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Ditches and canals in management of fens: opportunity or risk? A case study in the Drömling Natural Park, Germany

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Abstract

Up until the present, canals and ditches in Europe have been used to drain and thus devastate fens (lowland moors). However, in many cases, their function can be changed from drainage to irrigation and re-wetting of previously drained areas. These systems of canals and ditches are characteristic elements of the historically developed cultural landscape. Therefore, management and development plans should be oriented towards their continual maintenance. Despite the density of canals and ditches in many regions of Germany, especially of Eastern Germany, there are only a few studies to evaluate these systems of waterways, and an integrated approach towards their assessment has been totally absent. Existing approaches for typology and assessment of flowing waterbodies have been investigated in the Drömling Natural Park with regard to their applicability to such artificial canals and ditches. Special attention is given to the composition of macroinvertebrate fauna and the assessment of factors that determine it. Surprisingly, most water sectors have a high conservation value. High total numbers of species correlated well with the occurrence of endangered species.

Among the macroinvertebrates, limnophil and phytophil species were dominant, but rheophil fauna were also commonly present. This was caused by the intermediate status of canals and ditches, since they are neither completely flowing nor completely stagnant waterbodies. Habitat quality of these waters is determined by a small number of morphological parameters: bank steepness, depth of bottom, substrate diversity, hydraulic structures, and the structure of surroundings. In the framework of management and development measures, they should be maintained and improved for the future. To assess water quality, the Saprobic index and the Chemical index were appropriate, but for indication of trophic status, the Macrophyte-trophic index was adequate. Estimation of ecological integrity by a multimetric index using macroinvertebrates indicates that waterbodies are in a good status according to the demands of the European Water Framework Directive.

Introduction

Well-preserved fens are very important for water balance, microclimate stabilization, carbon storage and protection of endangered species (Succow and Jeschke 1990). Artificial drainage ditches can devastate fens. On the other hand, they are often a refuge for endangered and rare plant and animal species and their communities (Foster et al. 1990; Täuscher 1998; Painter 1999). Such manmade waterbodies can only be maintained with increasingly large management efforts (Langheinrich and Lüderitz 1998). But in most cases, conservation of traditional ditch and canal systems is an aim of nature protection in cultural landscapes, where a natural succession would lead to the disappearance of these structures over time. In the tradeoff between strict conservation (succession) and protection of cultural landscapes, guidelines for the development of surface waterbodies are necessary. A major prerequisite of such guidelines however, is a coherent ecological evaluation system for artificial ditches, canals, and streams.

Despite their number and density in many regions (especially in Eastern Germany), surprisingly little has be done in this field until recently (Painter 1999) – probably because these manmade waterbodies have an intermediate status between flowing and stagnant waterbodies, and as such, have not been well studied by limnologists. Indeed, they show the morphology of (disturbed) streams, but normally also have very low flow rates (Langheinrich and Lüderitz 1998). Additionally, since a potentially natural status (reference conditions – Leitbild) does not exist for these waterbodies, evaluation is difficult because the assessment methods must be adjusted for the manmade status of these waterbodies. The aim of this study was to present an integrated ecological evaluation of ditches and canals in the Drömling Natural Park, and thereby, make a contribution to the general evaluation methodology for such artificial waterbodies.

Such an evaluation should support the aims of management and development plans for fens, for instance for the Drömling Natural Park (Reichhoff 1996). In this framework, the high ecological value of the canals and ditches shall be maintained and developed. With this study, we extend our earlier results concerning water quality (Langheinrich and Lüderitz 1997), stream morphology (Langheinrich and Lüderitz 1998), and regeneration of fens (Langheinrich et al. 1998).

Using saprobic load (DIN 38410) and stream morphology, we found very small differences between canals. The saprobic index was – with one notable exception – between 2.1 and 2.3 (Langheinrich and Lüderitz 1997), and the whole stream morphology was evaluated as 'markedly disturbed' (grade 5) or at least as 'clearly disturbed' (grade 4). The waterbodies are straightened and lined, they have deep bottoms, a poor bottom structure, and steep banks (Langheinrich and Lüderitz 1998).

Surprisingly, random collections of macroinvertebrates showed important differences between the various sectors. To quantify these differences and to determine the underlying reasons for them, further investigations of macroinvertebrate communities were done in 1996, 1998, and 2000. They were complemented by macrophyte mapping in 1998 and 2000. Based on these data, the following questions could be answered:

- Which abiotic and biotic parameters cause differences in macroinvertebrate settlement?
- Which parameters should be included in an integrated evaluation procedure?
- What measures are necessary for sustainable management of canals and ditches?

In this study, the following parameters and indices were estimated or calculated:

- Total taxa richness of macroinvertebrates and macrophytes,
- Diversity index for macroinvertebrates,
- Steadiness, habitat preferences, stream preferences, and functional feeding groups of macroinvertebrates,
- Trophic index of macrophytes,
- Conservation value and
- Multimetric index as measure of ecological health and integrity.

Through analysis of this information, we present a framework for integrated ecological assessment of the watercourse system in the Drömling, as a general model for such waterbodies, and suggestions for their further sustainable management.

Study area

The Drömling in the north-west part of Saxony-Anhalt is a discrete natural unit. According to the Ramsar Classification System for Wetland Type the Drömling is a former peatswamp forest which was changed to a mainly non-forested peatland. Through the Eastern German National Park Programme in 1990, 26 000 ha of this fen were protected as a natural park. However, during previous centuries, drainage and intensive arable agriculture greatly altered the fen, so that actually only 7000 ha of peat soil exist. The management and development plan for the Drömling (Reichhoff 1996) commits itself to the following protection and management aims:

- The preservation of remaining areas of fen and (if possible) the stimulation of peat growth.
- Improvement of the water balance, by enhancement of the groundwater levels in most of the nature reserves in order to restore the nutrient sink function of the fen.
- Development of wet woodlands and meadows to create biotopes for endangered species.
- Maintenance and ecological improvement of waterbodies.

The widespread watercourse system (650 km canals and drainage ditches) shall be converted to allow the use of the system for irrigation and biotope re-connection. The water-holding function will be enhanced by carefully implemented hydraulic engineering. Simultaneously, the permeability of the watercourses for aquatic organisms is to be restored (Langheinrich and Lüderitz 1998).

Materials and methods

Macroinvertebrate sampling

In May and September 1996 and 1998, and also in April 2000, macroinvertebrate organisms were collected from 14 representative 100 m-sectors of 11 streams or canals (Figure 1). Hand nets (mesh size 0.4 mm) were used for collecting. All habitat elements and substrates were sampled over a period of 4 h in each sector. The abundances of species were estimated based on a seven degree scale analogous to DIN 38410. Thereby a degree of 1 mean a number of individuals (n) less than/equal 7 (2: $7 < n \leq 35$; 3: $35 < n \leq 150$; 4: $150 < n \leq 300$; 5: $300 < n \leq 1000$; 6: $1000 < n \leq 3000$; 7: $3000 < n$).

If possible, organisms were identified alive. If this was not possible, specimens were preserved (70% alcohol), transported to the laboratory and identified to species or genus level (Bellmann 1993; Waringer and Graf 1997; Studemann et al. 1992; Schönemund 1930; Schmedtje and Kohmann 1992; Freude et al. 1971, 1979).

Identification of dragonfly larvae was improved by catching and identifying adult insects.

Functional feeding groups were estimated using data from Vannote et al. (1980), Moog (1995) and Schmedtje (1996). Stream preferences were found in Schmedtje (1996). Saprobic index (SI) as a standard method of water quality assessment in Germany (DIN 38410) is a measure of saprobic load. Classification of saprobic load was done according to the actualized version by Sommerhäuser and Schuhmacher (2003). This version considers that an organically formed lowland stream will be reappraised as unloaded in a saprobic range from 1.75 to 1.89.

Chemical index (CHI) according to Bach (1984) is calculated including ammonium, nitrate and phosphate concentration, oxygen saturation, BOD_5, pH-value, temperature, and conductivity of water. CHI permits estimation of a chemical water quality class by invoicing mentioned physicochemical and chemical parameters.

For calculation of a diversity index, the formula of Shannon and Wiener (1949) was modified:

$$H_s = -\sum p_i \cdot \ln p_i \quad \text{with } p_i = \frac{q_i}{Q} \quad \text{and} \quad q_i = A_i^4$$

where
H_s: diversity index at species number s,
p_i: probability of the occurence of species i,
q_i: quantity of species i,
A_i: abundance number of species i and
Q: sum of quantities of all species

In the original formula of Shannon and Wiener, instead of quantities, the number of individuals is used. Because it is impossible to count the actual number of individuals of a predominant species in a 100 m-sector, we followed a suggestion of the LfU (1992) that the cubed seven-degree scale gives a good estimation of the number of individuals (however, for a shorter collecting time of 15 min). For our collecting time of four hours, we estimated by counting the individuals of selected species the power of four (i.e., A_i^4) was a good scale for the representing abundances.

Macrophyte mapping

In May 1998 and July 2000, macrophytes were mapped in the same sections. Species were identified according to Rothmaler (1981) and the quantity of species was estimated based on a five-degree-scale (1 = very rare; 2 = infrequent;

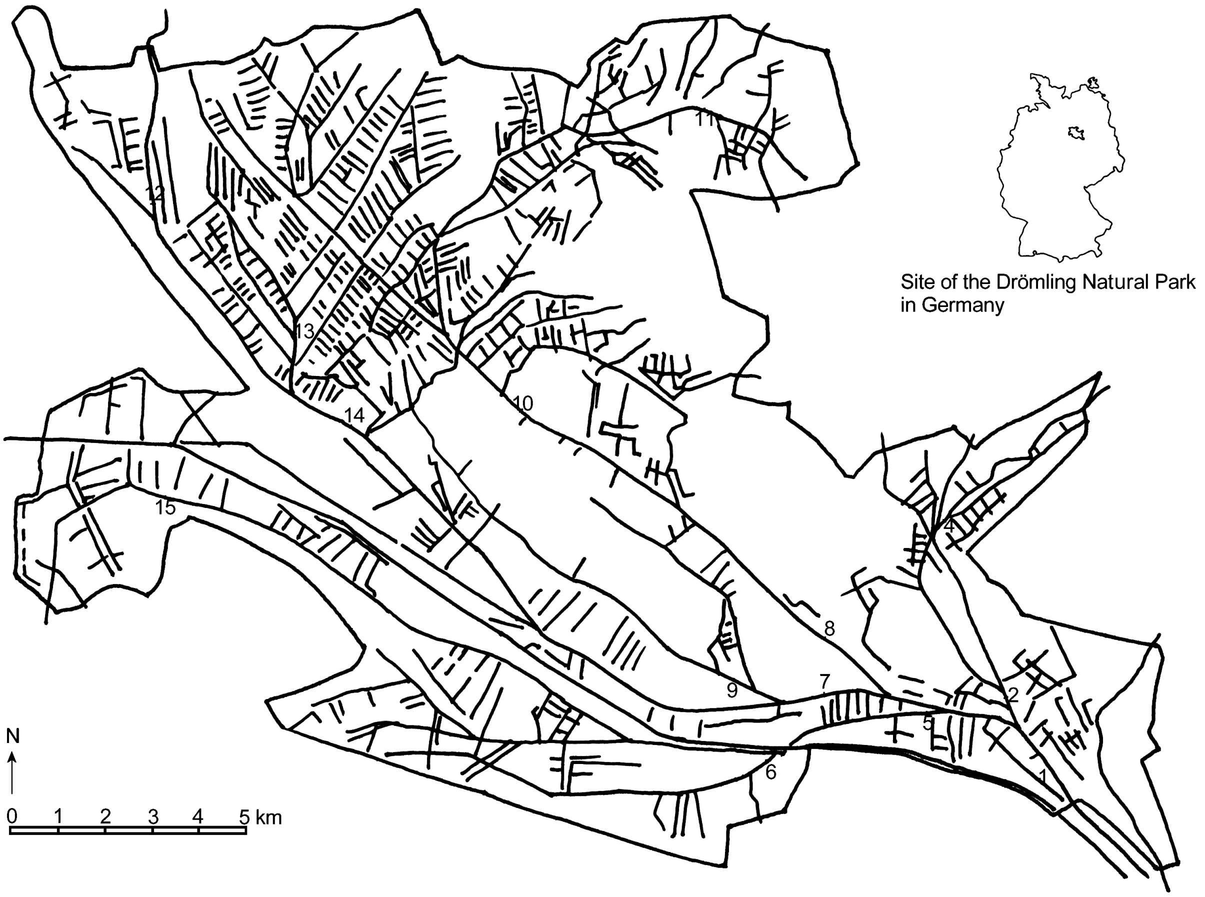

Figure 1. Evaluated water sectors in canals and ditches of the Drömling Natural Park.

3 = common; 4 = frequent; 5 = abundant, predominant) (Melzer 1993).

Plant communities and the degree of their endangerment were estimated according to Schubert et al. (1995).

Trophic index of macrophytes

Tropic index of macrophytes (TIM) was calculated with reference to Schneider (2000) who developed it to measure the trophic state of flowing waterbodies by means of aquatic and amphibic macrophytes.

$$\mathrm{TIM} = \frac{\sum_{a=1}^{n} IW_a \cdot G_a \cdot Q_a}{\sum_{a=1}^{n} G_a \cdot Q_a}$$

where
TIM: Trophic index of macrophytes,
$\mathrm{IW_a}$: indicator value of species *a*,
G_a: indicator weight of species *a* and
Q_a: quantity of species *a*.

Similarly to the macroinvertebrates, Melzer (1988) found that the cubed five-degree-scale gives a good estimation of the quantity of aquatic macrophytes.

Mapping of stream morphology

Stream morphology was mapped in 1995 and 1996 (Langheinrich and Lüderitz 1998) by assessing the following main parameters: stream course development, lengthwise profile, crosswise profile, bottom structure, bank structure, surroundings. The morphological grade as the degree of deviation from potentially natural status was calculated based on a seven-degree-scale (1 – not disturbed; 2 – slightly disturbed; 3 – moderately disturbed; 4 – clearly disturbed; 5 – markedly disturbed; 6 – strongly disturbed; 7 – excessively disturbed). Morphological grades of 4 and 7, for instance, represent a different degree of disturbance. Grade 4 means a more or lesser big disturbance of some parameters meanwhile grade 7 means the total channelization.

Assessment of conservation value (conservation index)

Conservation index (CI) was estimated according to Kaule (1991) and Geyer and Mühlhofer (1997). This index reflects the occurence of more or lesser endangered target species in the concerning landscape. In this system, areas or water sectors are classified according to the nine degrees of the CI:
Degree 9: Nationally important.
Degree 8: Supraregionally important.
Degree 7: Regionally important.
Degree 6: Locally important and relevant for species conservation.
Degree 5: Poor in different species but still relevant for species conservation.
Degrees 4–1: Without endangered species.
The index value of a habitat depends on the number of endangered species occuring there, and on the degree of their endangerment.

Multimetric index (MMI) is a holistic measure of ecological health and integrity. It considers organic and structural degradation as the two main impact factors currently affecting stream biota (Pauls et al. 2002). It was calculated by computer aided AQEM (The development and testing of an integrated **A**ssessment system for the ecological **Q**uality of streams and rivers throughout **E**urope using benthic **M**acroinvertebrates) – procedure and discerns five classes of ecological quality (5 – very good status, 4 – good status, 3 – moderate status, 2 – unsatisfactory status, 1 – bad status). Its calculation is based on weighted calculations from different metrics like percentage of caddisflies, of rheophile organisms, saprobic index, and functional feeding groups. A metric is a measurable component of a biological system with an empirical change in value along a gradient of human disturbance (Pauls et al. 2002).

Results

Stream morphology

Mapping and evaluating stream morphology according to the guidelines for streams and brooks (Lüderitz et al. 1996), yielded grades of 4 (clearly disturbed) or 5 (markedly disturbed) in all sectors (Table 1). Small differences between sectors (Langheinrich and Lüderitz 1998) probably reflect composition of bottom substrate, steepness of banks and structure of surroundings.

Water quality

Estimation of the SI has only a limited value for water quality assessment in stagnant or very slowly flowing waterbodies because it was developed for streams. Nevertheless, we found most sectors only moderately loaded by organic substances (Table 1). Evaluation by means of the CHI (Bach 1984) indicates only a low or moderate load in most water sectors. Calculation of TIM shows that some waterbodies are mesotrophic to eutrophic and most are in a eutrophic status. This corresponds to a concentration of total phosphorus that is between 0.03 mg l^{-1} and 0.2 mg l^{-1} (Langheinrich and Lüderitz 1997).

The Allerkanal (sites 5 and 15) showed worse water quality because of its load of insufficiently treated domestic wastewater.

Ecological structure of macroinvertebrate communities

Altogether, 227 macroinvertebrate species (or taxa) were found in the sampled sectors (Table 2). Calculation of the Diversity index led to high values in most sectors (Table 1). Not only species number was high in most sectors, but also the abundances of the species were relatively balanced.

The most dominant orders among insects were Trichoptera, Odonata, Coleoptera, and Heteroptera.

Despite the similar morphological status, species with different habitat preferences were found. Not surprisingly, organisms that prefer the phytal habitat were dominant among Trichoptera, Odonata, and Coleoptera. The quantitative and qualitative development of aquatic plant communities seems to be the main biotope-building factor for

Table 1. Parameters for ecological assessment of waterbodies in the Drömling.

Waterbody	Sector number	Species number (macroinvertebrates)	Diversity index	Saprobic index	Chemical index	Morphological grade	Conservation index	Trophic index of macrophytes	Species number (macrophytes)	Multimetric index
Drastingraben	1	61	3.61	II	2	5	8	2.75	12	4
Sichauer Beeke	2	78	3.92	II	2	4	9	2.93	14	4
Solpker Wiesengraben	4	61	3.50	II	2	4	9	2.90	11	4
Allerkanal	15	39	3.17	II–III	3	5	4		9	3
Allerkanal	5	53	3.48	II	2	4	6	2.77	6	4
Landgraben	6	71	3.75	II–III	2	4	8	2.59	20	3
Ohre	12	77	3.76	II	1–2	4	9	2.69	21	4
Ohre	14	69	3.86	II	1–2	4	8	2.79	20	4
Ohre	7	72	3.80	II	2	4	8	2.91	15	4
Friedrichskanal	10	93	3.84	II	1–2	4	9	2.65	23	4
Friedrichskanal	8	85	3.97	II	1–2	5	9	2.54	19	4
Wilhelmskanal	9	78	3.91	II	2	4	9	2.57	20	4
Flötgraben	11	69	3.68	II	1	5	8	2.54	15	4
Steimker Graben	13	64	3.75	II	2	4	9	2.71	14	4

Table 2. Macroinvertebrate species in canals and ditches of the Drömling.

Coleoptera		
Dytiscidae	*Hyphydrus ovatus*	**Haliplidae**
Acilius sulcatus	*Ilybius fuliginosus*	*Haliplus fluviatilis*
Agabus biguttatus	*Laccophilus hyalinus*	*Haliplus immaculatus*
Agabus bipustulatus	*Laccophilus minutus*	*Haliplus laminatus*
Agabus didymus	*Laccophilus poecilus*	*Haliplus ruficolis*
Agabus guttatus	*Platambus maculatus*	*Peltodytes caesus*
Colymbetes fuscus	*Porhydrus lineatus*	**Gyrinidae**
Dytiscus latissimus	*Potamonectes depressus*	*Aulonogyrus concinnus*
Dytiscus marginalis	*Potamonectes* sp.	*Gyrinus substriatus*
Graphoderus cinereus	*Rhantus suturalis*	*Orectochillus villosus*
Graptodytes pictus	*Stictotarsus duodecimpustulatus*	**Helophoridae**
Hydaticus seminiger	**Hydrophilidae**	*Helodes* sp.
Hydaticus sp.	*Anacaena limbata*	*Helophorus flavipes*
Hydaticus transversalis	*Helochares obscurus*	**Hydraenidae**
Hydroporus palustris	*Hydrobius fuscipes*	*Hydreana gracilis*
Hygrotus impressopunctatus	*Hydrochara caraboides*	**Hydrochidae**
		Hydrochus elongatus
Odonata		
Aeshnidae	*Coenagrion puella/pulchellum*	*Lestes sponsa*
Aeshna cyanea	*Coenagrion* sp.	**Libellulidae**
Aeshna viridis	*Erythromma najas*	*Libellula depressa*
Aeshna mixta	*Ischnura elegans*	*Libellula quadrimaculata*
Anax imperator	*Ischnura pumillio*	*Orthetrum cancellatum*
Calopterygidae	*Pyrrhosoma nymphula*	*Sympetrum danae*
Calopteryx splendens	**Corduliidae**	*Sympetrum flaveolum*
Calopteryx virgo	*Somatochlora metallica*	*Sympetrum* sp.
Coenagrionidae	**Cordulegastridae**	*Sympetrum vulgatum*
Ceriagrion tenellum	*Cordulegaster boltoni*	**Platycnemididae**
Coenagrion mercuriale	**Lestidae**	*Platycnemis pennipes*
Coenagrion ornatum	*Chalcolestes virides*	
Trichoptera		
Beraeidae	*Triaenodes bicolor*	*Limnephilus rhombicus*
Beraea pullata	*Triaenodes* sp.	*Limnephilus* sp.
Beraeodes minuta	**Limnephilidae**	*Limnephilus stigma*
Goeridae	*Anabolia furcata*	*Nemotaulius punctatolineatus*
Goera pilosa	*Anabolia nervosa*	*Phacopteryx brevipennis*
Hydropsychidae	*Glyphotaelius pellucidus*	*Potamophylax rotundipennis*
Hydropsyche angustipennis	*Grammotaulius nitidus*	**Molannidae**
Hydropsyche pellucidula	*Halesus* sp.	*Molanna angustata*
		Phryganeidae
		Agrypnia picta
		Phryganea bipunctata
		Phryganea grandis
Hydropsyche siltalai	*Limnephilus flavicornis*	**Sericostomatidae**
Leptoceridae	*Limnephilus fuscicornis*	*Sericostoma personatum*
Athripsodes sp.	*Limnephilus hirsutus*	*Sericostoma* sp.
Mystacides longicornis	*Limnephilus nigriceps*	
Ephemeroptera		
Baetidae	*Procleon bifidum*	**Ephemeridae**
Baetis rhodani	**Caenidae**	*Ephemera danica*
Baetis sp.	*Caenis horaria*	*Ephemera vulgata*
Baetis vernus	*Caenis macrura*	**Heptageniidae**
Centroptilum luteolum	*Caenis* sp.	*Heptagenia flava*
Cloeon dipterum	**Ephemerellidae**	*Leptophlebiidae*
Cloeon simile	*Ephemerella* sp.	*Leptophlebia vespertina*
Cloeon sp.	*Serratella ignita*	

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Table 2. Continued

Plecoptera	**Megaloptera**	
Nemouridae	**Sialidae**	
Nemoura cinerea	*Sialis lutaria*	
Crustacea		
Asellidae	**Cambaridae**	**Gammaridae**
Asellus aquaticus	*Orconectes limosus*	*Gammarus pulex*
Diptera		
Ceratopogonidae	**Culicidae**	**Simulidae**
Bezzia sp.	*Aedes* sp.	*Simulium* sp.
Charoboridae	*Anopheles maculipennis*	*Stratiomyiidae*
Chaoborus sp.	*Anopheles* sp.	*Stratiomys* sp.
Chironomidae	*Culex* sp.	**Tabanidae**
Chironomus plumosus Gr.	**Dixidae**	*Tabanus* sp.
Chironomus sp.	*Dixa* sp.	**Tipulidae**
Chironomus thumii Gr.	**Ptychopteridae**	*Tipula* sp.
	Ptychoptera sp.	
Heteroptera		
Corixidae	**Hydrometridae**	**Nepidae**
Corixa punctata	*Hydrometra stagnorum*	*Nepa cinerea*
Sigara striata	**Mesoveliidae**	*Ranatra linearis*
Gerridae	*Velia caprai*	**Notonectidae**
Gerris lacustris	**Naucoridae**	*Notonecta glauca*
Gerris sp.	*Ilyocoris cimicoides*	**Pleidae**
		Plea minutissima
Hirudinea		
Erpobdellidae	**Glossiphoniidae**	*Helobdella stagnalis*
Erpobdella octoculata	*Alboglossiphonia complanata*	*Hemiclepsis marginata*
Erpobdella testacea	*Batracobdella* sp.	*Theromyzon tessulatum*
	Glossiphonia complanata	**Piscicolidae**
	Haementaria costata	*Piscicola geometra*
Gastropoda		
Ancylidae	*Radix auricularia*	*Gyraulus laevis*
Ancylus fluviatilis	*Radix ovata*	*Planorbarius corneus*
Bithyniidae	*Radix peregra*	*Planorbis carinatus*
Bithynia leachi	*Stagnicola corvus*	*Planorbis planorbis*
Bithynia tentaculata	*Stagnicola turricula*	**Valvatidae**
Hydrobiidae	**Physidae**	*Valvata cristata*
Potamopyrgus antipodarum	*Physa fontinalis*	*Valvata piscinalis*
Lymnaeidae	**Planorbidae**	*Valvata studeri*
Galba truncatula	*Anisus vortex*	**Viviparidae**
Lymnaea stagnalis	*Gyraulus albus*	*Viviparus contectus*
	Gyraulus crista	*Viviparus viviparus*
Bivalvia		
Sphaeriidae	*Pisidium pulchellum*	**Unionidae**
Musculium lacustre	*Pisidium* sp.	*Anodonta cygnea*
Pisidium nitidum	*Pisidium subtruncatum*	*Unio pictorum*
Pisidium personatum	*Sphaerium corneum*	*Unio* sp.
Pisidium pseudosphaerium	*Sphaerium* sp.	
Oligochaeta		
Enchytraeidae	**Tubificidae**	
Lumbriculus variegatus	*Tubifex* sp.	
Turbellaria		
Dendrocoelidae	**Dugesiidae**	**Planariidae**
Dendrocoelum lacteum	*Dugesia lugubris*	*Planaria torva*
		Polycelis sp.

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Table 2. Continued

"Other"		
Argyronetidae	**Pyralidae**	**Unionicolidae**
Argyroneta aquatica	*Nymphula nymphaeata*	*Unionicola* sp.
Hydrodromidae		
Hydrodroma sp.		

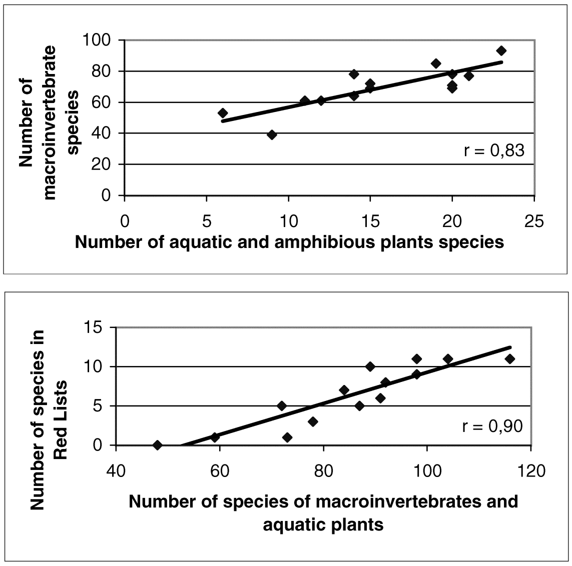

Figure 2. Correlation between different environmental quality parameters of waterbodies in the Drömling (error probability 1%).

macroinvertebrates. There was a relatively good correlation ($r = 0.83$) between the numbers of species of macroinvertebrates and aquatic plants (Figure 2). Observation of the functional feeding groups (Figure 3) confirms this: Shredders and collectors were the most common groups among Trichoptera (beside predators). Also the high abundances of *Gammarus* spp. (Table 2) that use particulate plant material should be noted. On the other hand, grazers and filterers were not as rare as might be expected, with deficient bottom structure and low flow velocities. Plant stalks and leaves serve as a good habitat for these types of organisms; they also diversify flow velocities in the cross-section of the canal. This and the influence of culverts, as well as the influence of groundwater may explain the variety of feeding strategies, and although limnophil and limnophil/rheophil species were dominant in all taxonomic orders, rheophil and rheobiont organisms were present with a percentage between 10% and 15%.

Conservation value

Not less than seven of the fourteen investigated sectors were evaluated with a conservation index of 9 (nationally important); and additionally, four had an index of 8 (supraregionally important). An index of 9 means that three or more species are present which are evaluated as 'endangered by extinction' in the Red Lists (RL 1). Altogether, 21 macroinvertebrate species and 19 plant species that are included in the Red Lists, were found in the canals and ditches of this study (Table 3). Some of these species shall be characterized in more detail with reference to their ecological needs and habitat conditions.

Odonata

Altogether, 43 dragonfly species occur in Drömling Natural Park (Suhling 2000). We found 25 of them at our sampling sites. Some remarkable species shall be characterized more thoroughly below:

Coenagrion mercuriale settles especially in groundwater-influenced, rather fast flowing brooks and ditches with well-developed emerged and submerged vegetation. This species was found in sectors 8 and 12 that are ecomorphologically very different. The Friedrichskanal (sector 8) is a slowly flowing canal but it is probably influenced by groundwater, while the Ohre (sector 12) is the only relatively fast ($\sim$0.3 m s^{-1}) flowing waterbody of this study. In sector 8, we found species-rich, dense vegetation that can serve as a habitat for *C. mercuriale* (Buchwald et al. 1984). Bellmann (1993) emphazises that this species prefers brooks with high density of *Berula erecta* as in sector 12.

With the occurance of *C. mercuriale* as a guideline-species according to the European Fauna-Flora-Habitat (FFH)-guideline, the corresponding waterbodies can be evaluated as FFH-biotopes.

Calopteryx virgo prefers fast flowing brooks and needs high water quality (Schmedtje and Kohmann 1992). In our case, this species occurs at sector 12 in

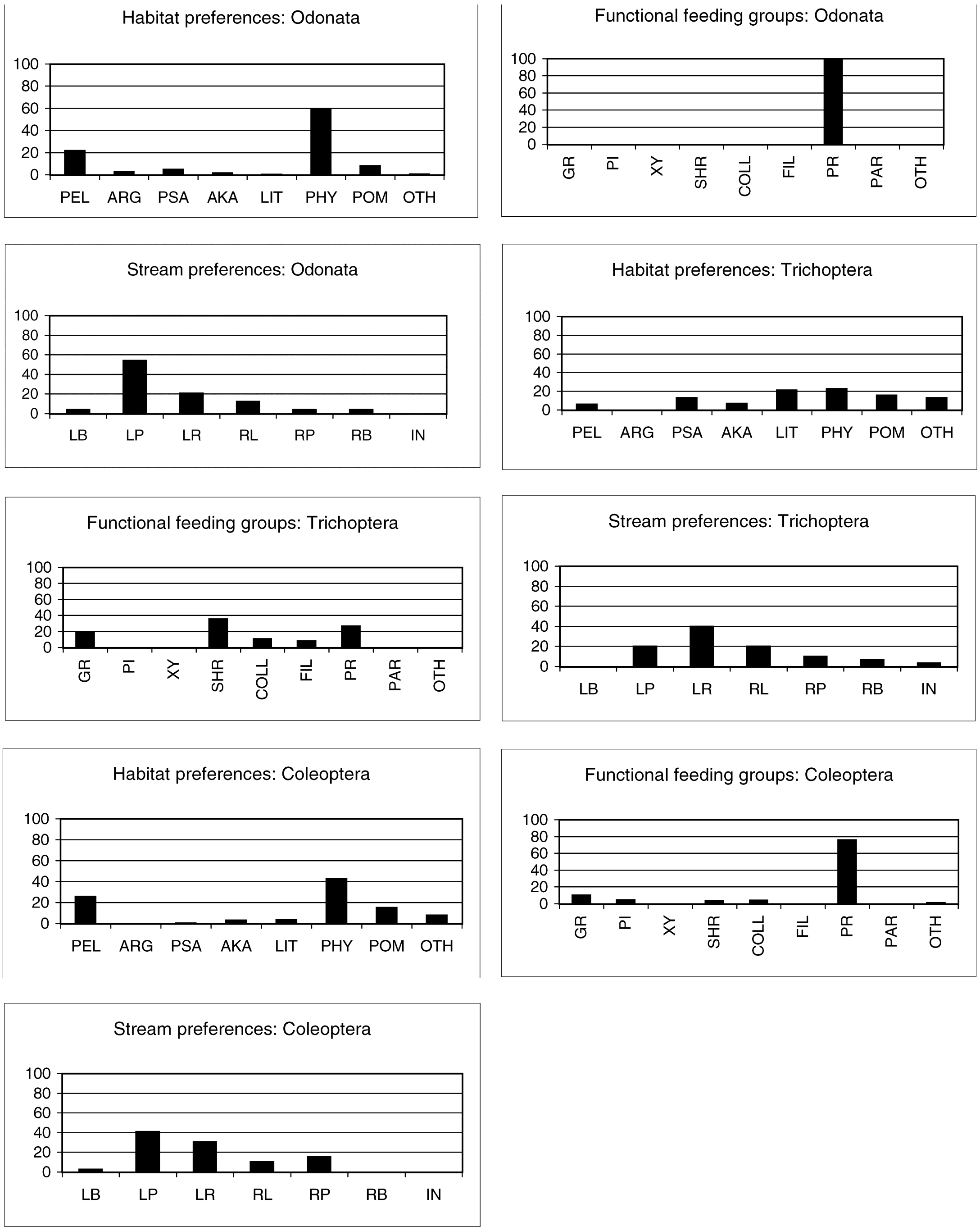

Figure 3. Distribution of species in ecological categories, expressed as % of total number of species per group. Habitat preferences: PEL, pelal (e.g., mud); ARG, argillal (e.g., loam); PSA, psammal (e.g., sand); AKA, akal (e.g., gravel); LIT, lithal (e.g., stones); PHY, phytal (e.g., plants); POM, particles of organic material (e.g., branches); OTH, other. Functional feeding groups: GR, grazers; PI, piercers; XY, xylophagous; SHR, shredders; COL, gathering collectors; FIL, filtering collectors; PR, predators; PAR, parasites; OTH, other. Stream preferences: LB, limnobiont; LP, limnophil; LR, limnophil/rheophil; RL, rheophil/limnophil; RP, rheophil; RB, rheobiont; IN, indifferent.

low abundances together with the much more frequent *C. splendens*.

Ceriagrion tenellum is generally rare in Central Europe. It is often characterized as a typical fen dragonfly, but it can also occur in other types of waterbodies (Bellmann 1993). This species is endangered by drainage and intensive agriculture. Surprisingly, larvae and adults were found at the Friedrichskanal (sector 8) in co-occurence with *C. mercuriale*. The intermediate status of the canals between flowing and stagnant waterbodies could be responsible for this result.

Cordulegaster boltoni is often characterized as a typical mountain species (Bellmann 1993), but it is also common in flat or hilly landscapes formed by the ice age (Donath 1989). We found larvae in the Wilhelmskanal (sector 9) that contains clear, cool, and macrophyte-rich water but has only very low flow velocities. Although this is the first time that this species has been found in recent decades in the Drömling, it is not surprising because *C. boltoni* is not rare in comparable waterbodies in the landscape units of northern Saxony-Anhalt (unpublished results).

Trichoptera

Phacopteryx brevipennis is characteristic of slowly flowing rivers and brooks and, generally, of waterbodies in fens (Tobias and Tobias 1981; Pitsch and Weinzierl 1992). Therefore, this species seems to be a native element of the Drömling fauna.

Beraeodes minutus prefers similar habitats, especially macrophyte-rich brooks and ditches (Schmedtje 1996).

Both species are evaluated in Saxony-Anhalt as 'endangered by extinction' (RL1) but they are relatively common in the Drömling. Of course, knowledge about caddisflies in Saxony-Anhalt is still too limited to make a final decision about Red list classification. Fortunately, many species seem to be more frequent than initially mentioned in the Red Lists.

Coleoptera

Generally, *Dytiscus latissimus* is very rare. This species normally lives in larger lakes and ponds (Brandtstetter and Kapp 1995) but individuals occasionally were found in our samples of canals of the Drömling.

Laccophilus poecilus is a characteristic species of waterbodies in fens (Brandtstetter and Kapp 1995). Knowledge about its occurence in Saxony-Anhalt remains fragmentary.

MMI

Integrating all metrics concerning macroinvertebrates, MMI shows a good status (quality class 4) according to the demands of European Water Framework Directive (EU–WFD) in 12 of 14 reaches. Two have a moderate status (quality class 3). Good status in this context means that macroinvertebrate assemblages are similar to reference conditions – in this case for organically formed lowland streams.

Discussion and conclusions

Wegener (1998) offered suggestions for protection and management of cultural landscapes, but did not mention drainage ditches and canals. In reality, until recently these constructed waterbodies have been the means by which many fens have been damaged or destroyed. But the harmful role of ditches and canals can be changed within the framework of intelligent management and development planning. These waterbodies can promote the implementation of Ramsar Convention by irrigation of growing mires and by serving as habitats for aquatic target species.

For the Drömling, we were able to show that the function of such canals can be changed from drainage to irrigation by limited hydraulic engineering (Langheinrich and Lüderitz 1998; Langheinrich et al. 1998). Re-wetting is necessary in the central part of the Drömling that is protected as Total reserve (zone I) or Nature reserve (zone II) for restoration of peat growth. However, fen redevelopment could also be attained by stopping all management of canals and ditches, but the result would be the uncontrolled return to a more or less original status. That is not the aim of the management and development plan, which favours a rich mosaic of different biotopes and allows an extensive land use (Langheinrich et al. 1998). The maintaineance and restoration of such a functionable cultural landscape is in the interest of both

Table 3. Endangered species and plants communities in canals and ditches in the Drömling (sectors 1 to 15 like used in Table 1).

Species	Water sector	Red lists	
		Saxony-Anhalt	Germany
Coleoptera			
Agabus biguttatus	8	3	
Dytiscus latissimus	10	1	
Laccophilus poecilus	9	1	
Odonata			
Calopteryx virgo	12	1	3
Ceriagrion tenellum	8	1	1
Coenagrion mercuriale	8, 12	1	1
Cordulegaster boltoni	9	1	3
Trichoptera			
Phacopteryx brevipennis	4, 7, 12	1	3
Beraeodes minutus	1, 2, 9, 10, 12	1	
Beraea pullata	11	3	
Oligotricha striata	11	3	
Ephemeroptera			
Heptagenia flava	12	3	
Gastropoda			
Ancylus fluviatilis	12		2
Bithynia leachi	8	3	2
Gyraulus leavis	2, 4	1	1
Planorbis carinatus	2, 5, 9, 14	3	3
Valvata studeri	2, 13	1	1
Viviparus contectus	7, 9, 11, 13, 14	3	3
Viviparus viviparus	4, 7, 8, 9, 10, 11, 14	2	2
Bivalvia			
Anodonta cygnea	2, 13, 14	3	2
Pisidium pulchellum	10	1	1
Unio pictorum	14	3	3
Plants and plants communities			
Callitriche palustris	12	3	
Callitriche hamulata	12	3	
Potamogeton praelongus	6	0	2
Potamogeton pectinatus	6, 11	2	
Potamogeton lucens	6	3	
Potamogeton obtusifolius	6	3	
Potamogeton pusillus	12	3	
Ranunculo – Hottonietum palustris	9		1
Hottonia palustris	6, 10, 14	3	
Hydrocharis – morsus – ranae	2, 4, 7, 8, 9, 10, 14	2	3
Hydrocotyle vulgaris	8, 11	3	
Ranunculus lingua	8	2	3
Ranunculus fluitans	11, 12	2	
Ranunculus aquatilis	10	3	
Myriophyllum spicatum	8, 9, 10	3	
Myriophyllum verticillatum	6, 9, 10	3	
Sagittaria sagittifolia	2, 8, 9, 10, 14	3	
Sparganium angustifolium	14	2	2
Sparganium emersum	2, 4, 7, 8, 10, 14	3	

Quantification of endangerement: 0 – extinguished or disappeared; 1 – threatened with extinction; 2 – heavily endangered; 3 – endangered.

species protection and environmentally compatible tourism.

In recent years, the conceptual barriers between waterbody 'management' and waterbody 'conservation' have begun to erode. As the environmental consciousness of water managers and conservationists broaden, there is a need for integrated methods of conservation assessment which can be of value for both groups (Boon 2000). In this sense, our results show that the widespread system of canals and ditches is very useful in establishing a coherent ecological network. The watercourse system is not only a characteristic and valuable element of the landscape, it also serves as an important biotope for many (endangered) species (Table 3). The surprisingly varied community with different habitat preferences (Figure 3) – for instance *C. mercuriale* and *C. tenellum* at the same site – can be explained by the intermediate character of the watercourses between flowing and stagnant waterbodies. However, this is also proof of the adaptability of most species. Narrowly adapted organisms can use special sectors of canals and ditches even if these are not their ideal biotopes. But these ideal biotopes exist only in small number in the intensively used landscape: stream morphology in about 88% of flowing waterbodies in Saxony-Anhalt is at least moderately disturbed (grade 3; LAU 1998), and about 60% of streams are still critically loaded with organic substances (grade II–III; MRLU 1997). Small ponds in the agricultural landscape are normally eutrophic or polytrophic and fail as habitats for demanding organisms. It is not expected that these circumstances will change during the next years. Under these conditions, canal-rich landscapes like the Drömling and the Elbe-Havel-area in Saxony-Anhalt, which are often protected by state acts or by the Fauna-Flora-Habitat-Directive of the European Union, play an important role as refuges for organisms with different ecological demands.

During the last decade, a clear enhancement of water quality in the Drömling was attained by decrease of cattle density, by the end of arable agriculture in many areas, and by improved sewage treatment (Langheinrich and Lüderitz 1997). The improvement of water quality and the immediate environment of the waterbody could be responsible for the increased presence of environmentally sensitive organisms in our study, compared with the findings of Müller and Walter (1993). An explanation is given by Janse and van Puijenbroek (1998): Eutrophication of drainage ditches by over-fertilization with nitrogen and phosphorus causes a shift from mainly submerged aquatic vegetation to a dominance of duckweed. This leads to anoxic conditions, poorly diversified assemblages which are always dominated by the same small set of species (Marmonier et al. 2000), and hindrance of the drainage function of the ditches.

Some difficulties in evaluation of artificial waterbodies will always remain because of their intermediate character and the fact that their unnatural origin does not allow a complete renaturalization. But there should be no doubt that an assessment and the definition of the "maximum ecological potential" according to the European Water Framework Directive must start from the point of view of biotope and species protection, and must focus on all valuable components of biodiversity (species diversity, community diversity, landscape diversity).

Our investigations stress the strengths and weaknesses of used indices: Calculation of Conservation index according to Kaule (1991) found the interesting (and quantitatively unexpected) result, that most of the investigated sectors are nationally or regionally important (Table 1). For this reason, removal or disappearance of the Drömling waterbodies by natural succession, would be inadvisable. We were able to show that there is a good correlation between total macroinvertebrate species number and the number of endangered species (Figure 2). So we agree that taxa richness of macroinvertebrates can serve as a metric because it shows a clear response to increase human disturbance (Karr and Chu 2000). This result corresponds with other literature indicating that species-rich waterbodies are in most cases also especially valuable for protection of rare species (Angermeier and Winston 1997; Lüderitz and Hentschel 1999). The use of endangered target species for indication of ecological status of canals and ditches performs also a contribution for a rapid and simple evaluation of complex interactions with view to the ecological value of these waterbodies.

On the other hand, the Diversity index (Shannon and Wiener 1949) does not seem to add any additional relevant information for waterbody evaluation. This assessment agrees with Braukmann (1987) who found the concept of diversity indices of little use for evaluation of waterbody quality. One reason is that dominant species are more considered than rare species which have a lower influence on the result, even though rare species can be of great importance for conservation.

We found macrophyte assemblages as main habitat building elements for macroinvertebrates (Figure 3). This corresponds with the results of Beckett and Aartilla (1992) whose recorded higher number of animals within areas of macrophyte stands as compared to open water areas on a homogenous sediment like in our case. Species richness of macrophytes, on its part, is not correlated with structural quality of waterbodies (Passauer et al. 2002). It depends on nutrient content, degree of shadowing, current velocity, and, probably on other factors. Nutrient content, especially phosphorus concentration can be indicated by Trophic index of macrophytes. TIM developed in Bavaria by Schneider (2000) is also a usable and simple method for estimation of trophic status under Northern German conditions. Using this index, short-time fluctuations of plant available nutrient concentrations can be neglected, because TIM indicates the combination of the phosphorus concentrations in the sediment and the overlying water (Schneider and Melzer 2003). In macrophyte dominated running waters, this indication system can be used to observe changes in nutrient potential. On the other hand, in uniform canal systems with low water exchange rate like in the Drömling such changes occur very slowly. Therefore, measured TIM values of this study are very unique.

Because of their intermediate status, estimation of water quality in canals should be done by the saprobic index as well as by TIM (Table 4). Evaluation by the saprobic index shows a moderate organic load respectively a good water quality. The fact that this metric is modified by abiotic parameters (like longitudinal gradient and flow rate) is a disadvantage, so that running waters with high physically oxygen supply (e.g., mountainous stream) will be better classified than lowland streams with the same organic load (Böhmer et al. 1999). Under the conditions of the very slowly flowing waterbodies in the Drömling, a moderate organic load is equivalent to reference conditions. This conclusion is supported by good values of Chemical index which is a measure of current chemical load.

Table 4. Parameters for evaluation of canals and ditches.

Parameter	Expressiveness
Biology/ecology	
Conservation index	xxx
Species number MI	xxx
Plant species number	xxx
Trophic index of macrophytes	xx
Saprobic index	xx
Diversity index	x
Stream morphology	
Steepness of banks	xxx
Substrate diversity	xxx
Structure of surroundings	xx
Depth of bottom	xx
Hydraulic structures	xx
Ecological integrity	
Multimetric index	xxx

xxx – high degree of expressiveness; xx – average degree of expressiveness; x – low degree of expressiveness.

The high conservation value of most water sectors, despite the low levels of their morphological evaluation, suggest that evaluation by the whole range of parameters is not appropriate. Characteristics of natural streams like degree of bend, bend erosion,variation in width, and variation in flow velocity, are contrary to the purpose of the waterbodies for drainage or irrigation, and cannot be used. Therefore, only parameters, whose improvement can lead to an enhancement of the diversity of the waterbody and banks, should be estimated and evaluated. These are steepness of banks, substrate diversity, depth of bottom, hydraulic structures, and the structure of surroundings (Table 4). Estimation and evaluation of these five parameters should be sufficient for an complete morphological assessment of drainage canals and ditches.

In sum, the Conservation index, the number of species of aquatic plants and macroinvertebrates, and the trophic status of water, are the most sensitive biological and ecological parameters for evaluation of canals and ditches (Table 4). Furthermore, they are indicators for the degree of ecological integrity of these aquatic ecosystems and their surroundings, in terms of the meaning given by Woodley et al. (1993): Ecological integrity is a state of ecosystem development that is optimized for its geographic location, including energy input, available water, nutrients and colonization history.

With regard to canals and ditches in fens, ecological integrity is realized if:

- they are functionable for conservation and the wise use of fens (Joosten 2001),
- there is little demand for their maintenance and management,
- target species occur.

As a holistic measure, integrating several metrics concerning macroinvertebrates, MMI shows the degree of difference from reference conditions. This difference is small in case of most Drömling waterbodies. Despite their artificial history, they offer habitat species and assemblages which are similar to those in natural fen waterbodies.

Nevertheless, all management measures should try to improve ecological integrity by means of prior parameters:

- A decrease of bank steepness leads to increases in shallow flooded areas, so that organisms with a preference for the phytal zone are provided with a greater (and in most cases) more diverse habitat. The enrichment of soil substrate with different structures is effective in the same way.
- Raising of the bottom serves the general aim of higher groundwater levels and protection and development of native fen structures.
- Removal or change of hydraulic structures enhances the ecological permeability, although the influence of such structures seems to be lower than in natural streams.
- To avoid natural succession that would lead to species-poor reed assemblages, occasional removal of vegetation will be necessary in most cases. Bi-annual removal on only one bank, can promote the development of species with a longer life cycle like Anisoptera (Diederich et al. 1995).
- Prevention zones serve as habitats and shield the waterbody against influences from land use. This influence is visible in sectors 6 (Landgraben) and 8 (Friedrichskanal) where a continuous prevention zone supports the establishment of species-rich plant and macroinvetebrate communities.

By following these measures, the 'maximum ecological potential' demanded by the European Water Framework Directive can be defined and achieved for artificial waterbodies in fens of Northern Germany.

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