Sustainable land use in an agriculturally misused landscape in northwest Germany through ecotechnical restoration by a ‘Patch-Network-Concept’

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Abstract

The development of a method of sustainable land use balanced with an ecosystem stability parallel to intensive cultivation was the aim of a restoration project in northwest Germany. The results of a substantial experiment in landscape ecology, conducted on a 1000-ha area in the past decade, demonstrate that small-sized, unused patches and linear structures connecting them are important parts of a protective concept for nature conservation. Thus, a restoration of semi-natural water courses with temporarily inundated floodplains, and other linear landscape structures, such as dam hedges, have a variety of functions, not only as paths of migration, habitats and protection against substance transports, but also as sites of active elimination of a nutrient surplus and other substances. Buried ecological potential, in the form of seeds of past communities, regenerates as soon as barriers to adequate survival have been removed. Restoration, creating and connecting a variety of smaller ecosystems within a landscape not only will be an important contribution to stabilizing floristic and faunistic assemblages and to the elimination of a nutrient surplus, but will result in significant improvements to ecosystem functioning of nearby intensively cultivated landscapes. However, an unalterable precondition for sustainable land-use must be the adjustment of cultivation to the carrying capacity of the land. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Agriculture; Ecological engineering; Localized conservation; Patch connectivity; Restoration; Sustainable land use

1. Introduction

In the late 1950s, a disastrous change in land-use practices began in Western Europe. Politicians and administration officials were convinced that the poor unpredictable production of some agri-
cultural systems could be ameliorated with the help of science and technology. Nature was to be exploited industrially, a plan that consequently received financial support. The fundamental concepts of the natural functioning of ecological systems, although well-known at the time, were not taken into account.

Very soon, the disastrous effects of this policy became obvious. The majority of independent farmers had to quit farming. Commercial and economically focused land use caused unemployment in rural regions and traditional agriculture disappeared almost completely in favour of over-production and price-dumping, all of this absurdly made possible and backed by subsidies.

There has also been a dramatic increase in the number of cattle in the region. Today, more than 2.9 million pigs, over 600,000 head of cattle and more than 23 million cocks, hens and other poultry are kept in the northwest German districts of Grafschaft Bentheim, Emsland, Osnabrück, and Vechta (NIW, 1995).

The number of animals kept in concentrated populations in that same region (over 26 million) is a multiple of the number of human beings living there (1 million) and surpasses the natural carrying capacity. The region mentioned above is 691,500 ha in size, 440,000 of which are used by agro-industry and remaining independent agriculture. Although the use of fertiliser is restricted by statute to the equivalent of 1.5 ‘big-cattle-units’ per ha, more than 3 million ‘big-cattle-units’ are raised. The resulting cattle manure still has to be disposed of. The majority of pastures have been ploughed in order to produce food for the large herds of cattle. Currently, the proportion of natural grasslands in the area is only less than 20%. In the new fields, corn is usually cultivated.

An improved drainage of the commercial fields became necessary and was achieved by deeper ditches and the regulation of brooks and rivers, thus eliminating fertile floodplains. Precipitation can no longer be held in the soil but quickly reaches the watercourses. Consequently, there are frequent floods in the lower parts of the region.

Most of the protecting dam-hedges have been removed in order create access for large commercial machinery. Now, wind erosion causes a remarkable loss of soil, especially in wintertime when the crop has been brought in and the vast corn fields are left bare. Sandstorms are frequent.

The principle of crop rotation has been widely abandoned. In many cases, corn is permanently cultivated because of its tolerance of large quantities of liquid manure derived from the large concentrated cattle herds. Only rarely are cereals and potatoes cultivated in turn with corn.

Our restoration project tried to put a stop to this kind of unfavourable development. Ecologists from different fields of science (biology, chemistry, and landscape planning) formed an interdisciplinary team. Their first task was to record and assess the existing flora and fauna, as well as water-chemical, geohydrological and soil microbial conditions along with the condition and structure of the landscape in question (Schuller et al., 1996; Janiesch et al., 1997a).

The main focus of this experiment was to determine whether it might be possible to develop a scheme of land use in long-term accordance with natural ecosystem functioning by restoring confined semi-natural spaces and linking them through linear structural elements while the rest of the area remained under intensive cultivation (ARSU and NWP, 1989).

The first step was to select appropriate patches of land for ecologically oriented reconstruction within the area, places where the preliminary examinations yielded remnants of an ecological potential or structural and connecting elements. For each of these patches, equalling about one-tenth of the surveyed area of 825 ha, a detailed concept of rehabilitation and restoration was designed and implemented with consideration for special deficiencies in each area. Research and documentation of the results continued throughout the reconstruction period (Schuller et al., 1997; Janiesch et al., 1997b). As soon as the ecotechnical measures had been concluded, a comprehensive scientific monitoring began and will be continued until the turn of the century. Current data collections already allow an evaluation of this substantial experiment in landscape ecology.
2. Origin and development of landscape

The agricultural region chosen for this model project is situated in northwest Germany, 5 km east of the city of Lingen in the Emsland district. The actual boundaries of the 825-ha, scarcely populated area is based on pragmatic planning, and natural aspects.

The area is part of a former outwash plain belonging to the ecological unit ‘Brögerner Tal-sandgebiet’. There are occasional soft rises, sandy soils and a groundwater table close to the surface. The average above sea level is 24 m to the north and 28 m to the south (Meisel, 1959). The sandy material has produced gley soils under the influence of groundwater, podzols under drier conditions, and gley-podzols in between. In wet hollows, fen peat has developed. The natural vegetation for this kind of sandy plain is dominated by common oak and birch forests, depending upon local humidity. Under natural conditions, fen sites are covered by birch and alder swamps.

In some parts of the area, the poor sandy soils have been converted to soil suitable for cereal cultivation by decades of coverage by dung-drenched heath-turfs as a means of soil improvement. Finally, this led to the formation of poor podzol-gley soils. More recently, vast stretches of the region underwent deep tillage in order to blend layers of peat with the underlying sands, the so-called sand-mix cultivation, another means of amelioration.

During the first half of the last century, there still existed a varied landscape with ploughlands and grasslands of various states of humidity as well as unused or impossible to use bogs, fenites, and swamp forests. The arable land was divided into patches by a comprehensive hedge system.

At that time, the highlands, which were more exposed to the wind (with frequent velocities of more than 70–80 km h\(^{-1}\)) were divided into relatively small lots by earth walls and planted with hedges and trees, to protect the soil against the erosive forces of winter winds (Stadt Lingen 1989/1990).

The most significant changes were undertaken in the 1950s and 1960s when comprehensive measures of amelioration were begun. Forests and grasslands were turned into cultivated land so that almost 95% of the area was either in agricultural use or covered with support-buildings at the beginning of the 1990s. A bout 60% of the area (470 ha) had been turned into grain, turnip, rape, and potato fields, with the majority (two-thirds) in corn. The remaining meadows and pastures (about 25% of the acreage; 180 ha) have since been subjected to intensive use. A bout half is ploughed regularly and sown with rye grass, sometimes blended with Timothy grass. Those patches are being heavily fertilised and may be mowed up to three times per year. The other half is used as a pasture or as combined meadow and pasture in a less intensive fashion.

Before initiation of the restoration project, only 7% of the area (55 ha) could be generally classified as semi-natural; the status of less than 1% of the acreage was regarded as almost natural (Fig. 1). These sites, more or less degenerated remnants of former fen meadow, alder swamp, and oak and birch forest of medium humidity, were scattered, constituting isolated spots of a few m\(^2\) up to 6 ha. The hedge system has been reduced by 60% in recent years. Most of the remaining natural or semi-natural areas can be found in the northern part of the area. The brooks and ditches have all been regulated. The few remaining ponds are used as fish ponds. Natural open waters have been converted to grasslands or fields.

3. Concept of ecological restoration

The restoration goals of this project are based upon the assumption that although the area in question was formerly dominated by wetlands, but changed radically in the past few decades, and since it had not been completely devastated, there must be some potential left for restoration. The intention is to revive the former conditions of about 50 years ago (Dreyer, 1995). These goals are realistic and in accordance with popular notions of nature preservation. They represent an acceptable compromise solution with respect to relevant financial and legal issues.

The ecological aims and measures are focused upon the remnants of a semi-natural landscape. They concentrate on seven so-called ‘shaped-spaces’ totalling about 110 ha, four of which are
Table 1
Measures taken in the area (Fig. 2)

<table>
<thead>
<tr>
<th>Restoration area</th>
<th>Measures taken</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Lake and Fen Woods 'Great Lake Brögbern' (27.2 ha, reconstruction concluded in spring 1995)</td>
<td>Creation and revival, respectively, of a larger marsh with water surfaces, silted-up and swampy zones as well as wet woods; creation of a feeder including a floodplain landscape (Fig. 3). The upstream portion of the lake encompassed an aerobic part of the brook course, meandering between islands. In that situation excellent conditions for nitrification of ammonium are given. No open connection exists between the meandering open part of the brook and the outlet of the system to the main brook. The water must take the subterranean path through the fen. There an anoxic situation, the nitrate contents of the water and the presence of oxidizable organic material enable the process of denitrification.</td>
</tr>
<tr>
<td>2 Lake and Fen Woods 'Little Lake Brögbern' (11.8 ha, reconstruction concluded in winter 1997/1998)</td>
<td>Creation and revival, respectively, of a larger swamp with open water surfaces, silted-up and swampy zones as well as wet shrublands. Recreating a larger swamp with silting-up and swampy zones will effect an increased residence time of the water. This will enable microorganisms to digest, probably in a co-metabolic reaction, the otherwise hard to break-down chlorinated hydrocarbons.</td>
</tr>
<tr>
<td>3 Fen Meadow near Brockhausen (6.0 ha, managed extensively since 1991, reconstruction concluded in 1992)</td>
<td>Enlargement of fen meadows by giving up drainage and returning to low-intensity use; creation of ponds and pools.</td>
</tr>
<tr>
<td>4 Fen region 'Baccumer Bruch' (37.4 ha, managed extensively since 1992, reconstruction concluded and inundation started in spring 1996)</td>
<td>Creation and revival, respectively, of larger wetlands with alder Fen region 'Baccumer Bruch' (37.4 ha, managed extensively since 1992, reconstruction concluded and inundation started in spring 1996) swamps, fen meadows and open water surfaces with silted-up and swampy zones.</td>
</tr>
<tr>
<td>5 Brook 'Lingener Mühlenbach' (4.7 ha, reconstruction concluded in spring 1996)</td>
<td>Reconstruction of a floodplain landscape with a variety of habitats ranging from stagnant waters to wet shrublands (Fig. 4).</td>
</tr>
<tr>
<td>6 Brook 'Schillingmanngraben' (7.2 ha, reconstruction concluded in spring 1996 and winter 1997/1998 resp.)</td>
<td>Reconstruction of a floodplain landscape with a variety of habitats ranging from stagnant waters to wet shrublands.</td>
</tr>
<tr>
<td>7 Hedgebanks (approx. 9 ha, approx. 9 km long and 10 m wide, planting concluded in winter 1997/1998)</td>
<td>Closing up the hedge system using with the typical species.</td>
</tr>
</tbody>
</table>
stepping stones (wetlands) with three linear bridges (brooks and hedges) in this biological network (Fig. 2 and Table 1).

The following tasks were accomplished through interdisciplinary co-operation by biologists, chemists and planning engineers:

- Landscape-analysis, including historical review of development.
- Research for hidden ecological potentials and parts of networks yet present in the area.
- Detailed analysis of pollution in the landscape, including research for point and non-point sources. Risk-assessment and analysis of potential source-elimination.
- Definition of environmental quality goals for the landscape, including creation of social acceptance by survey and analysis of economical feasibility, political discussion of the regional quality goals, and political decision.
- Planning of landscape reconstruction, environmental risk assessment and permission for the reconstruction plan by local and regional authorities (NWP, 1991).
- Technical initiation of the reconstruction plan (Figs. 3 and 4).
- Quality assurance and control by longer-term monitoring (biological, chemical, and physical development-analysis), socio-economic monitoring (concerning economical stability and social acceptance).

To assure the permanent change of use on a long-term basis, the relevant properties were purchased by public holders. As acceptance of the measures by the local population, especially farmers, is crucial for the success of the project, all parties remotely concerned about the outcome of

![Fig. 1. The area in the 1950s and the late 1980s. Basic: topographic map 1992.](image.png)
the project were integrated into the planning process from the start.

4. Results of the efficiency control

4.1. Conditions prior to restoration

4.1.1. Chemical and microbiological situation

The project area is approximately 1000 ha, containing very deep ditches and straight courses of brooks; among other sites an alder fen and ancient depressions have been drained, resulting in a dramatic degradation of fauna and flora.

That condition was very carefully analysed by investigation of a multitude of biotic and abiotic parameters. We found a very degraded system (Schuller et al., 1996; Janiesch et al., 1997b), characterised by extremely severe local soil and water pollution, especially by nutrients (Figs. 5–8).
The retention capacity of the poor sandy soils for water, dissolved nutrients, and other substances was very small and the brooks' capacity of self-purification was practically nil. Thus, with every precipitation event, great quantities of nitrogen-compounds were transported to the Ems and to the North Sea.
The alder fen was damaged by the dry situation: the ancient depressions had been filled up with material from other places to provide good conditions for the cultivation of corn. Nevertheless, we found the old surface of the ancient fen underneath, full of seed still capable of germination.

The diversity of animals and plants was poor because of the almost complete lack of a network of corridors between habitat patches, even if only linear structures, enabling the migration of organisms. By the regular, concentrated applications of liquid manure to areas in corn-cultivation, soils
were systematically degraded. Liquid manure contains high quantities of ammonium, which, like all monovalent cations, creates a breakdown of the clay-humic-acid-complexes, thus damaging the structures of the soil. Ammonium is normally well adsorbed in soils. In very high concentration, however, the poor, sandy soils of the region cannot retain the ammonium, which is consequently transported to the groundwater (Figs. 6 and 8). High concentrations of ammonium in the upper layer of the soil are quickly oxidized to high concentrations of nitrate in two microbially catalysed steps. By that reaction hydrogen is liberated, leading to an acidification of the soil. The high nitrate concentrations are very quickly transported to the groundwater, so that denitrification processes, which could compensate for the acidification, cannot take place in the thin fertile upper layer of soil. In the deeper horizons, nitrate is stable and, due to the absence of oxidizable material, no denitrification was possible.

Fig. 7 shows the high level of Nitrate in the groundwater for 2 years. The regulatory standard for drinking water is 50 mg l⁻¹.

4.1.2. The condition of vegetative stands

In the experimental restoration area, 27% of the agricultural lands were still grassland in 1989. More than half of this land has been ploughed at regular intervals to be sown anew. Such patches are very poor in species composition and allow scarcely any conclusions as to the natural species composition of grassland communities typical for the region. Most of the remaining grasslands are used as combined meadows and pastures. There, we found limited relics of wet grassland communities, depending upon the state of use and soil type. Wherever insufficient drainage causes high water-levels, Alopecurus geniculatus, Glyceria fluitans, Agrostis stolonifera and other species of seasonal flooded grassland communities were encountered, at times even reeds of Phalaris arundinacea and Glyceria maxima (for details see von Lemm and Janiesch 1997a).

Grassland communities of poorer sites such as those dominated by sedge reeds are very rare in the area. A part from the few described grassland sites, species adapted to humid conditions were found only on narrow stretches along the watercourses.

As all portions have been regulated without exception, the Lingener Mühlenbach, the only brook with a natural source, and its tributaries are characterized by a very uniform riverbed, both from a cross-sectional and longitudinal aspect. Therefore, typical river structures (stagnant water areas, bluffs, and point bars) are rarely found.

The distance between the streambanks and adjoining fields, meadows, and pastures is no more than 1 m, in most instances. Streambank heights of up to 1.6 m combined with embankments sloping by 40–60° present a significant ecological gradient in a very confined space.

Macrophyte communities are impoverished in species due to the regular clearing of the beds. The predominant species, all very common in the Northwest-German plains, are Callitriche palustre and Elodea canadensis, while in smaller ditches Glyceria maxima, Sparganium erectum, or Filipendula ulmaria may prevail.

The narrow banks are covered by a diverse vegetation. Here, relics of wet-meadow communities have been preserved, at times with high coverages of Caltha palustris and Carex nigra.

Species less able to compete, like Juncus acutiflorus, grow along the margins of small ditches running through heavily used stretches of land (meadows, field paths). Here, sedge reed elements like Carex nigra, Ranunculus flammula, Potentilla palustris, and less frequently Viola palustris, Juncus filiformis, and Hydrocotyle vulgare can still be found.

From a floristic point of view, the most important aim of the reconstruction measures was to give more room for expansion of the existing potential of endemic plant communities.

The hedges in the area usually grow on 50–80 cm high dams. Most of these dam hedges were degraded and without a shrub layer. Their margins were often dominated by stinging nettles, influenced by adjacent agricultural use.

The hedges on more humid sites were characterised by alder and willow shrubs with Salix pentandra, Salix cinerea, and Salix aurita. As sites became drier, more birches and oaks dominated.
Alder swamps are the natural woodland communities on fen sites. Their development and preservation depend on high groundwater levels and they tolerate longer periods of flooding. They develop in the course of succession out of reeds and sedge communities (Trautmann and Lohmeyer, 1960). The typical species assemblage of alder swamps, containing Carex elongata, Carex remota, and Carex acutiformis, has remained in existence only in a small area of 1.5 ha in the southwest of Baccumer Bruch, where groundwater levels have stayed high and there are regular inundations during the winter months.

As a consequence of drainage, a herbaceous layer, dominated by quickly spreading raspberry and blackberry bushes, is characteristic of all the alder swamp remnants.

The vegetation survey yielded a total of 263 species. In analysis of the species distribution, a high share of endemic species of each natural community could be found. Therefore, we assumed that the ecosystem fragments still in existence held a high potential for recolonizing the areas to be rehabilitated. However, the long-term success of the project will depend on whether it will be possible to change the ecological conditions with respect to the groundwater level and nutrient supplies in such a way as to allow communities of poorer and wetter sites to become established and persist.

There is a considerable potential for recolonization from these small-sized relics. The preliminary examinations yielded a substantial accumulation of wetland and reed species in the seed bank where even long vanished species were found, particularly for the preserved layers of fen peat (Fig. 9). A concentrated search for the relevant soil layers was initiated in order to use these supplies in the establishment of native plant communities during restoration (von Lemm and Janiesch, 1997b).

4.1.3. The situation of the fauna

An inventory of the area yielded 86 vertebrate species, 1158 species of terrestrial invertebrates, and 254 species of freshwater invertebrates prior to the start of the project (Table 2, for details see Niedringhaus, 1997). While there were 71 species of breeding birds, representing 36% of all species generally reported from northwest Germany, amphibians, reptiles, and fish were only represented by 22, 14, and 20%, respectively, of fauna within the region. However, it must be considered that only the fish fauna of the brooks were examined.

As far as terrestrial invertebrates are concerned, the highest number of species was reported, as expected, with phytophagous beetles (259 spp.), followed by spiders (234 spp.) and terrestrial bugs (201 spp.). Composition of species relative to regional fauna differ according to the various taxa, ranging from 15 (day-flying Lepidoptera) to 44% (Cicadina).

Concerning freshwater invertebrates, the most comprehensive species spectrum was found with water beetles and caddisflies, the former being represented by 99, the latter by 52 species. Furthermore, the inventory yielded considerable potential for the three other taxa examined (water bugs, dragonflies, and molluscs). This is confirmed by the high proportion relative to all northwest German species in the different groups ranging from 26 (caddisflies) to 59% (water-bugs).

The majority of the 1500 recorded species are not firmly established in the area (Fig. 10).
Table 2
Species numbers in the observation area and share of the Northwest German fauna (situation prior to restoration)

<table>
<thead>
<tr>
<th>Category</th>
<th>Species number</th>
<th>Share NWG (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertebrates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fish (only watercourses)</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Amphibians</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>Reptiles</td>
<td>1</td>
<td>14</td>
</tr>
<tr>
<td>Breeding birds</td>
<td>71</td>
<td>36</td>
</tr>
<tr>
<td>Terrestrial invertebrates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spiders</td>
<td>234</td>
<td>39</td>
</tr>
<tr>
<td>Ground beetles</td>
<td>119</td>
<td>30</td>
</tr>
<tr>
<td>Phytophagous beetles</td>
<td>259</td>
<td>22</td>
</tr>
<tr>
<td>Day-flying butterflies</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Night-flying butterflies</td>
<td>282</td>
<td>28</td>
</tr>
<tr>
<td>Sawflies</td>
<td>156</td>
<td>31</td>
</tr>
<tr>
<td>Grasshoppers</td>
<td>10</td>
<td>22</td>
</tr>
<tr>
<td>Land bugs</td>
<td>201</td>
<td>35</td>
</tr>
<tr>
<td>Cicadas</td>
<td>166</td>
<td>44</td>
</tr>
<tr>
<td>Freshwater invertebrates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molluscs</td>
<td>22</td>
<td>31</td>
</tr>
<tr>
<td>Dragonflies</td>
<td>23</td>
<td>39</td>
</tr>
<tr>
<td>Caddisflies</td>
<td>52</td>
<td>26</td>
</tr>
<tr>
<td>Water beetles</td>
<td>99</td>
<td>40</td>
</tr>
<tr>
<td>Water bugs</td>
<td>41</td>
<td>59</td>
</tr>
</tbody>
</table>

Among vertebrate species, between 23 (breeding birds) and 70% (fish, only watercourses) are widespread and durably established. This proportion is smaller among terrestrial invertebrates, ranging from less than 25 (night-flying Lepidoptera and phytophagous beetles) to 50% (day-flying Lepidoptera, grasshoppers and beetles) and larger among freshwater invertebrates, namely between 40 (dragonflies, caddisflies, and water beetles) and 60% (molluscs and water bugs).

A total of 410 rare and/or endangered species have been recorded, of which 87 are highly endangered and belong to Red Data Book categories 0, I, or II. This amounts to 30 and 5% respectively of the occurring species (Fig. 11). About 17% (n = 260) of the species found are common while two-thirds (n = 1036) can be regarded as typical for the region. 82 species can be classified as ecologically specific target species, 29 species (26 terrestrial, three freshwater spp.) as introduced or transient.

The detailed inventory of the existing conditions before start of restoration documented that even in a landscape almost totally devoid of natural elements, stretches with a relatively high faunistic potential have persisted. However, most of the species characteristic of the natural habitats of the region have been confined to semi-natural remnants of former landscape elements and most of the species are no longer firmly established. Therefore, it may be expected that the long-term persistence of the species within these scattered habitat islands is low to non-existent in most cases. One of the chief goals of the restoration measures has been to re-establish locally extinct species, as well as to secure habitats of those still present but more or less in the process of retreating.

The evaluation of the existing conditions, by means of a specially developed numerical assessment system (Niedringhaus, 1998), established the expected low values (Fig. 12). The most important and valuable areas from a faunistic point of view are Restoration Areas 5 (eastern fen meadow complex) with a value of 3.6, 6 (Baccumer Bruch wetlands) with the value of 2.3, and 7 (hedge system) with a value of 2.9. The four remaining selected patches yielded much lower values because of their considerable proportion of fields (sometimes amounting to more than two-thirds). As a whole they are only slightly more valuable than the rest of the area (2.2 as opposed to 2.1).

4.2. Conditions after restoration

4.2.1. Chemical situation

The chemical situation of Great Lake Brögborn has thoroughly changed in the years following reconstruction. The overall condition of Great Lake Brögborn has been affected continually by a considerable nutrient input, mostly through surface runoff from fields on both sides of the main brooks upstream. The majority of those nutrients, especially phosphates, have been directly transformed into biomass, causing a profuse growth of green algae. These covered most of the water
surface in the upper half of Great Lake Brögbern during the summer months and led to eutrophication-related problems within the system. Up to the present, the breakdown of nitrogen compounds (ammonium and nitrate) is still guaranteed (Fig. 13). The situation, however, remains dramatic. Whereas the elimination of nitrogen compounds until now has been successful, the layer of algae and the corresponding oxygen shortage in the water will result in a decrease of nitrification. The phosphate shows a clear tendency towards a breakthrough downstream. The anaerobic system where denitrification occurs represents no barrier against that phosphate breakthrough. So it will only be a question of time before activities of nitrogen-fixing blue-green algae cause the return of full eutrophication downstream.

Directly after the reconstruction had been concluded, purely sandy soils prevailed; no nitrogenous nutrients could be found (Fig. 14), whereas phosphates had been mobilised. Small-scale microbial activity was recorded immediately (Fig. 15). Along with the increase of the humus layer,
ammonium and nitrate contents increased, thus improving the conditions for micro-organisms. Because of the algae, contents of organic dry matter and phosphate increased significantly during the second half of 1997. Even so, the first measurements in 1998 showed that they returned to their original level.

Reconstruction of Little Lake Brögborn was concluded in the spring of 1998. Recreating a larger swamp with depositional and swampy zones will increase the residence time of the water.

This will enable micro-organisms to digest the otherwise hard-to-break-down chlorinated hydrocarbons.

Microbial activity is still relatively low in this freshly reconstructed area with immature soils. Ammonium and nitrate contents are higher than before reconstruction, which is usually the case in this area at the beginning of the year, because of agricultural fertilisation. Phosphates have been mobilised and the content of phosphates has decreased by 50% compared to the initial state (Fig. 16).

Drainage systems in an intensively cultivated area, Lingener Mühlenbach and Schillingmanngraben, may serve as an example of the multiple stresses on water in agricultural regions. Flattening the banks and removing the productivity of the newly created floodplain blocked direct nutrient transport into the water, thus, relieving the watercourses. There have been considerable improvements in oxygen balance and nutrient processing. The presence of nitrate, accompanied by low concentrations of ammonium, indicates high microbial activity by nitrification processes. Thus,
Fig. 14. Organic dry matter and total Kjeldahl-nitrogen in the soil.

Fig. 15. Dehydrogenase activity of micro-organisms in the soil.

Fig. 16. Phosphate concentration in the soil of the Little Lake Brögbern.
our data imply that biological self-cleaning, in the form of breakdown of organic substances to carbon dioxide, water, nitrate and phosphate, has increased.

In the area of the Baccumer Bruch, a gradual change can be ascertained with respect to nutrient content and activity of micro-organisms. Although average phosphate, nitrate, and ammonium contents are decreasing over time, there are still distinct fluctuations. On the other hand, average microbial activity has increased since reconstruction in the winter of 1996.

4.2.2. Groundwater
Since prevailing sandy soils in the observation area allow for rapid percolation, dissolved nutrients and organic compounds reach the higher aquifer without delay. This was especially clear when intensively cultivated grounds were being examined. Because of the flattening of the banks, some patches of land had to be taken out of agricultural use. In these areas, the organic charge of chlorinated hydrocarbons, for example, decreased significantly right after reconstruction.

In the area of Great Lake Brögbren, examinations yielded the highest groundwater nutrient concentrations due to intensive cultivation. Since restoration, this situation has improved noticeably.

Groundwater nutrient concentrations around Baccumer Bruch could be considered acceptable before reconstructive measures were taken. Raising the groundwater level and the entailing anaerobic conditions in the ground, however, caused increased mobilisation of phosphates, concentrations of which consequently rose.

4.2.3. The situation of flora and vegetation
Since the conclusion of the reconstruction, a varied mosaic of vegetation units has developed according to the different site conditions (planted areas, laid open soils, new water surfaces, dispersed soil material containing seed potential) in the area around Great Lake Brögbren. There is a noticeable difference in species numbers between areas with and without dispersed soil material, as well as in distribution, which are both higher where material from buried seed banks was spread. Within three growing seasons of the initial reconstruction, the vegetation from the latter areas has already begun to invade the less densely populated places with laid-open soils.

A special problem with vegetation development has occurred at Great Lake Brögbren. There is an abundance of green algae covering most of the water surface around small islands during the summer months. Our analyses have revealed that algae contain larger quantities of phosphorus and calcium. In the first growing season, drastic changes in species diversity and dominance could be observed on the permanent quadrates, especially in areas covered by soil material containing seed potential and those in close vicinity. Furthermore, there are alternating effects between the various sites, influenced by variations in water movement and transport of nutrients.

The following ecological units can be distinguished:
1. Dyke: dry grassland, sowed with adapted grasses.
2. Small islands: planted mostly with alders and willows on the banks.
4. Watercourse: with occasional aquatic plants; during summer, mostly covered with green algae.
5. Stagnant waters with aquatic plant communities (dominated by Potamogeton gramineus and Ranunculus peltatus).
6. Reeds: rich in species, partly dominated by Typha latifolia, on soils covered with material containing seedbank material, alternating with pond-bottom communities.
7. Wet grasslands/reeds: on soils covered with material containing seedbank material.
8. Hedge remnants: partly dominated by Myrica gale.

During the growing season of 1995, the soil conditions around Little Lake Brögbren were thoroughly examined and a large number of samples were taken and tested for seed potential. It was found that even after years of intensive cultivation, considerable amounts of viable seeds belonging to wetland communities have persisted, a fact that was considered useful for restoration purposes. On an abandoned corn field, seeds brought to the surface by ploughing down to the
underlying peat quickly germinated. Among others, Iris pseudacorus and Oenanthe fistulosa were growing profusely. The reconstruction of Little Lake Brögbbern started by the beginning of September 1997. Soil material containing seed potential was dispersed over future wetland areas. The higher margins were planted with typical woody plants of the swamps and floodplains.

Vegetation development in differently used parts of the fen meadow, Brockhausen, was carefully documented by means of quadrates and vegetation surveys. It becomes obvious that extensive land use affects the species composition of plant communities. The dominance and abundance of nitrophytes decreases, particularly on patches that are mowed, and mesophytes invade. The introduction of a small pond yielded a positive effect. Numerous species hitherto absent could be recorded as growing along the pond’s embankments. The population of Dactylorhiza maculata has expanded and begun to invade the neighbouring abandoned corn field. In 1997, the population of Dactylorhiza was five times as high as in 1992, having increased from 400 to 2000 plants.

4.2.4. ‘Baccumer Bruch’

Due to a very dry growing season in 1996, noticeable effects of the elevated water level could not be observed until the winter of 1996/1997. One of those observations was the initiation of a succession pattern in accordance with the ecological goals for the cleared fen areas and on the banks of the new pond. The development is clearly influenced by the gradual adjustment of natural groundwater dynamics. The area of hitherto very dry alder forest is now inundated until summer, a situation that causes indicators of degeneration, like raspberry bushes and brambles, to die, but provides the necessary conditions for swamp species like Carex acutiformis and Phragmites. On the other hand, some of the old alders were unable to adapt and died off.

During the entire observation period, nitrogen turnover during each of three growing seasons of the various vegetation units in the alder swamp forest, Baccumer Bruch, was determined. While nitrogen turnover rates were atypically high in 1989 and 1993, our 1996 readings revealed obvious shifts towards lower rates. Nitrogen turnover underwent a distinct decline in now wetter soils, and nitrate production decreased in favour of ammonium production throughout the area, a characteristic of alder swamps. The remnants of intact swamp forest communities in particular could be seen to be stabilised.

The banks of the brooks have been flattened on both sides to form floodplains. These zones, 20 m wide on either side, were supplied with a number of additional water bodies shaped like oxbows or potholes, as well as pools that will only be inundated in times of high water.

An analysis of the observational data obtained during the first 2 years following reconstruction revealed a significant development in those newly shaped areas. There was a rapid growth of alders and willows, especially along the banks. Preservation of these narrow riparian stretches, with their abundance of species and re-integration of the previously cleared topsoils into the newly shaped wetlands, influenced a rapid distribution of endemic species populations. The creation of stagnant waters provided the necessary conditions for species hitherto absent in the area.

While the reconstruction of Baccumer Bruch and Little Lake Brögbbern was under way, the material for approximately 6.1 km of hedgebanks was deposited and planted by the end of 1997. One kilometer of hedgebanks was formed to serve as an external border for the Baccumer Bruch and an additional 4 km of hedgebanks to adjoin the brooks. The choice of vegetation was based on the species composition of the existing hedges.

4.2.5. The situation of the fauna

Immediately upon completion of the main constructional measures in 1995/1996, the first positive effects could be observed. Seventy new species, in conformity with the ecological goals, have settled in the reconstructed areas. Whether they can be firmly established as resident populations in the area remains to be seen. Especially in the new ponds and pools, high numbers of primary colonists could be found. Improvements in the conditions of surface waters in the area attracted ten new dragonfly and eleven other aquatic insect species. The num-
bers of some dragonfly populations rose more than one-hundredfold.

While the first evaluation of the area, immediately after restoration measures (Fig. 17), produced only slight improvements in the terrestrial fauna, improvements in freshwater fauna were quite distinct. This is not very surprising in view of the known mobility of many aquatic insects, in combination with a normally fast colonisation rate.

5. Discussion

The development and implementation of this experiment in landscape ecology by interdisciplinary co-operation of environmental scientists (biologists, chemists, planning engineers) as well as the Federal Office for Nature Conservation, regional administration, and representatives of the local farmers and politicians had a simple and clear main issue: would it be possible to develop a plan of sustained land-use compatible with natural ecosystem processes by restoring confined semi-natural spaces and linking them through linear structural elements while the rest of the area remains under intensive cultivation?

Although the preconditions for this experiment may have been excellent (with smooth co-operation of everyone concerned and generous financial means through the Federal Environmental Office),

![Terrestrial Fauna](image1)

![Freshwater Fauna](image2)

Fig. 17. Faunistical evaluation of the shaped spaces and the rest of the area immediately after the principle measures in 1995/1996. (grey, value prior to restoration; black, increase of value; *, measures not yet concluded; for details see Niedringhaus, 1998).
some restrictions and limitations of the project must be stated clearly. Although 10 km² in size, the experimental area is not yet large enough. The main concern is that it only comprises the catchment area of a tributary (Schillingmanngraben) to the more important main brook (Lingener Mühlenbach), little of which has been integrated into the project and is still being used for intensive agriculture.

In spite of these restrictions, which define the limits of application of the results, it may be stated that a significant improvement of the natural ecosystems is possible if relatively small parts of the landscape are taken out of agricultural production and connected in a way to support the effective dispersal of organisms throughout the area.

With respect to the flora, it becomes especially clear that ecological restoration potentials may persist for a very long time. In fact, there has been a successful revival of endemic species whose seeds have been buried, in a figurative as well as true sense of the word, for decades.

Regarding the terrestrial fauna, only slight improvements could be achieved. The situation of the freshwater fauna, however, could be enhanced considerably.

Changes in chemical processes are of a more short-term nature. The elimination of nutrients and other agents of agricultural production, which are harmful if brought into the system in great quantities, is only possible to a limited extent. Although nitrogen can be controlled quite effectively and the elimination of pesticides can at least be initiated, a phosphate and potassium surplus presents a real difficulty, which in the former case can only be overcome by means of special harvesting methods and in the latter case cannot be handled at all as long as agricultural production is not reduced to a natural level throughout the area.

From the results of 9 years of this substantial experiment in landscape ecology, the following conclusions may be drawn:

- Decomposition in semi-natural systems is an effective way to eliminate nitrogen compounds as long as the system's capacities are in accordance with the expected flows.
- In the case of other nutrients, especially phosphate and potassium, there is no possibility of elimination by supporting a natural breakdown. In this case, the only option is removal during crop harvest or reduction at the source.
- Unused, small-sized, linear structures are not only important pathways for the migration of organisms but also protective elements against the input of substances into adjacent ecosystems.
- Buried ecological potentials, in the form of endemic seedbanks, retain an ability to regenerate independently as soon as existing ecological barriers to colonization have been removed, even after long periods of suppression and excessive misuse.
- Restoration and connection of a number of smaller ecosystems can result in significant improvements of natural communities within intensively cultivated areas.
- Restoration of semi-natural watercourses with temporarily inundated flood plains is of outstanding importance. These structural landscape elements are not only responsible for improved water retention, they are paths of migration for organisms. They provide a number of habitats and ecotones and enable the elimination of excessive nitrogen input by natural breakdown processes.
- Other linear landscape structures, too, such as dam hedges adjacent to pools, have a variety of functions, being paths of migration and habitats as well as protection against substance transport into the water.
- Creating and connecting a variety of ecosystems within a landscape can be a valuable technique for the elimination of a nutrient surplus and other substances. As this is only possible to a very limited extent, an unalterable precondition for land-use in long-term accordance with ecosystem processes must be the adjustment of cultivation to the carrying capacity of the land.

Among other results of this experiment in landscape ecology, it becomes quite clear that any action taken on a landscape is closely intertwined with a network of natural conditions and reactive relations, thus, presenting preconditions for any
use that must be closely observed if natural resources are not to be irreversibly destroyed.

These processes explain the special importance of developing regional environmental quality goals and bringing about their socio-economic and political acceptance in connection with the realisation of restoration projects.

Acknowledgements

This project is financed by the Umweltbundesamt, Lower-Saxony, Emsland County and the City of Lingen. The Bundesamt für Naturschutz is in charge of the scientific side of the project. Special thanks to Dr Christiane Schell.

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