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EFFECTS OF HABITAT RESTORATION ON THE MACROINVERTEBRATE FAUNA IN A FORELAND ALONG THE RIVER WAAL, THE MAIN DISTRIBUTARY IN THE RHINE DELTA

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ABSTRACT

River engineering in the Rhine delta and water pollution have been major threats for the ecological functioning of the river in The Netherlands. To mitigate effects of river engineering, secondary channel construction in the forelands along the existing distributaries is considered to be an important measure for river restoration. These areas are the remnants of the former Rhine floodplain and the only area where habitat restoration is possible due to the river functions assigned. Secondary channel construction in the area called 'Gamerensche Waarden' was taken as an example to show effects of habitat restoration on the macroinvertebrate fauna. Totally 322 macroinvertebrate taxa were found during the monitoring period. During the first 3 years species richness in the area increased rapidly due to colonization processes in the channels following habitat development. After that period total number of taxa found in the channels stabilized at around 170. A clear positive relationship was demonstrated between habitat quality and species richness. Furthermore, the density of exotic species in the secondary channels was less than in the groyne fields of the main channel. The relatively low number of taxa in polluted habitats could be explained by the presence of the PCB 28 congener. Copyright © 2007 John Wiley & Sons, Ltd.

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INTRODUCTION

Exponential increase of anthropogenic stress in European rivers started several centuries ago when inhabitants of floodplains attached an increasing number of functions to them. In the Rhine delta this type of stress started already about 11 centuries ago with the construction of levees. Step by step, the river basin lost his naturalness and ecological integrity (Smits *et al.*, 2000). River regulation was a first step (Middelkoop, 1997). Floodplains in the Rhine delta were narrowed by the construction of levees (summer dikes) and higher dikes (winter dikes) for land reclamation and for protection against floods. From the 16th century on, groynes of braided willow twines were constructed at banks threatened by the river. Behind these groynes rapid sedimentation took place and also in this way new land was reclaimed. During high river discharges sedimentation in the remaining floodplain between the summer and winter dikes resulted in the formation of a thick clay layer covering the former variation in soil types. The effect of channel modification was the disappearance of more or less all natural shallow lotic habitats.

Another effect of river engineering on macroinvertebrate communities in the alluvial Rhine delta was the introduction of stony substrates for bank protection or groyne construction. By these activities, lithal habitats were introduced in the littoral of river sections where under natural circumstances only psammal and pelal habitats are present.

Anthropogenic stress increased when the River Rhine was also used for the downstream transport of wastes and waste water from urban areas. River pollution became particularly manifest following the industrial revolution in

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Europe (Tittizer and Krebs, 1996; Nienhuis and Leuven, 2001). Klink (1989) distinguished four types of river pollution covering more or less successive phases in the pollution history of the River Rhine. Pollution started with the discharge of organic substances in domestic waste waters, followed by heavy metals pollution, being the combined result of mining and industrial activity. The third type was formed by pollution with chlorinated organic compounds (e.g. PCB's, PAH's), and the last type by pesticides. The implementation of national laws against pollution and protection of the environment, and the establishment (in 1950) of the International Commission for Protection of the River Rhine, which got its internationally recognized juridical basis after signing the Treaty of Bern in 1963, were important impulses for water quality improvement (Dieperink, 1997). From the second half of the 1970s water quality in the River Rhine improved considerably although relatively high concentrations of harmful substances remained in sediments in the forelands (Beurskens *et al.*, 1993; Bij de Vaate *et al.*, 2006). Thermal pollution, however, became a major threat for ecological rehabilitation of the river. Compared with the situation at the start of the 20th century, average water temperature had increased by 3°C till around 1980 (Wessels, 1984) and with 0.5°C per 10 years from 1952 (Bij de Vaate *et al.*, 2006). The higher water temperature and water quality improvement created new niches and non-indigenous species profited by that (Den Hartog *et al.*, 1992; Van der Velde *et al.*, 2002).

By the end of the 1980s, the concept of river rehabilitation was introduced in river management in The Netherlands in order to restore the ecological integrity of large rivers (Van Dijk *et al.*, 1995; Pedroli and Postma, 1999; Nienhuis and Leuven, 2001). However, restoration of geo-morphological processes to improve lateral connectivity in the heavily modified Rhine delta is only possible in a very limited way because of its functions assigned (Bij de Vaate, 2003). Unhampered discharge of water and ice, and the economic considerations (e.g. shipping) have remained more important than the ecological functions, due to safety and socio-economic reasons. In practice, possibilities for restoration of the distributaries in the Rhine delta are thus mainly feasible in the forelands by increasing lateral connectivity of the aquatic/terrestrial transition zones (Heiler *et al.*, 1995, Simons *et al.*, 2001). Several large ecologically important reaches (1000–6000 ha each), with smaller areas in between, were identified for river restoration along the Rhine distributaries.

Secondary channel construction is considered to be an important measure for riverine habitat restoration. Three secondary channels were constructed in the Gamerensche Waarden, a foreland on the left bank of the River Waal, downstream of the town of Zaltbommel. The secondary channels were constructed in the period September 1996 to October 1999 to restore lotic habitats that were lost during river regulation in the past. The aim of this habitat restoration project was to promote colonization of rheophilic flora and fauna. Biotic and abiotic developments during and after the restoration works were intensively monitored. Changes in the macroinvertebrate community in these channels were monitored during the period 1998–2002 as part of the habitat restoration evaluation.

STUDY SITE

The Gamerensche Waarden (51.48N, 5.12E) along the River Waal is situated at the upstream limit of the freshwater tidal area. The present restoration consisted of the construction of three secondary channels: one permanently flowing, the south channel completed in October 1999 and two periodically flowing, the east and west channels, both dug in 1996 and designed to flow 100 and 265 days annually, respectively (Figure 1).

Before restoration, the Gamerensche Waarden was characterized by sand sedimentation during floods, resulting in the formation of river dunes and by marsh formation in the lower parts. During the intervention, the foreland was lowered and secondary channels were created. The permanently flowing secondary channel was created by connecting small isolated remnants of a former shallow clay extraction pit and a former sand extraction pit with a maximum depth of about 20 m at the start of the channel construction. After connecting to the main channel the mean sedimentation rate in the former sand extraction pit was assessed at 8.9 cm year^{-1}. In the rest of the channel the mean erosion rate was 0.2–5.7 cm year^{-1}. The mean sedimentation rate in both periodically flowing channels was 4.4 and 2.0 cm year^{-1} in the east end west channels, respectively.

The main channel of the River Waal is characterized by a relatively narrow and deep bed. A minimum depth is maintained by groynes (Figure 1) and periodically by dredging. Due to intensive navigation on the River Waal, the secondary channels are continuously affected by water movements caused by barges. On average 19 barges per hour pass the foreland.

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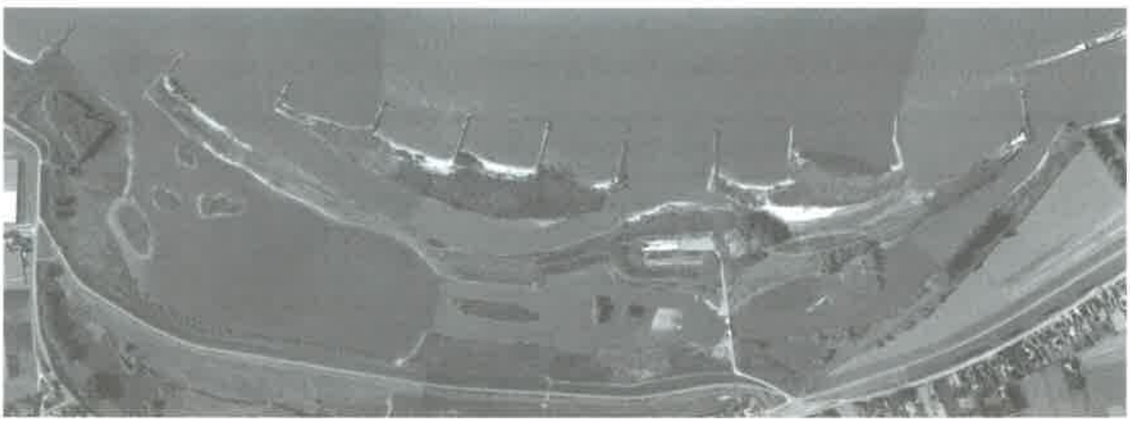
April, 23, 1998; Water level: 220 cm above sea level

June, 9, 2000; Water level: 220 cm above sea level



June, 17, 2002; Water level: 230 cm above sea level

Figure 1. Aerial photos of the secondary channel development in the Gamerensche Waarden. The south channel is permanently flowing, the east and west channels periodically. This figure is available in colour online at www.interscience.wiley.com/journal/rra

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At the start of the survey, the restoration of the foreland was not yet completed. The east and west channels function since September and November 1996, respectively, while the construction of south channel was completed in October 1999.

MATERIALS AND METHODS

Macroinvertebrates in the secondary channels and in the adjacent main channel of the River Waal were monitored during the period 1998–2002. Samples were taken in spring and autumn in several biotopes: different bottom types, solid substrates (stones and woody debris) and aquatic vegetation (Table I).

Bottom samples were taken with an Eckman Birge grab with a sampling surface area of 0.225 m^2. The contents of a grab were immediately rinsed on a 500 μm mesh sieve and the macroinvertebrates were preserved in 80%–90% ethanol. Solid substrates (stones and woody debris) were taken from a depth of about 30 cm and sampled by brushing them into a plastic tray. The contents of the tray were sieved and preserved in the same way as the bottom samples. The surface areas of the substrates were calculated after measuring relevant dimensions. Aquatic vegetation and firm clay banks were sampled with a standard 500 μm mesh size hand net (ISO, 1985). Macroinvertebrates in all samples were identified to species level as far as possible.

Grain size of the bottom sediment was analysed in accordance with the Dutch Standard Method NEN 5753 (NNI, 1994) and classified according to Reinhold-Dudok van Heel and Den Besten (1999). Contaminant concentrations were normalized in order to compensate for differences in adsorption characteristics between sediments. Standardized sediment is considered to have 25% of particles <2 μm and 10% organic matter on a dry weight basis. Normalized contaminant levels were compared with the Dutch sediment quality criteria in which sediment quality ranges from class 0 (not contaminated) to class 4 (highly contaminated), based on the contaminant with the highest concentration (Van de Guchte *et al.*, 2000).

The physical habitat quality, expressed in a habitat quality index (HQI) value, was derived from the abiotic parameters degree of connectivity, water depth, stream velocity, degree of hydrodynamical disturbances due to navigation, sediment composition and organic matter content (Table II). A two-way ANOVA was used to compare means (Sokal and Rohlf, 1981).

RESULTS

During the first 3 years of the monitoring period species richness in the area increased rapidly due to colonization processes in the channels following habitat development (Table III). After 2000, the total taxa number found in the three channels stabilized at around 170.

Table I. Numbers of samples taken in the secondary channels in the Gamerensche Waarden and in the main channel of the River Waal

Year	Secondary channels Gamerensche Waarden						River Waal	
	South channel		East channel		West channel		Main channel	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
1998	4[a]		3		8			
1999	6[b]		2[b]		5[b]			
2000	7	8	3	2	4	4	4	4
2001	10	8	3	3	5	4	4	4
2002	8	6[c]	3	2[c]	4	3[c]	4	2[c]

[a]Sampling of remnants of a former clay extraction pit.
[b]Sampled in June due to high water level in May.
[c]No sampling of the solid substrates and some shallow parts due to low water level.

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Table II. Determination of the habitat quality index (HQI)

		Value
Connectivity	Permanent	1
	Semi-isolated	2
	Isolated	3
Water depth	0–5 m	2
	5–10 m	1
	>10 m	0
Stream velocity	Stagnant	1
	Slow flowing	2
	Fast flowing	3
	Very fast flowing	4
Hydrodynamical disturbances due to navigation	Absent	1
	Much	0
Sediment composition	Sandy silt	4
	Silt	2
	Sand	1
Organic matter content	0%–2% on a dry weight basis	1
	>2% on a dry weight basis	3

Habitat quality index (HQI): Sum of parameter values.

Table III. Species richness development of macroinvertebrates in the secondary channels in the Gamerensche Waarden

Year	Number of	
	Taxa	Samples
1998	76	15
1999	98	13
2000	174	28
2001	165	33
2002	170	27

Totally 322 macroinvertebrate taxa were found during the monitoring period. The highest species richness was found in spring when 284 taxa were identified of which 149 taxa were found only in that season. In autumn 173 and 38 taxa, respectively. Taxa occurring in one sampling period only were mainly chironomid species. The absence of larvae in specific periods can be attributed to their emergence period.

Results of the habitat restoration works in the Gamerensche Waarden were significant in the south channel (Figure 2). In 1998, before the channel construction, isolated remnants of a former clay extraction pit at the projected location of this permanently flowing channel were sampled. They became part of the south channel at the end of 1999. During the period 1998–2000, the silty bottom in the remnants of the former clay extraction pit changed into a dominantly sandy channel bottom.

Increase of species richness was clearly visible in the groups of molluscs (Table IV) and chironomids (Table V). The channel bottom was colonized by psammophilic taxa and abandoned by pelephilic ones. A number of chironomid species characteristic for stable sandy flats colonized the secondary channels (*Chironomus nudiventris*, *Lipiniella moderata*, *Stictochironomus* species and *Stempellinella bausei*) including species adapted to the most harsh conditions (*Kloosia pusilla*, *Paratendipes nubilus* and *Robackia demeijerei*). Also some lotic mayflies colonized the secondary channels (*Caenis macrura* and *Ephoron virgo*).

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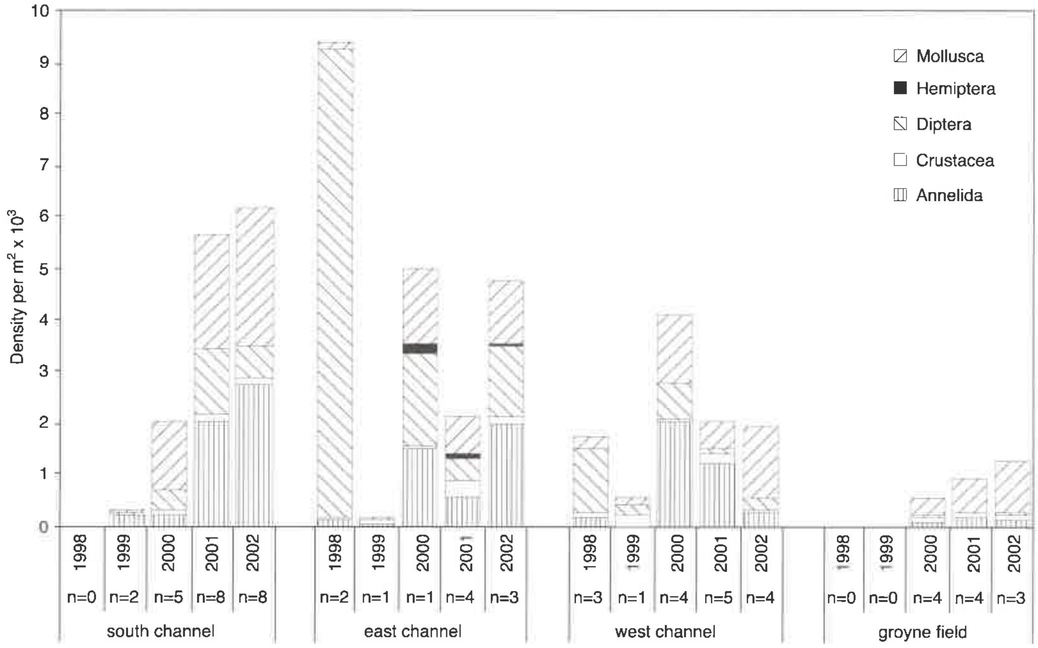

Figure 2. Mean macroinvertebrate density on sandy substrates in the three secondary channels and in the groyne fields of the main channel (n = number of samples)

However, within the chironomids, taxa feeding on coarse organic particles (*Glyptotendipes pallens* and *Endochironomus albipennis*) or decaying organic matter (*Clinotanypus nervosus* and *Acricotopus lucens*) disappeared. Species from other groups that disappeared were the caddis flies *Agraylea multipunctata*, *Mystacides longicornis* and *Oecetis lacustris*, and the mayflies *Caenis horaria* and *C. robusta*.

Table IV. Development of the mollusc abundance in the sandy sediments of the south channel

Taxon	Year				
	1998	1999	2000	2001	2002
Bithynia tentaculata	+				
Radix ovata	+				
Gyraulus albus	+	+			
Musculium lacustre	++	++			+
Valvata piscinalis	+++	++	++	+	+
Corbicula fluminalis		++	+++	+++	+++
Pisidium casertanum plicatum		++	++	++	++
Pisidium supinum		++			+++
Potamopyrgus antipodarum		+	+++	+++	+++
Corbicula fluminea		+	+++	+++	+++
Pisidium subtruncatum		+	++	++	++
Pisidium moitessierianum		+	++	++	++
Unio pictorum		+	+		
Pisidium casertanum			++	++	++
Pisidium henslowanum			++	++	++
Pisidium nitidum			++	+	++
Dreissena polymorpha			++	++	+
Sphaerium solidum			+	++	++
Number of samples	2	4	13	13	9

In 1998 only isolated remnants of a former clay extraction pit were sampled (+: 1–10 per m^2; ++: 11–100 per m^2; +++: >100 per m^2).

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Table V. Development of the chironomid abundance in the bottom substrates of the south channel

Taxon	Year				
	1998	1999	2000	2001	2002
Clinotanypes nervosus	+				
Acricotopus lucens	+				
Glyptotendipes pallens	+				
Procladius species	+++	+++	++	++	++
Cladotanytarsus mancus group	++	+++	++	++	++
Polypedilum bicrenatum	+	+++	++	+	+
Cryptochironomus species	++	++	++	++	++
Polypedilum nubeculosum	++	++	+	++	+
Harnischia species	++	++	+		+
Chironomus plumosus aggregatum	++	+		+	++
Tanypus punctipennis	++		+	+	+
Psectrocladius sordidellus group	+		+		+
Chironomus acutiventris		+	+++	+++	++
Microchironomus tener		++	++	++	+
Tanytarsus species		+	++	++	+
Polypedilum scalaenum		+	+	+	+
Endochironomus abipennis		+			
Chironomus nudiventris			++	+++	++
Paratendipus nubilus			+	++	++
Pseudosmittia species			++	+	+
Prodiamesa olivacea			+	+	+
Cryptochironomus rostratus			+	+	+
Kloosia pusilla			+	+	+
Paratendipus albimanus			+	+	+
Stictochironomus species			+	+	+
Stempelinna bausei			+	+	+
Orthocladius species			+	+	+
Lipiniella moderata			+		+
Chironomus bernensis				+	+
Robackia demeyerei				+	+
Tanytarsus brundini				+	+
Number of samples	2	4	13	13	9

In 1998 only isolated remnants of a former clay extraction pit were sampled (+: 1–10 per m^2; ++: 11–100 per m^2; +++: >100 per m^2).

Exotic species, the polychaete worm *Hypania invalida*, the crustaceans *Dikerogammarus villosus*, *Chelicorophium curvispinum* and *Jaera istri*, the molluscs *Potamopyrgus antipodarum*, *Corbicula fluminea* and *C. fluminalis*, were dominant in the secondary channels as well as in the groyne fields of the main channel (Table VI). Compared with the macroinvertebrate community in the groyne field, the secondary channels hosted more species in higher densities (Table VI). Densities of the exotic species comprised 5%–30% of the macroinvertebrate density in the east channel, 30%–60% in the south channel, 35%–80% in the west channel and 50%–90% in the groyne field.

Differences between species richness of the communities on stony substrates in both the secondary channels and the groyne field were relatively small. Notable was the absence of the gastropod *Ancylus fluviatilis* in the secondary channels which can be explained by unfavourable conditions (rapid water level fluctuations in relation to its colonization speed).

No trends were observed in the development of macroinvertebrate communities in the east and west channels due to their semi-lotic character (Figure 2). Compared with the groyne fields in the main channel, densities of Diptera and Annelida in both channels tended to be much higher on the sandy bottom substrates. Differences in macroinvertebrate communities in the three secondary channels were mainly attributed to differences in connectivity with the main channel and bottom quality. Differences in connectivity resulted in a silty bottom in the

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Table VI. Occurrence of dominant taxa (except Tubificidae) in the secondary channels and in the groyne field of the main channel (sc, secondary channels; gf, groyne field; +: 50–250 per m^2; ++: 251–500 per m^2; +++: >501 per m^2; exotic species underlined)

Taxon	Sandy substrates		Silty substrates		Stone substrate	
	sc	gf	sc	gf	sc	gf
Dikerogammarus villosus	+		++		+++	+++
Hypania invalida	++	+	+++	+		
Chelicorophium curvispinum				+	+++	+++
Potamopyrgus antipodarum	++		+++			
Chironomus acutiventris	+++		+			
Corbicula fluminea	++	++	+	+		
Jaera istri					+	++
Ancylus fluviatilis						++
Corbicula fluminalis	+	+	+			
Pisidium casertanum	+		+			
Chironomus nudiventris	+		+			
Cladotanytarsus mancus group	+		+			
Cricotopus bicinctus					+	+
Cricotopus triannulatus aggregatum					+	+
Chironomus plumosus aggregatum	+					
Kloosia pusilla				+		
Orthocladius species					+	
Paratrichocladius rufiventris						+
Procladius species			+			
Pisidium casertanum			+			
Valvata piscinalis			+			
Number of samples	63	11	21	1	10	10

east channel, a coarse sand bottom in the west channel and a bottom ranging from coarse sand to silt in the south channel (Figure 3).

A significant ($p < 0.005$) relationship between habitat quality (HQI) and species richness was demonstrated, despite the contribution of polluted sites (Figure 4). Eight out of nine samples with a number of taxa below the 95% confidence interval were taken in habitats from pollution class 3–4. The relatively low number of taxa in these habitats can be explained by the presence of the PCB 28 congener ($p < 0.05$, Table VII) and at a lower significant level ($p < 0.1$) by the presence of DDT and α-endosulphan.

DISCUSSION

The forelands along the distributaries in the Rhine delta are the remnants of the former floodplain in The Netherlands and the only area where habitat restoration is possible due to the river functions assigned. They are bordered by relatively high embankments (so-called winter dikes) and by much lower embankments (summer dikes) on the banks of the main channel. The former floodplains were up to 10 km wide (Van Urk and Smit, 1989; Middelkoop, 1997; Schoor *et al.*, 1999), width of the forelands is on average about 1 km (Buijse *et al.*, 2002). The summer dikes allow intensive agriculture in large parts of the forelands. At a discharge of >4300 $m^3 s^{-1}$, measured at the German-Dutch border, the forelands are inundated. This mainly occurs before or after the growing season (Van de Steeg and Blom, 1999).

The Dutch policy aim for river restoration is to reduce habitat fragmentation in the forelands since river valleys are considered to be important corridors for migration and dispersal of aquatic and terrestrial animal species, and for biodiversity conservation (Anonymous, 1998). As the consequence of this policy, structure and functioning of ecological networks need to be improved in order to create viable populations of target species (Foppen and Reijnen, 1999; Chardon *et al.*, 2000). For the aquatic component, activities focus on aquatic/terrestrial transition

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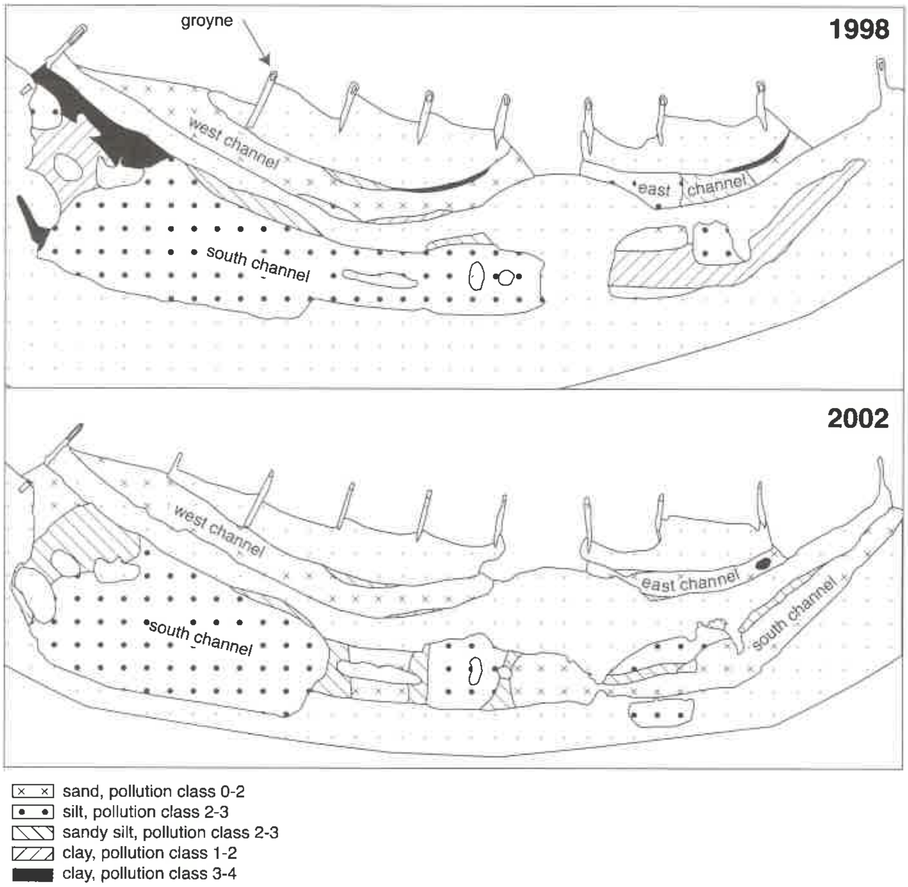

Figure 3. Changes in bottom substrate, including their pollution degree, in the secondary channels of the Gamerensche Waarden. Quality classes according to Van de Guchte *et al.* (2000)

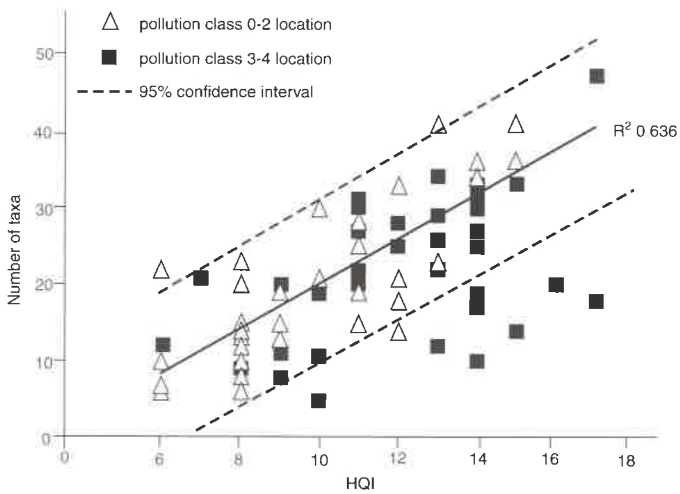

Figure 4. The relationship between a habitat quality index (HQI) of the secondary channel bottoms and species richness in those habitats

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Table VII. Significance levels (two-way ANOVA) for comparing means between bottom samples inside (n = 28) and under the lower limit (n = 9) of the 95% confidence intervals given in Figure 4

	F	Sig.
HQI	6.931	0.013
Number of taxa	10.840	0.002
Spring-samples	0.749	0.393
Autumn-samples	0.749	0.393
Year	2.817	0.102
Depth	0.251	0.620
Stream velocity	0.896	0.350
Grain size fraction <63 μm	0.488	0.490
Grain size fraction <2 μm	0.617	0.438
Organic matter	0.157	0.695
Cd	0.995	0.325
Hg	0.206	0.653
Cu	0.645	0.427
Ni	0.427	0.518
Pb	0.667	0.420
Zn	0.754	0.391
Cr	0.202	0.656
As	0.381	0.541
Sum heavy metals	0.515	0.478
Mineral oil	0.126	0.725
PCB 28	7.853	0.008
PCB 52	2.580	0.117
PCB 101	2.256	0.142
PCB 118	1.227	0.276
PCB 138	1.446	0.237
PCB 153	1.254	0.270
PCB 180	1.293	0.263
Sum PCB	2.089	0.157
β-HCH	0.001	0.978
Dieldrin	0.987	0.327
DDD	0.698	0.409
DDE	0.133	0.717
DDT	2.993	0.092
HCB	0.184	0.671
α-Endosulphan	3.311	0.077
Sum-PAH	1.232	0.275

zones by improvement of the lateral connectivity (Heiler *et al*., 1995; Van Dijk *et al*., 1995; Buijse *et al*., 2002). However, non-indigenous species strongly influence communities and hamper the creation of viable populations of target species (Van der Velde *et al*., 2002).

Effects of water quality changes in the River Rhine were clearly observed in the epilithic macroinvertebrate community. Increase of species richness and density was clearly demonstrated and attributed to water quality improvement (Van Urk, 1981; Bij de Vaate *et al*., 1992).

From recolonization patterns of autochthonous species in the Rhine delta, two phases in water quality recovery could be distinguished. Between 1975 and 1985 stress tolerant insects (in this initial period mainly chironomid and a few caddis fly species) and molluscs started to recolonize the river again. Density increase of these macroinvertebrates in the years after that period correlated well with a decrease of chemical pollutants in the river water (Van Urk, 1981; Van Urk and Bij de Vaate, 1990; Van Urk *et al*., 1993). Recolonization of the Lower Rhine by the burrowing mayfly *Ephoron virgo* in 1991 (Bij de Vaate *et al*., 1992) and its mass development in the following years marked the start of the second phase in water quality rehabilitation of the river. Concentrations of toxicants had strongly decreased in the past two decades, and oxygen concentration had reached a level that seemed no longer

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Table VIII. Rare or extinct macroinvertebrate species found in some temporary pools along the distributaries in the Rhine delta after floods in February to March 1995, autumn 1998 and spring 1999 (unpublished results), their occurrence in paleoecological studies (Klink, 1989) and their occurrence in the secondary channels in the Gamerensche Waarden. (+): only unidentified specimens of the genus found, probably the given species

Taxon	Habitat preference[a]	Palaeo[b]	Secondary channels Gamerensche Waarden[c]
Crustacea			
Niphargus aquilex	HR		
Ephemeroptera			
Baetis rhodani	LR	+	
Caenis horaria	L	+	+
Caenis macrura	L	+	+
Caenis robusta	L	+	+
Centroptilum luteolum	E		
Heptagenia flava	LR	+	
Heptagenia sulphurea	LR	+	
Potamanthus luteus	LR	+	
Plecoptera			
Nemoura cinerea	LR	+	
Odonata			
Calopteryx splendens	V		+
Gomphus vulgatissimus	PS		
Hemiptera			
Aphelocheirus aestivalis	LR	+	
Callicorixa praeusta	V		
Coleoptera			
Agabus nebulosus	V		
Esolus species	PS		
Graptodytes pictus	V		
Haliplus flavicollis	V		+
Platambus maculatus	V		
Oulimnius tuberculatus	E		(+)
Potamonectes canaliculatus	V		
Trichoptera			
Anabolia nervosa	V		
Halesus radiatus	V		(+)
Hydropsyche bulgaromanorum	LR		+
Limnephilus fuscicornis	V	+?	
Mystacides azurea	PS		(+)
Neureclipsis bimaculata	L	+	
Oecetis notata	LR	+	(+)
Plectrocnemia geniculata	LR?		
Polycentropus flavomaculatus	LR	+	
Psychomyia pusilla	LR	+	+
Triaenodes bicolour	V		
Chironomidae			
Apsectrotanypus trifascipennis	PS		+
Cricotopus vierriensis	V		(+)
Diplocladius cultriger	V		
Heterotrichocladius marcidus	E		+
Parametriocnemus stylatus	PS	+	
Paratendipes albimanus gr.	?	+	+
Polypedilum convictum	P		(+)
Potthastia gaedii	P	+	+
Thienemanniella clavicornis agg.	V		
Thienemanniella flaviforceps agg.	V		

(*Continues*)

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Table VIII. (Continued)

Taxon	Habitat preference[a]	Palaeo[b]	Secondary channels Gamerensche Waarden[c]
Simuliidae			
Boophthora erythrocephala	R		
Odagmia ornata	R		+
Simulium species	R		+
Wilhelmia species	R		

[a]Habitat preference: E = eurytope, L = lithon, LR = litho-rheon, P = pelon, PS = psammon, R = rheon, V = vegetation.
[b]Found in palaeoecological studies in the forelands of the Rhine distributaries (Klink, 1989).
[c]Found in the secondary channels in the Gamerensche Waarden, 2000–2002.

to be the limiting factor for the colonization of many macroinvertebrate species with a higher demand for oxygen. Another example is the dragonfly *Gomphus flavipes* that recolonized the Rhine delta from 1996 (Habraken and Crombaghs, 1997; Goudsmits, 1998).

Although potentially several other sensitive autochthonous macroinvertebrate species also could extend their territory in the Rhine distributaries due to water quality improvement, other factors like the absence of physical habitat and the increased water temperature most probably prevent successful colonization of these species. Effects of elevated water temperature on autochthonous species are different. In general, increase in water temperature has mostly a negative effect on Trichoptera and Ephemeroptera, and a positive effect on Amphipoda and Mollusca (e.g. Benda and Profitt, 1974; Sankurathri and Holmes, 1976). Klink (1989) stated that the temperature increase benefits chironomids like *Rheocricotopus chalybeatus*, *Nanocladius rectinervis* and species of the genus *Rheotanytarsus*, which are nowadays abundant in the Rhine delta. Absence of physical habitat was concluded from observations in temporary pools formed by erosion during floods in the periods February to March 1995, autumn 1998 and spring 1999 (unpublished results). About 20% of the taxa found in those pools was rare in or extinct from the Rhine delta (Table VIII). The relatively large number of rheophilic taxa between them is obvious. None of these species was able to build up self-sustainable populations in the main channel of the distributaries in the Rhine delta, as was concluded from results of the national monitoring program (unpublished results). However, some species were able to colonize the secondary channels directly, underlining severe habitat limitation in the main channel. Other notable species found in these secondary channels were the chironomids *Eukiefferiella brevicalcar* (rare), *Lipiniella moderata* (second observation in The Netherlands), *Micropsectra atrofasciata* (rare), *Neozavrelia fuldensis* (first observation in The Netherlands), *Paralauterborniella nigrohalteralis* (first observation in The Netherlands), *Stempellina bausi*, *S. brevis*, *S. minor* (all rare), *Thienemannimyia pseudocarnea* (second observation in The Netherlands) and *Tventia calvescens* (rare). Colonization of these species seems to be the result of sand sedimentation that leads to an increased particle size of the channel bottom top layer (Figure 3). According to Rae (2004), species richness of the chironomid community in sandy sediments appears to increase with the particle size, indicating that this factor strongly influences the microhabitat choices of individual lotic chironomid species.

The relationship between HQI and species richness also explains the species poverty in the groyne field bottom of the main channel and underlines the positive effects of habitat restoration on the macroinvertebrate fauna along degradated river channels.

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