Casper & Krausch, 1980; Haramoto & Ikusima, 1989; Kadono, Nakamura, & Suzuki, 1997; Dutartre, Haury, & Jigorel, 1999). Casper and Krausch (1980) describe a high competitive capacity against *Elodea canadensis*. In Europe the species migrated to France, Great Britain, the Netherlands and Germany (Countryman, 1970; Casper & Krausch, 1980; Dutartre et al., 1999). In Northrhine-Westphalia it occurs in the River Erft and in the region of Mettmann and Siegburg (Galunder, Patzke, & Woike, 1989). The first plants in the River Erft were collected at the end of the 1980 (Abts, 1994; Diekjobst & Wolff, 1995).

Myriophyllum aquaticum (Velloso) Verdcourt (Haloragaceae)

This species is a perennial and almost completely submerged plant with up to 100 (600) cm long shoots. It is native to tropical and subtropical South America (Aiken, 1981). In 1890 first plants reached North America and since then the species spread to many areas (Les & Mehrhoff, 1999). In Europe the species is known from Spain, Portugal, Southwest France, Great Britain and Austria (Chicken, 1977; Milner, 1979; Casper & Krausch, 1980; Stace, 1991; Leute, 1992; Moreira., Ferreira, Monteiro, Catarino, & Vasconcelos, 1999a; Moreira, Monteiro, & Ferreira, 1999b). In Great Britain populations are in part not permanent and *Myriophyllum aquaticum* (parrot's feather) shows an explosive spread only under favourable conditions. In Germany, beside the existence in the River Erft, just a few more locations are known (Bank-Signon & Patzke, 1988; Diekjobst & Wolff, 1995). Also Bruinsma (pers. comm.) found this species in different canals and rivers in the neighbouring Netherlands.

Vallisneria spiralis L. (Hydrocharitaceae)

This species is a submerged macrophyte possessing strap-shaped, up to 100 (600) cm long leaves (Hegi, 1965; Casper & Krausch, 1980). The species is widespread in the tropical and subtropical areas of both hemispheres. From its native occurrences in South Europe this species spreads northwest to France, Germany, Belgium, Netherlands and South of Great Britain (Michel, 1951; Corillion, 1955; Castagne, 1956; van Oostroom & Reichgelt, 1962, 1963; Casper & Krausch, 1980; Preston & Croft, 1997, Bruinsma, pers. comm.). In Germany it was first collected from the rivers Mosel and Lippe (Ant, 1966, 1970) and from a drain near Karlsruhe (Hegi, 1965). In the River Erft the species was hitherto unknown.

Results

Occurrences, distribution and socialization of alien and native plant species in the River Erft

In the River Erft 14 native and five alien plant species were found (Table 5). Some sections were dominated by alien aquatic plant species, but most areas of the river were dominated by native species. The different alien aquatic macrophytes showed species-specific distribution patterns. Some of them (*Egeria densa*, *Myriophyllum aquaticum* and *Vallisneria spiralis*) showed a wide adaptability to different habitat conditions and were widespread in the river (Fig. 1), whereas the floating neophytes *Azolla filiculoides* and *Lemna minuta* were linked to stagnant zones at the river, either between emerged shoots of plants or in naturally stagnant parts of the waterbody.

The two floating species *Azolla filiculoides* and *Lemna minuta* favour sections of the River Erft with very slow running water, almost all living directly above embankments, between the floating leaves of *Nuphar lutea* and the emerged shoots of *Myriophyllum aquaticum*. Both species are existent in very rare to frequent abundance in the River Erft (Fig. 1, Table 5) and are often associated

Table 5. Occurrence of aquatic plants documented for the sections between Bergheim and mouth of the River Erft (compare Fig. 1)

Section no.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Average flow velocity	m	m	m	m	m	m	m	m	m	m	l	l	l	l	m	m	m	m	m	m	m	m	m	m	m	m
Alien plant species																										
Azolla filiculoides Lam																1		1	2			2	2			
Egeria densa Planchon.						1	1			5						5	3	4	4	4	1	2		2		
Lemna minuta Kunth									2	1		3	2	2	2	1	1	3	2	3	2	3	3	1		
Myriophyllum aquaticum (Velloso) Verdc.												4	3	3	4	2		2		2		2	5	2		
Vallisneria spiralis L.										1					4					1		3	2	1	3	
Native plant species																										
Callitriche platycarpa Kütz.																								1		
Callitriche spec.									1		1	2			1	1				1	1	1				
Ceratophyllum demersum L.	1		1				1		2	1	1	3		4	3	2		4	2	3	1	3		1	1	
Lemna minor L.	1		1				1		1	1					1	1	1	2	3	2	1	2	2	1		
Myriophyllum spicatum L.	2	3	2	4	3	2	4	2	3	1	3	3	2	2	1	1		2	1	3		1		2		
Nuphar lutea L.																					2	2				
Potamogeton crispus L.																										
Potamogeton natans L.					4	4	3		2	2			2			2	1	3		1		1				
Potamogeton pectinatus L.	3	4	3	3	4	5	3	2	3	3					2	4	5	4	3	3				1		
Ranunculus fluitans Lam.	1		1				1	1	1						2											
Ranunculus peltatus agg.																		3	1	2		2	3	1		
Sparganium emersum Rehmann	1	3	3	1	2	1	2		2	1		1	3	4	4	1	4	5	1	2	5	4	3	5	3	
Sparganium erectum L.									2	1						1	2			1		2			2	
Spirodela polyrhiza (L.) Schleiden												1	1			1			1		1	1				

Section no.	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52
Average flow velocity	m	m	m	m	m	m	m	m	m	l	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m	m
Alien plant species																										
Azolla filiculoides Lam					1	1			1		1		1	2	2	1		3	3	1	2	1		2	1	
Egeria densa Planchon.	1		2	1	1	2	2	1		1		1	1	2	1	1	2		1	1		1	1	1		
Lemna minuta Kunth			2	2	2	1			1		1	1	1	2	2		1	2	3	2	1	1	1	1	1	
Myriophyllum aquaticum (Velloso) Verdc.			2	1	2		2	1						1	1	1	1		1		1					
Vallisneria spiralis L.	1		2	3	3	2	3									2		1	2		2					
Native plant species																										
Callitriche platycarpa Kütz.																										
Callitriche spec.					1	1																				
Ceratophyllum demersum L.	1		2		1		2			1	1	1	1	1		1	2	2	1	1	2	1	2	1		
Lemna minor L.			2	2	1	1			1			1		1	1		1	2	1	1		1	1	1	1	
Myriophyllum spicatum L.				1	1	2	2		2	1	1	1	2	2	1	1	2	2	1	1		1	1	1	1	
Nuphar lutea L.	5		4			3	2		2		2	1	1	2		1		3	4	2	1	1	1	1		
Potamogeton crispus L.							1																			
Potamogeton natans L.				1	1		1		1				1	2												
Potamogeton pectinatus L.			2		1	2	3	3			2	5	4	5	4	2	4	3	1	1	2	1	2	2	1	
Ranunculus fluitans Lam.			2		2	4	3	3	1	2	1	2	2	1	2	2	2			1		1	2	2		
Ranunculus peltatus agg.			1			1						1	1													
Sparganium emersum Rehmann			2	3	3	3	4	2	2	1	2	2	2	3	3	2	2	2	2	1	2			1		
Sparganium erectum L.																										
Spirodela polyrhiza (L.) Schleiden						1						1		1		1	1		1			1				

Flow velocity class: n: no flow, stagnant; l: low flow velocity; m: medium flow velocity; h: high flow velocity.

Table 6. Distribution of alien plant species related to various limnological parameters

Species name	River width (m)	Flow velocity (m/s)	Water depth (cm)	Preferred substrate type	Preferred turbidity	Number of samples
Myriophyllum aquaticum						
Emerged	8–32	0–0.3	10–150	Fis, De	High	14
Submerged	8–15	0.4–1.0	30–80	Gr, Sa	Low	3
Vallisneria spiralis	8–32	0–0.8	10–100	Sa, Fis, De	Low-medium	21
Egeria densa	10–25	0–1.0	15–210	Sa, Fis, De	High	9

Substrate types: De: Detritus or other organic material; Fis: Fine predominantly inorganic substrate; Gr: Gravel; Sa: Sand.

Table 7. Transect across the Kasterer Mühlenerft near Kaster (compare Figs. 1–3)

Area ($m \times m$)	1×2	1×2	1×2	1×2	1×2	1×2	1×2	1×2
Coverage macrophytes (%)	3	2	—	—	40	120	120	120
Substrate	Sr/De	Sr/De	Sr/De	Sr/De	Fis/De	Fis/De	Fis/De	Fis/De
Flow velocity[a]	0.2	0.3	0.3	0.3	0.3	<0.1	<0.1	<0.1
Flow velocity[b]	—	0.3	0.3	0.3	0.3	<0.1	<0.1	<0.1
Maximum depth (cm)	70	130	170	170	160	133	106	52
Rorippa amphibia	1	—	—	—	—	—	—	—
Ceratophyllum demersum	1	—	—	—	—	+	—	—
Myriophyllum aquaticum	+	—	—	—	3	5	5	5
Myriophyllum spicatum	—	1	—	—	—	—	—	—
Lemna minuta	—	—	—	—	2	3	3	3
Spirodela polyrhiza	—	—	—	—	+	+	+	+

Substrate types: Sr: Solid rock or mega-, macro- and mesolithal; De: Detritus or other organic material; Fis: Fine predominantly inorganic substrate. Coverage level (according to Braun–Blanquet): r = a single plant, coverage level <1%; + = <1%; 1 = 1–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%

[a]Measuring depth: 10 cm below water surface.

[b]10 cm above ground, max. depth 1 m.

with the native floating species *Spirodela polyrhiza* and *Lemna minor*.

The rooting plant *Egeria densa* favours sections with high or low current velocity and low or high turbidity (Tables 5 and 6). In these locations this species dominates the vegetation (Fig. 1, Table 5). It is rooting in muddy sediments of up to 2 m depth. In the fast flowing parts of the river with high turbidness, *Egeria densa* is often associated with the native species *Potamogeton pectinatus* and *Potamogeton natans*. Rarely, *Egeria densa* is present in the fast flowing and very clear sections of the river (in Fig. 1 Section 15; Fig. 3, Table 8). In these areas the sediment is largely sand or gravel and the plants grow poorly.

In the River Erft *Myriophyllum aquaticum* showed an enormous adaptability to different habitat conditions (Table 6). Although *Myriophyllum aquaticum* was mostly found in sections where very slow current velocities prevail, this species was not absent in medium or even fast flowing sections of the river. In some parts of the Kasterer Mühlenerft, a side arm of the River Erft, *Myriophyllum aquaticum* dominated the vegetation and the plants formed dense emerging populations (Fig. 2, Table 7). At this location the plants root in muddy sediment up to 1.5 m below the water surface. As early as in April a dense presence of emerged shoots of *Myriophyllum aquaticum* plants was observed. In the slow running and very turbid water, for instance in some parts of the Sections 12, 13, 14 and 15 (Figs. 2 and 3; Tables 5, 7 and 8) there were almost no other submerged macrophytes, apart from some *Potamogeton natans* in rare to frequent abundance, whereas in shallower and less turbid parts of these sections, *Myriopyhyllum spicatum, Ceratophyllum demersum* and *Sparganium emersum* dominated the vegetation.

In the River Erft near Grevenbroich, the parrot's feather dominated a shallow, muddy bank (up to 20 cm deep; see Table 5, Section 23). The plants formed dense emerged patches with dimensions up to 1000 m^2. There, they did not spread before June, 2 odd months later then in the deeper parts of the river or in the Kasterer Mühlenerft.

In the lower reaches of the Kasterer Mühlenerft *Myriophyllum aquaticum* was also found in sections with high current velocity above 0.7 m/s (Section 15; see Figs. 1 and 3, Tables 5 and 8). In these areas the plants

Table 8. Transect across the upper region of the Kasterer Mühlenerft (compare Figs. 1–3)

Area (*m* × *m*)	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2
Coverage macrophytes (%)	100	70	20	50	60	75	60	15	70	100
Substrate	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr	Sr/Gr
Flow velocity[a]	0.4	0.7	0.7	0.8	0.8	0.8	0.8	0.7	0.7	<0.1
Flow velocity[b]	—	—	—	—	—	—	—	—	—	—
Maximum depth (cm)	35	37	45	50	51	46	39	44	27	14
Phragmites australis	5	—	—	—	—	—	—	—	4	5
Egeria densa	—	3	—	—	—	—	—	—	—	—
Myriophyllum spicatum	—	2	r	—	—	—	—	—	—	—
Vallisneria spiralis	—	1	2	3	3	4	4	2	—	—
Myriophyllum aquaticum	—	—	1	—	—	—	—	—	—	—
Ceratophyllum demersum	—	—	1	2	—	—	—	—	—	—
Potamogeton pectinatus	—	—	—	1	2	2	2	1	—	—

Substrate types: Sr: Solid rock or mega-, macro- and mesolithal; Gr: Gravel.
Coverage level (according to Braun–Blanquet): r = a single plant, coverage level <1%; + = <1%; 1 = 1–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%.
[a]Measuring depth: 10 cm below water surface.
[b]10 cm above ground, max. depth 1 m.

have only submerged leaves and they are associated with other neophytic (*Vallisneria spiralis*, *Egeria densa*) and some native species (*Potamogeton pectinatus*, *Ceratophyllum demersum*, *Myriophyllum spicatum*).

The neophytic species *Vallisneria spiralis* was in the River Erft hitherto unknown but its wide distribution indicates quite a long settlement period in this river (Fig. 1, Table 5). In May and November flowering female plants were found. This species prefers sections of clear water (Table 6). In areas of turbidness the plants grow badly and accumulate a layer of sediments on their leaves. The species is found in stagnant, slow and fast running (up to 0.8 m/s; Fig. 3, Table 8) water, rooting in depths of up to 1 m on muddy, sandy or gravely sediment. In most cases *Vallisneria* occurred as associated with the native species *Sparganium emersum*, which bordered *Vallisneria spiralis* to deeper parts of the river. At some places both species grew jointly as a close alliance (Fig. 4, Table 9).

Discussion

The macrophyte vegetation in the River Erft is to be appreciated as unique among comparable rivers of Central Europe. Throughout the 1970s Friedrich (1966, 1973) found only one neophytic aquatic plant (*Compsopogon hookeri*, a Rhodophyceae) in the river. Since that time five further aquatic neophytes have established and now characterize this river floristically. They established in competition with native species, replaced them locally but did not exterminate them. Kowarik (2003) points out, that the heterogeneity of the macrophyte vegetation is more affected by abiotic heterogeneities of the water body than by the occurrence of alien species. Replacement may occur only when the different species prefer comparable habitats. Such replacements were documented by Countryman (1970), Barko & Smart (1981), Feijoo, Momo, Bonetto, & Tur (1996); Boylen, Eichler, & Madsen (1999), Moreira et al. (1999a) and Wallentinus (2002). In the River Erft sections with a heterogeneous vegetation always had a similarly variable water body (current, turbidity, depth, and others). Habitat separation between alien and indigenous plants was documented, but locally also a competitive replacement.

Egeria densa, e.g. repressed the formerly widely distributed native species *Potamogeton natans* and *Potamogeton pectinatus* (Friedrich, 1973) from their earlier locations. In river sections without *Egeria densa* these two native species remained unchanged and were as widely spread as had been documented 30 years ago. Moreover, it is possible that *Egeria densa* supplanted the two neophytic species *Elodea canadensis* and *Elodea nuttallii* from their habitats. Both were found in the River Erft before *Egeria densa* was collected first (Diekjobst & Wolff, 1995), but became rare afterwards and were not found in 2003. All three species have comparable demands on the environment and in this case a direct replacement of the two smaller neophytes by a more vigorous one appears feasible.

Myriophyllum aquaticum depressed in some cases the native hygrophyte *Rorippa amphibia* in shallow (up to 20 cm) and mud sections of the river. *Rorippa amphibia* flowers in April and May, two months before *Myriophyllum aquaticum* grows rapidly and forms dense patches. Moreira et al. (1999a) described *Myriophyllum aquaticum* as a weed because it occurs in comparable dense patches in some waters in Portugal. In parts of the

Table 9. Transcect across the River Erft near Gustorf (compare Figs. 1 and 4)

Area ($m \times m$)	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2	1 × 2
Coverage macrophytes (%)	<1	—	—	—	—	—	—	—	—	<1	5	60	70	80	80	80	90	7	8	2
Substrate	Sr/Gr	Sr/Gr	Gr	Gr	Gr	Gr	Gr	Gr	Gr/Sa	Sa	Sa	Sa/De	De	De	De	De	De	De	De	Sr/De
Flow velocity[a]	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	<0.1	<0.1	<0.1	<0.1
Flow velocity[b]	0.2	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.2	0.1	0.1	—	—	—	—	—	—	—	—
Maximum depth (cm)	106	>200	>200	>200	>200	>200	190	170	155	141	117	75	48	48	50	41	32	25	17	10
Sparganium erectum	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	+
Spirodela polyrhiza	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	r	r	r
Lemna minuta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1
Ranunculus peltatus agg.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	r	r	—
Ceratophyllum demersum	+	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Myriophyllum spicatum	r	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sparganium emersum	—	—	—	—	+	—	—	—	—	+	2	1	+	+	+	r	r	—	—	—
Vallisneria spiralis	—	—	—	—	—	—	—	—	—	—	—	4	4	5	5	5	5	5	—	—
Egeria densa	—	—	—	—	—	—	—	—	—	—	—	+	r	—	+	+	+	+	—	—

Substrate types: Sr: Solid rock or mega-, macro- and mesolithal; Gr: Gravel; Sa: Sand; De: Detritus or other organic material.
Coverage level (according to Braun–Blanquet): r = a single plant, coverage level <1%; + = <1%; 1 = 1–5%; 2 = 5–25%; 3 = 25–50%; 4 = 50–75%; 5 = 75–100%.
[a]Measuring depth: 10 cm below water surface.
[b]10 cm above ground, max. depth 1 m.

River Erft (e.g. in the Kasterer Mühlenerft), which are very turbid and barely colonized by native hydrophytes, *Myriophyllum aquaticum* causes an enrichment of the local vegetation by rooting of up to 1.5 m deep (Fig. 2, Table 7). No native species are suppressed here. In fast running (up to 0.8 m/s) and very clear regions of the river, *Myriophyllum aquaticum* was present at lower densities too (Fig. 3, Table 8). This documents the adaptability of this species, even though Moreira et al. (1999b) considered water velocity an important factor for the controll of parrot's feather distribution in river systems. Other records of *Myriophyllum aquaticum* in neighbouring countries (Chicken, 1977; Milner, 1979; Bruinsma, pers. comm.) suggests that the species will further be able to colonize water bodies in the oceanic climate regions.

A similar spread can be expected for *Vallisneria spiralis*. Some recent reports in the Netherlands indicate this (Bruinsma, pers. comm.). In the River Erft this species is in competition with *Sparganium emersum* without any signs of replacement. Frequently both taxa form common stands. In this case *Vallisneria spiralis* dominates the shallow (up to 1.0 m) and clear water regions whereas *Sparganium emersum* roots in the deeper and more turbid sections of the river. Here, under competition a partial separation and narrowing of the common ecological niche occurs which is broader in both species if growing without competition.

At present neophytes make up 25% of the macrophyte flora of the River Erft (Table 5). They contribute therefore remarkably to and increase the α-diversity of this medium-sized river. Locally they may shift the competition balance, but nowhere native taxa were seriously threatened. It is remarkable that the spread of neophytes occurred only during the last 30 years because Friedrich (1973), in his detailed floristic investigations, did not report any higher plant species alien to this river. A discharge of geothermically heated water in the River Erft occurred also when Friedrich made his relevees. The contemporary widespread occurrence of neophytes in the river obviously results from recent processes of plant migrations.

In some instances as with *Lemna minuta* or *Myriophyllum aquaticum*, an immigration of the alien taxa seems to occur as part of their general spread from warm-temperate to cool-temperate regions in Europe. Just like *Azolla filiculoides* they are often transported from waterbody to waterbody by waterfowl. *Egeria densa*, *Myriophyllum aquaticum* and *Vallisneria spiralis* most probably originated as neophytes in the River Erft from aquarium waste. The probability of discharge of exotic plants from aquaria, supplied from pet and lifestock markets, has increased enormously when during the last decades many amateurs became aquarium-keepers. For this reason this particular form of neophyte colonization may be understood as a change of diversity that is based upon socio-economic rather than on environmental influences.

However, the presence of some of these species in thermally not very exceptional water bodies – in contrast to the River Erft – indicate that *Myriophyllum aquaticum* or *Vallisneria spiralis* may become naturalized in Western and Central Europe if, by global warming, average water temperatures will increase even by only one or two degrees. The situation in the River Erft, with temperatures of up to 5 °C above average, presents only about optimal conditions for a high macrophyte diversity contributed from both, native and alien water plants. The actual situation does not call for measures to control the alien taxa. Indeed, it seems that quite a dynamic arrangement between native and adventitious taxa is given during the course of the river, and that a high α-diversity of primary producers may even influence positively other organisms in the river.

The floristic enrichment of the macrophyte stands by the alien species should be taken into consideration when valuation scores are developed for a quality assessment of rivers. The long-term trend of other aquatic systems in Central Europe will be that of a slight but steady increase of temperature. The artificially heated River Erft and its assemblages of macrophyte vegetation can show the direction of succession, which the vegetation of medium-sized rivers will take under the influence of global warming, of water discharge to rivers from the population, and of an increased plant exchange with foreign floristic regions due to aquarium-keepers in the densely populated regions of Europe.

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