Ökosystemrenaturierung und nachhaltiges Management

Pictures, Back:
Re-connected meander of river Main near Ebensfeld (Bavaria) /
wieder angeschlossene Mainschleife bei Ebensfeld (Bayern)
(Foto: U. Langheinrich)

Altered sector of a ditch in the Natural Park Drömling (Saxony-Anhalt) /
umgestalteter Graben im Naturpark Drömling (Sachsen-Anhalt)
(Foto: U. Langheinrich)

Front:
Renaturalised river Ihle near Grabow (Saxony-Anhalt) /
renaturierter Bereich der Ihle bei Grabow (Sachsen-Anhalt)
(Foto: U. Langheinrich)

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Forest Ecology, Landscape Research and Nature Conservation

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Liebe Leserin, lieber Leser,

mit Heft 10 von WLN (Waldökologie, Landschaftsforschung und Naturschutz) setzen wir die erfolgreiche Tradition von thematisch fokussierten Sonderheften fort, die sich mit ihren Beiträgen einem aktuellen Forschungskomplex der Landschaftsforschung widmen. Im vorliegenden Heft finden Sie ausgewählte Fachbeiträge zum Thema Ökosystemrenaturierung und nachhaltiges Management von Flüssen und Feuchtgebieten, die einer Tagung an der Hochschule Magdeburg-Stendal im Juni 2009 entstammen. Der geographische Fokus der vorgestellten Arbeiten reicht von Mitteleuropa bis Südamerika und Zentralasien und die inhaltliche Breite bewegt sich von Feuchtgebieten zu Fließgewässern und von der Erfassung natürlicher Prozesse bis zum intensiven Management von Ökosystemen.

Da Naturschutz in unserer anthropogen überprägten Welt neben der Bewahrung der „Restnatur“ auch in starkem Maße die Wiederherstellung der Funktionsfähigkeit der Ökosysteme beinhaltet, freuen wir uns, dass sich Heft 10 diesem Thema in besonderer Weise widmet.

Wir wünschen unseren Leserinnen und Lesern eine anregende Lektüre und bedanken uns herzlich bei den Autorinnen und Autoren sowie den Herausgebern des Sonderbandes.

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Ökosystemrenaturierung und nachhaltiges Management

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Ecosystem restoration and sustainable management of rivers and wetlands – Introduction to the special issue

Ökosystemrenaturierung und nachhaltiges Management von Flüssen und Feuchtgebieten – Einführung in den Sonderband

Volker Lüderitz, Stefan Zerbe, Robert Jüpner, and Jose Ramon Arevalo

The restoration of ecosystems has become a major challenge throughout the world in the 21st century (see comprehensive surveys from, e. g. Temperton et al. 2004, van Andel & Aronson 2006, Walker et al. 2007, and Zerbe & Wiegleb 2009). Due to non-sustainable land use and inefficient use of natural resources, many ecosystems have been degraded or completely destroyed. Consequently, the functioning of ecosystems has been severely affected and many ecosystem services have been lost.

The Society for Ecological Restoration (SER 2004) defines ecosystem restoration as the "*process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed*". Aronson et al. (2006) add the necessity of the restoration of ecosystem functions and Zerbe et al. (2009) give priority to the restoration of ecosystem services. Restoration, on the one hand, might be achieved through natural processes. In many cases, however, the restoration process must be initiated and supported by technical measures and continuous management. Restoration ecology has become an important scientific discipline in recent decades, which elaborates the basic and the theoretical background for practical ecosystem restoration. Today, restoration ecology as well as ecosystem restoration have to be considered as prerequisites to tackling environmental problems on a global scale, such as climate change, the loss of biodiversity, desertification and soil salinization, and biological invasions.

Since wetlands and rivers, in combination with their floodplains, provide many ecosystem services, e. g. the purification of water, combating desertification, the accumulation of carbon, and providing habitats for plants and animals, a particular focus is laid on their restoration (e. g. Lüderitz & Jüpner 2009). Although much experience and knowledge has been gathered on restoration ecology and practical ecosystem restoration in recent years, there are still many open questions and problems to be solved in order to successfully achieve restoration objectives for rivers and wetlands.

We want to address some of these questions with regard to basic and applied ecology and sustainable management within this special issue. It is comprised of papers which were presented at an international workshop at the University of Applied Sciences in Magdeburg in June 2009. The studies range from Central Europe to South America and East Asia, from streams to wetlands, from natural processes to intensive management, and from ecosystem assessment to practical implication.

For example, Mann & Tischew focus on species-rich, wet grasslands located in floodplains that are within the focus of the European nature conservation policy. In order to develop and implement new cost-efficient strategies for restoration and long-term management of wetlands on former arable land, local NGOs and the Anhalt University of Applied Sciences in Bernburg started a cooperation within a project on a heavily degraded floodplain in the Elbe river valley (Germany). Different grazing regimes by large herbivores, such as Heck cattle and Przewalski horses, were compared by applying various re-vegetation variants.

Wiegleb & Krawczynski investigate the introduction of water buffalos to very wet sites on which cattle or other domestic animals cannot graze. They report on the first results of a ten-year project in East Germany ('Bubalus' project) carried out by the Brandenburg University of Technology of Cottbus. Their study indicates the beneficial impact of moderate grazing on avifauna, amphibians, vegetation, and insects for those wetlands under consideration.

Langheinrich et al. present examples for the implementation of measures and first results of re-wetting assessment in the Drömling Natural Park, the largest fen area in Central Germany. The habitat quality of canals and ditches was enhanced and new shallow ponds were created. They conclude that all applied restoration measures help to maintain and enhance aquatic and amphibian biodiversity and the conservation value. However, the maintenance of a diverse landscape and water body structure demands comprehensive management efforts. Additionally, invasive animal species are a rising problem for the original ecosystems.

In the biosphere reserve Pfälzerwald (Palatinate Forest), Germany the maintenance of approximately 1,000 artificial ponds is endangered due to increasing abandonment. However, a large number of these ponds are of considerable significance for nature conservation and as historical heritage. Frey et al. present assessment methods which are based on easily available data for the evaluation of the ecological and cultural-historical importance of the waters. Recommendations for further development of these ponds are derived from the assessment and summarized in a priority list of ponds where actions are preferential.

Brauckmann et al. carry out an interdisciplinary research project on the integration of nature conservation objectives into organic farming, using a region in the federal state of Hessia, Germany as an example. Since 1998, conventional agricultural land use has been replaced by organic farming in this area. Restoration measures were implemented in running water courses through loess soils and then monitored. The

monitoring program comprised morphological, hydro-chemical, and biological aspects.

The study from Tröstler et al. represents a comprehensive biological and hydro-chemical assessment of small coastal ponds. Special attention is paid to brackish water biotopes. As the main problems regarding these ponds biological invasions and the decline of threatened species are identified.

Using an example from the Canary Islands, Spain, Lüderitz et al. address the problem that a considerable number of streams have decreased dramatically due to non-sustainable consumption of water for agriculture and tourism in the past decades. However, natural reaches of streams with an endemic, macro-invertebrate fauna still exist in protected areas of Tenerife and La Gomera. Those reaches serve as reference status for the development of a specific assessment method for island streams, with particular emphasis on water quality and hydro-morphology.

Ettmer & Alvarado-Ancieta investigate the Ucayali River, whose headwaters are located in high altitudes of the Andean Mountains, and which is one of the water sources of the Amazon River. A broad database on hydrology, sediment transport, and topography of the river bed could be analysed due to a study on the navigability of the Ucayali River, conducted by the Ministry of Transport and Communication in Peru. Since there has been no stream channel modification of the Ucayali River in the past, this database gives insight into the flow pattern of a natural stream in South America. The paper presents the first results, e.g. on sediment transport of the Ucayali River.

Zerbe et al. investigate the Tarim River in Xinjiang, NW China, a river system with its floodplains in continental-arid Central Asia, focusing on vegetation, ecosystem dynamics, and ecosystem restoration. The floodplains of Central Asian rivers harbour riparian, so-called 'Tugai' forests, reeds with *Phragmites australis*, and shrub communities which form a mosaic depending on the variety of available ground water. In recent decades, these natural ecosystems have been strongly altered anthropogenically or completely destroyed. In order to restore these ecosystems, knowledge of vegetation, ecosystem dynamics, and natural regeneration processes is essential. Zerbe et al. present results on soil, vegetation, forest stand age, tree vitality, river course dynamics, and land use on the landscape level. From these investigations, recommendations are derived for the maintenance of these highly valuable floodplain ecosystems, in particular with regard to their biological diversity.

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Role of megaherbivores in restoration of species-rich grasslands on former arable land in floodplains

Bedeutung der Megaherbivoren-Beweidung für die Renaturierung artenreicher Feuchtgrünländer auf ehemaligen Ackerflächen

Sandra Mann and Sabine Tischew

Abstract

Species-rich wet grasslands in floodplains are on focus of European nature conservation policy. However, since the seventies of the last century large areas with grasslands in floodplains have been meliorated, ploughed and used for intensive cropping in Germany. Therefore, restoration strategies for large-scale conversion of former arable land into species-rich grasslands and integration into a long-term sustainable land use regime are needed. Dealing with large areas in restoration projects causes high costs which often exceed the possibilities of NGO's or other stakeholders. Aiming to develop and implement new cost-efficient strategies for restoration and long-term management of wetlands on former arable land local NGO's and the Anhalt University of Applied Sciences started a co-operation within a project in a heavily degraded floodplain in the Elbe river valley. Up to now, more than 40 ha former arable land was successively bought and immediately grazed by large herbivores (Heck-cattle and Przewalski-horses). The local farmers apply a year-round grazing regime without additional feeding and low stocking density. Scientific evaluation of the project progress and experiments with different re-vegetation variants (natural recovery, hay transfer, seeding of commercial seed mixture) revealed the following results: (1) on former arable land immediate grazing with large herbivores without additional feeding is possible and leads to a successive development of typical grassland communities with low nutrient status, (2) integration of old pastures into the grazing system enhances colonization of native grassland species alongside animal tracks, (3) seeding of a commercial seed mixture impedes the colonization of native grassland species, (4) transfer of species-rich hay accelerates the colonization rate of several grassland species, and (5) highest cover of target species was found on regularly wet sites. Therefore, we conclude that grazing with large herbivores proved to be successful in converting former arable land into species-rich grasslands. Nevertheless, rising of the groundwater table is most important for further development of species-rich wet grasslands in the Wulfener Bruch.

Keywords: *restoring former arable land, floodplains, species-rich grassland, megaherbivore grazing, natural recovery, animal tracks, hay transfer, seeding of commercial seed mixture*

Zusammenfassung

Artenreiche Feuchtgrünländer stehen stark im Fokus europäischer Naturschutzstrategien. Dennoch wurden auch in Deutschland, insbesondere in den 70er Jahren des vergangenen Jahrhunderts, viele dieser Feuchtgrünländer durch Meliorationsmaßnahmen, Umbruch oder intensivste Grünlandnutzung zerstört oder degradiert. Es werden jetzt dringend Renaturierungsstrategien benötigt, die eine großflächige Umwandlung und nachhaltige Landnutzung dieser ehemaligen Ackerflächen in artenreiche Grünlandbestände gewährleisten können. Diese großflächigen Renaturierungsvorhaben überschreiten jedoch häufig die finanziellen Möglichkeiten von Naturschutzorganisationen oder anderen Interessensgruppen, so dass Methoden entwickelt und getestet werden müssen, die effektiv und dennoch kosteneffizient sind. Zusammen mit dem vor Ort aktiven Naturschutzbund initiierte die Hochschule Anhalt (FH) ein Projekt, um solche ehemaligen Ackerflächen in den Auenbereichen der Elbe wieder in artenreiches Grünland umzuwandeln und langfristig zu sichern. Mittlerweile konnten über 40 ha ehemalige Ackerflächen erworben und unverzüglich in ein Beweidungssystem mit Heckrindern und Przewalski-Pferden integriert werden. Durch die Bewirtschafter wird eine extensive Ganzjahresbeweidung ohne Zufütterung umgesetzt. Auf Basis der wissenschaftlichen Begleitung dieses Beweidungsprojektes und der Durchführung von verschiedenen Versuchsvarianten zur erfolgreichen Begrünung der Flächen (Spontanentwicklung, Mahdgutübertrag, Ansaat einer kommerziellen Regelsaatgutmischung) können mittlerweile folgende Ergebnisse belegt werden: (1) durch die extensive Beweidung mit Megaherbivoren unter dem Verzicht auf eine Zufütterung können auf ehemaligen Ackerflächen erfolgreich standorttypische Grünlandgesellschaften mit einem vergleichsweise niedrigen Nährstoffstatus entwickelt werden, (2) die Integration bereits bestehender artenreicher Grünländer in das Beweidungssystem fördert die schnelle Etablierung von Zielarten, insbesondere entlang der Hauptweidepfade, (3) eine Ansaat von herkömmlichen Regelsaatgutmischungen behindert die Etablierung standorttypischer Grünlandarten, (4) durch Mahdgutüberträge wird die Etablierungsrate verschiedener Zielarten erhöht, (5) am erfolgreichsten ist die Etablierung der Zielarten auf den bereits ganzjährig nassen Standorten. Die extensive Ganzjahresbeweidung mit Megaherbivoren ist folglich eine geeignete Methode für die Renaturierung artenreicher Grünlandbestände auf ehemals intensiv ackerbaulich genutzten Flächen. Es wird jedoch auch deutlich, dass neben der Beweidung die Anhebung der Grundwasserstände enorm wichtig für die positive Entwicklung dieser Grünlandbestände im Wulfener Bruch ist.

Schlüsselwörter: Renaturierung ehemaliger Ackerflächen, Flussauen, artenreiches Grünland, Megaherbivoren-Beweidung, spontane Besiedlungsprozesse, Tierpfade, Mahdgutübertrag, Ansaat herkömmlicher Regelsaatgutmischungen

1 Introduction

Species-rich wet grasslands in floodplains are on focus of European nature conservation policy (European Council 1992). However, since the seventies of the last century large grasslands areas in floodplains have been meliorated, ploughed and used for intensive cropping in Germany. Comparable trends have been observed in many other regions in Europe (Neuhauser 2001). In addition to the substantial loss of biodiversity, important ecosystem functions of wet grasslands such as water retention or carbon storage had been damaged and the intensive farming led to severe eutrophication of nearby ecosystems, especially of water courses. Therefore, restoration schemes for restoring species-rich grasslands on former arable land in floodplains are needed (Šeffer et al. 2008, Donath et al. 2003, Hölzel & Otte 2003, Vécrin et al. 2002).

In converting former arable land into species-rich grasslands active restoration measures such as topsoil removal and/or transfer of species-rich hay from donor populations in the surroundings had been successful (Hölzel & Otte 2003, Donath et al. 2003). Dealing with these methods on large areas in restoration projects causes high costs though which often exceed the possibilities of NGO‘s or other stakeholders. In addition, as for many other semi-natural grasslands of high nature conservation value, securing an adequate management regime is a major challenge. The restored floodplain grasslands are typically used for hay production. However, hay from species-rich grasslands of nature conservation value is often not suitable to be used in intensive cattle breeding. Furthermore, management of large-scale wetlands by mowing is often economically inefficient and long-term success depends largely on the availability of agri-environmental subsidies (Kaphengst et al. 2005). Besides these economical aspects large-scale meadows often lack structural diversity because of a uniform mowing regime (e. g. Kleijn et al. 2001). Therefore, cost-efficient restoration strategies for large-scale conversion of former arable land into species-rich grasslands and integration into a long-term sustainable land use regime are needed.

Aiming to develop and implement such a new strategy local NGO’s (Nabu Köthen and Primigenius gGmbH) and the Anhalt University of Applied Sciences started a co-operation within a project in a heavily degraded floodplain in the Elbe river valley in 1999. Up to now, more than 40 ha former arable land was successively bought and immediately grazed by large herbivores (Heck-cattle and Przewalski-horses). Similar grazing project were successfully carried out in other floodplain areas in Europe (e. g. Bunzel-Drüke et al. 2008, Pykälä 2000, Oppermann & Luick 1999, Vulink & Van Eerden 1998).

Nevertheless, the immediate grazing of fallow arable land without seeding of grassland species was never tested before and provoked many critical questions in the first years of the project. Therefore, a systematic evaluation of the project progress was started in 2002 focusing on the following questions: (1) How long does it take to restore species-rich wet grasslands on former arable land using megaherbivore grazing with regard to plant species composition and soil parameters? (2) Is it necessary to accelerate vegetation development by transferring species and how does seeding of commercial seed mixtures effects the colonization of target species?, and (3) Is there any evidence that megaherbivore grazing supports the colonization of target species on the former arable land?

2 Methods

2.1 Study area

The Wulfener Bruch is situated near the town Köthen in Saxony-Anhalt. In former times it was periodically flooded by the river Elbe. Until the seventies of the last century the groundwater table was high even in spring and summer. That resulted in the formation of soil with high organic content (> 15 %). Since the seventies of the last century large areas of the grasslands in the Wulfener Bruch were meliorated and used for intensive cropping. The remaining grasslands were intensely used. As a result of these changes in land use the organic soil has been degraded and many of the formerly species-rich grasslands has been destroyed or lost their typical species assembly. Nevertheless, 972 ha within the Wulfener Bruch are actually designed as Natura 2000 site and Special Protected Area for birds. The Wulfener Bruch is also integrated into the Biosphere Reserve “Mittelelbe”.

The actual hydrological conditions are characterized by strong groundwater table fluctuations. Especially in winter and spring the groundwater table is relatively high, but the summer is characterized by long dry periods. During the last years a slow rise of the groundwater table was achieved in some parts of the Wulfener Bruch by regulating the drainage channels. However, a further rise of the groundwater table is not possible because of still existing arable land.

2.2 Grazing Regime

Most of the bought fallow arable land was fenced together with old pastures or already developed grasslands and left for natural recovery. The local farmers (Primigenius gGmbH) apply a year-round grazing regime without additional feeding and a low stocking density with 3 up to 6 animals per 10 ha.

2.3 Soil analysis

To investigate the effects of megaherbivore grazing the following soil properties were measured in 2008: pH ($CaCl_2$), total nitrogen and organic carbon content (Leco-analyzer), and calcium-acetate-lactate (CAL) soluble phosphorus and potassium (AG Boden 1994).

Samples were taken randomly at 14 locations on megaherbivore pastures formerly used as arable land, at four locations on megaherbivore pastures established on formerly intensive grasslands, and at four locations used as dunging areas by the animals above average.

For each soil sample ten soil cores were taken in a depth of 0–10 cm using a 3 cm diameter corer, and subsequently pooled for analysis. The same method was applied at eight locations on remnants of species-rich old grasslands and at 8 locations on still existing arable land. The number of soil samples was adapted to the extension of the studied sites. For statistical analysis of data we applied a Kruskal-Wallis Test and a Post Hoc Test (Tamhane) using SPSS 16.0.

2.4 Experiments

On newly integrated fallow arable land experiments were implemented to test the effect of hay transfer from adjacent species-rich grasslands as well as sowing of commercial seed mixtures against the natural recovery of the grasslands. The two experiments were implemented in complete block design in 2002 and 2003 with three replicates for the three variants (= 3 blocks). The three variants (natural recovery – nat, hay transfer – hay, and seeding of commercial seed mixture – seeds) were randomly arranged within the three blocks. The size of one block is approximately 240 m x 100 m (three stripes for each of the variants; stripe size 80 m x 100 m).

For hay transfer, material was harvested on two of the species-rich wetland remnants of the Wulfener Bruch (Hirschteich and Strudellöcher) which are characterized by C n i d i - o n -plant communities. They are approximately in 1,300 m respectively 900 m distance from the receptor sites. The hay-transfer ratio from donor to receptor sites was 2 : 1.

The commercial seed mixture consisted mainly of different *Festuca rubra*-varieties, as well as *Lolium perenne* and *Dactylis glomerata*.

Depending on the uneven ground profile the water conditions vary from dry to periodically wet. Experiment A is characterized by wet conditions in most parts whereas experiment B shows predominantly dry to periodically wet conditions. Complete species lists with frequency classes were compiled for the whole area of each replicate.

On each replicate of the variants relevés with percentage cover of each single species were performed on five permanent plots (size 25 m^2, altogether 15 permanent plots per variant). In addition the individuals of target species were counted on these permanent plots. Plant species (e. g. *Cnidium dubium*, *Serratula tinctoria*, *Allium angulosum*, *Galium boreale*, *Centaurea jacea*, *Leucanthemum vulgare* and *Sanguisorba officinalis*) were considered as target species if they occurred regularly in old species-rich grasslands of the Wulfener Bruch. Rare species were included if they are typical for species-rich floodplain grassland in general.

During the monitoring it became obvious that some parts of the megaherbivore pastures are benefiting more from the local rising of the groundwater table and vegetation develops differently from the dryer parts. Therefore, we established additional permanent plots on those sites in 2006. In order to compare the natural recovery within the experiments with vegetation development on regularly wet sites we randomly selected twelve 25 m^2-plots in nearby parts of the pastures representing such conditions and monitored them in the same way since 2006.

2.5 Floristic and animal track mappings

Since 2002 complete species lists of all vascular plants were compiled on the megaherbivore pastures. In 2005 and 2009 all locations of target species were mapped on former arable land which has been connected with already developed species-rich old grasslands by fencing these sites together. In addition we drew all visual recognizable animal tracks in another map. Finally these two maps were blended together.

3 Results

3.1 Soil Analysis

The soil analyses reveal the degradation of the former organic soil (Fig. 1). This is particularly true for the pastures on former arable land, but the carbon content is already slightly higher compared to still existing arable land in the surroundings. Megaherbivore pastures on former grassland sites have much higher carbon content. Remnants of species-rich wet grasslands (= target vegetation) can be found only in small depressions in the Wulfener Bruch. These grasslands show a carbon content of about 10 to 14 percent.

Potassium and phosphorous values reveal dislocation processes on the megaherbivore pastures. Dunging areas have much higher potassium and phosphorous values, but they occur only in small parts of the pasture. Large areas of the megaherbivore pastures have potassium and phosphorous values comparable to those of the target vegetation or show even lower values. Phosphorous values of the megaherbivore pastures are particularly low compared to the still existing arable land in the surroundings. PH-values range from 6.7 to 7.6 without notable differences between groups.

3.2 Experiments

Figure 2 shows the development of target species (dots) and ruderal species (rectangles). Ruderal species increased rapidly in the first two years in nearly all variants, but continuously decreased afterwards. Only on dry to periodically wet sites the commercial seed mixture impeded the development of ruderal species. However, the dense grass swards created by this seed mixture also impeded the colonization of target species, which was faster on all other sites. On periodically wet sites the commercial seed mixture did not work. Therefore, the development was similar to the control variants.

Transfer of species-rich hay from other wetlands accelerated the percentage coverage of target species. In the last year control variants achieved comparable cover of target species. The realized transfer rate on receptor site was 86 %, but the population density and coverage, especially of rare species, is still rather low and some rare species of the donor sites are still missing. However, all together 35 species, which were not able to colonize spontaneously, could be established by hay transfer until 2008, among them typical wetland species such as *Allium angulosum*, *Cirsium canum*, *Tetragonolobus maritimus*, *Galium boreale*, and *Sanguisorba officinalis*. High transfer rates and coverage on receptor sites were observed for more common species such as *Centaurea jacea*, *Leucanthemum vulgare*, and *Galium album*.

Best results regarding target species were achieved on natural recovered permanently wet sites which were monitored since 2006.

The percentage cover of *Cirsium arvense* was extremely high in the first two or three years in all variants, except for the dry variant with commercial seed mixture. However, the percentage cover decreased rapidly in the next years (Fig. 3).

3.3 Floristic and animal track mappings

Floristic mappings revealed that more than 280 species spontaneously colonized the former arable land since 2002. Among them are rare or red list species such as *Carex vulpina*, *Centaurium pulchellum*, *Cnidum dubium*, *Inula britannica*, *Pulicaria dysenterica*, *Samolus valerandi*, *Scutellaria hastifolia*, *Senecio aquaticus*, *Teucrium scordium*, *Thalictrum flavum*, and *Viola stagnina*.

The mappings of the selected target species locations show a predominantly linear pattern. By blending the results together with the mappings of the animal tracks almost all species were found alongside these animal tracks (Fig. 4). For all target species we located donor populations in the old species-rich grassland which is connected by a passage with the former arable land. That refers to dispersal by fur, dung and adhesion on hooves whereas wind dispersal should not be excluded since the old grassland is situated in the main wind direction (west of the pasture on former arable land). At the same time the animals created through their hooves prints small disturbances in which the target species could establish. In autumn 2008, we even could find many seedlings from *Cnidium dubium* on open sites in hooves prints of the animals. Nevertheless, target species density was higher on wet sites close to the ditch “Landgraben” or in wet small depressions within the pasture. In 2009 population sizes of most target species increased considerably.

4 Discussion

4.1 Grazing with megaherbivores as a tool for developing wetlands after abandonment of arable land?

Our results are in line with many studies which show the benefits of grazing with large browsing animals in wetland restoration (McCoy & Rodriguez 1994, Redecker et al. 2000, Vulik 2001, Reeves & Champion 2004, Bunzel-Drüke et la. 2008). Even in our special case of developing wetlands after abandonment of arable land grazing with megaherbirvores proved to be most successful in converting the initial ruderal plant communities to species-rich grasslands. For reducing rude-

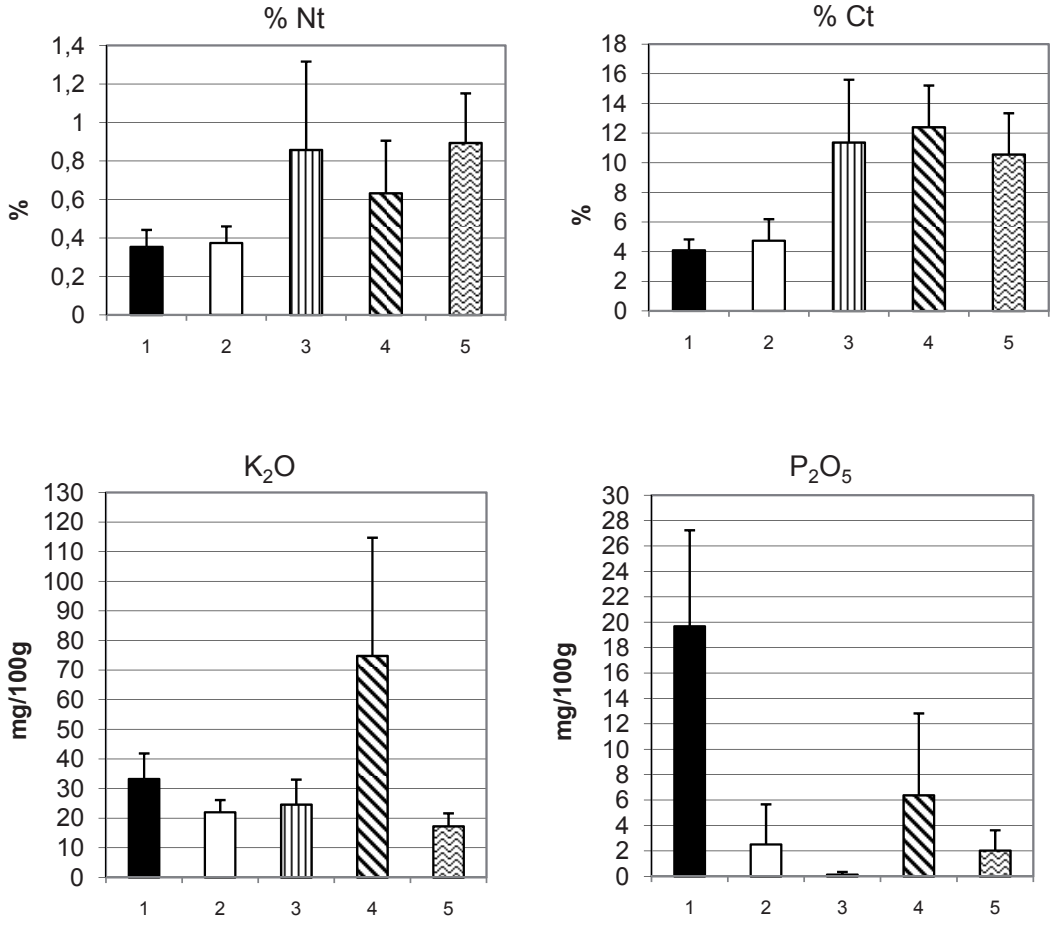

Fig. 1: Results of the soil analysis in 2008; 1 – arable land (n = 8), 2 – megaherbivore pasture on former arable land (n = 14), 3 – megaherbivore pasture on former intensively used meadow (n = 4), 4 – dunging areas on megaherbivore pasture (n = 4), 5 – target vegetation (n = 8); Kruskal-Wallis Test: significant differences between groups ($p < 0.05$); Post Hoc Test (Tamhane): differences are significant for % Nt 1–5 (0.006) and 2–5 (0.009), % Ct 1–5 (0.004) and 2–5 (0.006), K_20 1–5 (0.013), P_2O_5 1–2 (0.004), 1–3 (0.002), and 1–5 (0.004).

Abb. 1: *Ergebnisse der Bodenanalysen im Jahr 2008; 1 – Ackerflächen (n = 8), 2 – Extensivweide mit Megaherbivoren auf ehemaligem Ackerland (n = 14), 3 – Extensivweide mit Megaherbivoren auf ehemaligem Intensivgrünland (n = 4), 4 – Kotplätze/ Lagerflächen auf Extensivweide mit Megaherbivoren (n = 4), 5 – Zielvegetation (n = 8); Kruskal-Wallis Test: signifikante Unterschiede zwischen den Gruppen ($p < 0.05$); Post Hoc Test (Tamhane): Differenzen signifikant für % Nt 1–5 (0.006) und 2–5 (0.009), % Ct 1–5 (0.004) und 2–5 (0.006), K_20 1–5 (0.013), P_2O_5 1–2 (0.004), 1–3 (0.002) und 1–5 (0.004).*

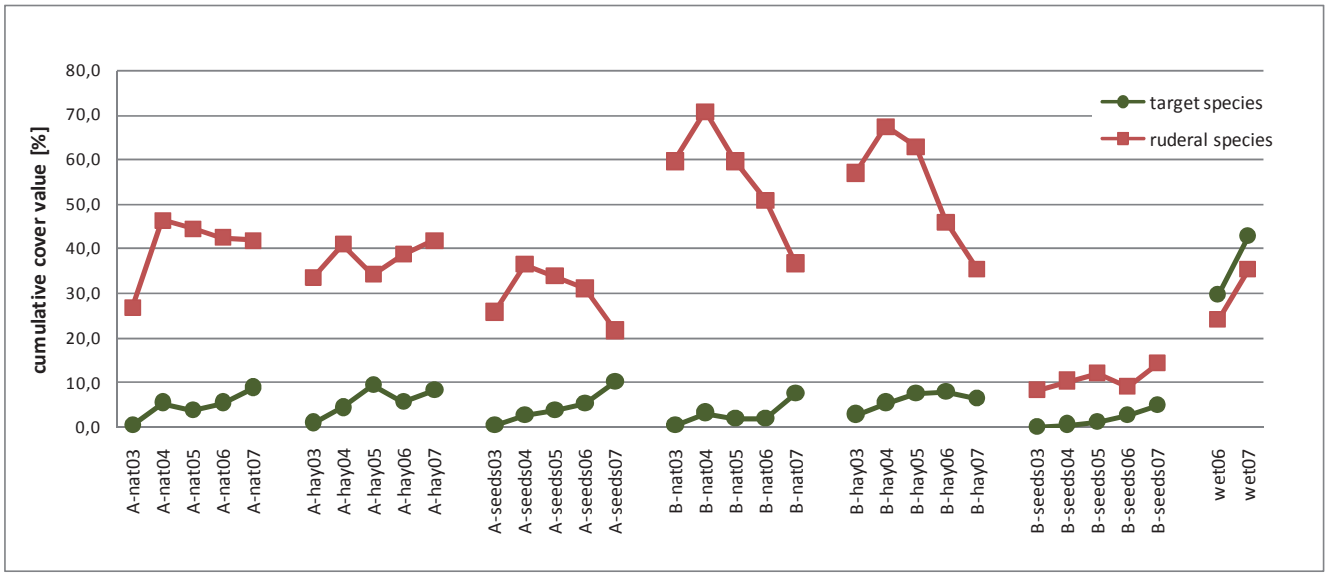

Fig. 2: Mean cumulative coverage of target species (dots) and ruderal species (rectangles); A – wet to periodically fresh conditions, B – dry to periodically wet conditions; variants: natural recovery – nat (n = 15), hay transfer – hay (n = 15), seeding of commercial seed mixture – seeds (n = 15); wet – plots with natural recovery on permanent wet sites (n = 12).

Abb. 2: *Durchschnittliche Deckungsgradsummen der Zielarten (Kreise) und Ruderalarten (Vierecke); A – feucht bis periodisch frisch, B – trocken bis periodisch frisch; Varianten: Spontanbesiedlung – nat (n = 15), Mahdgutübertrag – hay (n = 15), Ansaat mit Regelsaatgutmischung – seeds (n = 15); wet – Flächen mit Spontanbesiedlung und kontinuierlich guter Wasserversorgung (n = 12).*

ral species such as *Cirsium arvense* winter and early spring grazing was most important. Gerken et al. (2008) observed the same reduction of *C. arvense* on former arable land after grazing with cattle and horses. Only in these seasons ruderal species were consumed in large quantities. Five years after abandonment of intensive farming species composition is actually dominated by typical grassland species. Many target species have been established either by spontaneous colonization or after introduction by hay transfer and several Red list species could be determined. Even *Cnidium dubium* which is one of the typical species of alluvial grasslands and successful germination is considered a rather rare event (e. g. Kotorová & Lepš 1999) established successfully. On the other hand, the cover value of target species is relatively low except for the permanent plots characterized by permanent wet conditions. That refers to the importance to improve water conditions in the Wulfener Bruch in the future.

Large areas of the megaherbivore pastures have potassium and phosphorous values which are already favourable for restoration of species-rich floodplain grasslands. This is particularly important for phosphorous since floodplain restoration is only successful if plant available phosphorous is limited (Hölzel & Otte 2003). In contrast, after more than three decades of intensive cropping and melioration the carbon content of our studied former arable sites is still low. In addition to the unsuitable water regime in most parts of the

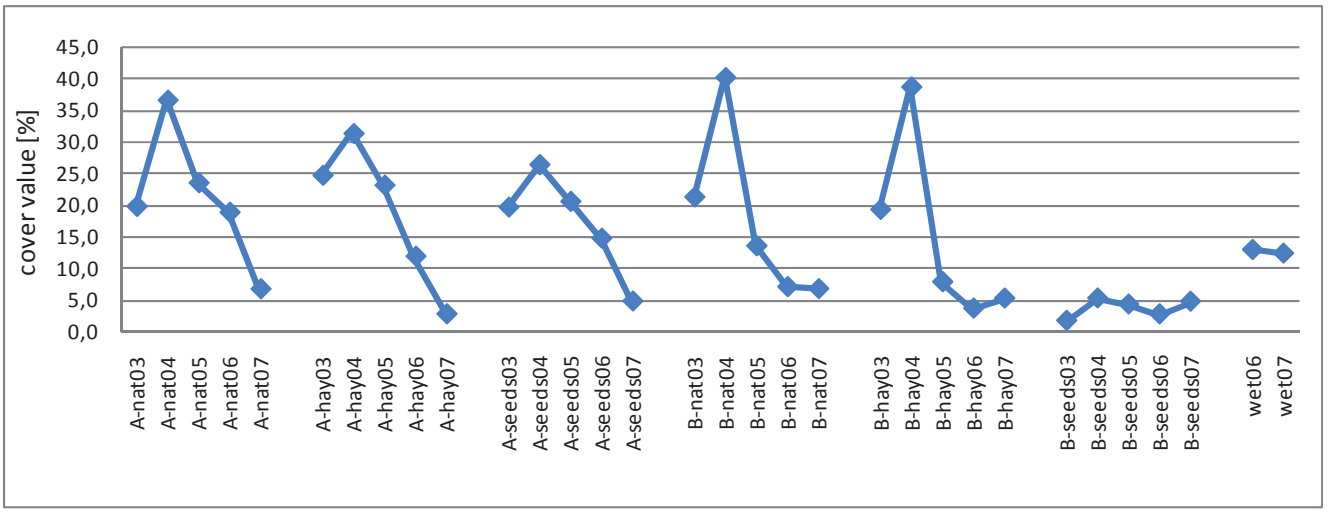

Fig. 3: Mean cover value of Cirsium arvense; A – wet to periodically fresh conditions, B – dry to periodically wet conditions; variants: natural recovery – nat (n = 15), hay transfer – hay (n = 15), seeding of commercial seed mixture – seeds (n = 15); wet – plots with natural recovery on permanent wet sites (n = 12).

Abb. 3: *Durchschnittliche Deckungsgrade von Cirsium arvense; A – feucht bis periodisch frisch, B – trocken bis periodisch frisch; Varianten: Spontanbesiedlung – nat (n = 15), Mahdgutübertrag – hay (n = 15), Ansaat mit Regelsaatgutmischung – seeds (n = 15); wet – Flächen mit Spontanbesiedlung und kontinuierlich guter Wasserversorgung (n = 12).*

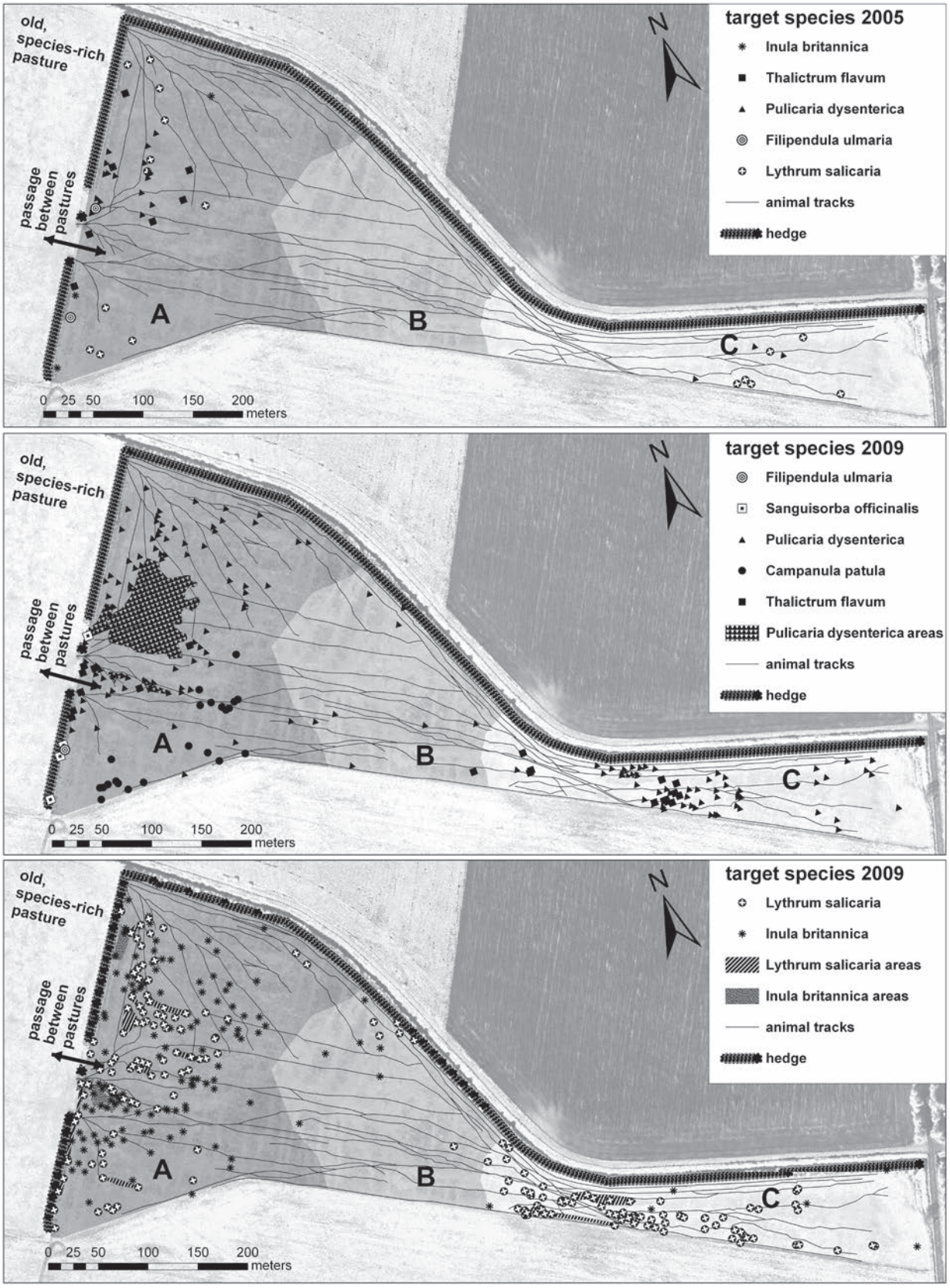

Fig. 4: Colonization of selected target species alongside animal tracks on pastures established on former arable (until 2001) land between 2005 and 2009. On the western edge the new pasture is connected with old species-rich grassland (see arrow). (A & C – wet to periodically fresh conditions, B – dry to periodically wet conditions; data source background map: aerophoto from area inventory 2005. Ministry for Agriculture and Enviroment Saxony-Anhalt)

Abb. 4: *Etablierung ausgewählter Zielarten entlang von Tierpfaden bis zum Jahr 2005 und 2009 auf einer Beweidungsfläche, die bis zum Jahr 2001 ackerbaulich genutzt und seit 2002 beweidet wird. Westlich der Hecke ist die Fläche mit einer artenreichen Grünlandfläche verbunden (siehe Pfeil). (A & C – feucht bis periodisch frisch, B – trocken bis periodisch frisch bis feucht; Datengrundlage Hintergrundbild: Aufnahme aus der Geländeinventur 2005 Ministerium für Landwirtschaft und Umwelt Sachsen-Anhalt)*

Wulfener Bruch that seems to be another reason for the relatively low cover value of target species up to now. Therefore, we conclude that high nature conservation value farmland on former arable land obviously needs time for development even under target-orientated management.

In context of landscape development our Megaherbivore project creates a multifunctional landscape (see also Schley & Leytem 2004). Besides the improvement of biodiversity and structural diversity the extensive grazing regime supports carbon fixation and soil formation. Furthermore a sustainable and high quality meat production had been established at former intensively used farmland. And last but not least, our megaherbivore project achieves best regional acceptance because there is always an opportunity to watch the impressive Heck-cattle and wild horses on the pastures.

4.2 Is it necessary to accelerate vegetation development by transferring species and which effect causes seeding of commercial seed mixtures?

Many studies showed that without species introduction colonization of target species on former arable land proved to be less successful (e. g. Bakker & Berendse 1999, Verhagen et al. 2001, Donath et al. 2007). Hay transfer is obviously the most applied method for transferring species in restoration projects and leads to high transfer rates and the development of plant communities rich in target species (Kirmer & Tischew 2006). In our studies, hay transfer accelerated the development of target species in general. 35 species, which were not able to colonize spontaneously, among them many target species which did not have donor populations in the nearby surroundings, were transferred to the study site. Nevertheless, in the fifth year spontaneously developed sites reached a similar target species-cover.

In contrast to the above mentioned studies our sites were a) connected with sites were many target species have donor populations and b) instead of mowing the sites were managed by grazing. Both circumstances obviously supported the natural recovery of species-rich grasslands. Therefore, in similar situations hay transfer should be applied on selected (rather small) sites to add species which do not have nearby donor populations and subsequently colonization of the whole site can be expected afterwards. That procedure also reduces the relatively high cost for species introduction dealing with large areas (Neuhauser 2001).

In addition special preparation of sites where seed-rich hay is to be applied is recommended to enhance establishment of target species. In our study hay transfer was performed when vegetation cover was already more or less closed with ruderal species and some grasses. That high competitive situation caused high seedling mortality of the target species. Therefore, we recommend for hay transfer experiments to create at least small stripes of bare soil by ploughing or harrowing (see also Donath et al. 2007).

Sowing of commercial seed mixtures led to dense vegetation cover, mainly dominated by the sown species and delayed the colonization of target species. These findings are in line with a study by Vécrin et al. (2002) where ruderal and annual species had decreased three years after restoration, but target species were still poorly represented in the sown grasslands. Commercial seed mixtures are often used because they are cheap and they suppress the development of ruderal species on fallow arable land. However, in addition to the above mentioned negative effects related to delayed colonization of target species there is a risk for bastardization with native flora since non-native species or genotypes are introduced by these seed mixtures (McKay et al. 2005). By using native grass ecotypes in restoration projects of floodplain meadows along the northern Upper Rhine simultaneous sowing of grasses did not hamper seedling recruitment from seed-rich hay in most cases, and thus seems to be a feasible measure to accelerate the integration of newly created floodplain meadows into farming systems (Donath et al. 2006).

4.3 Is there any evidence that megaherbivore grazing supports the colonization of target species into the former arable land?

Seed dispersal via ingestion, defecation or adhesion in combination with the creation of small-scale disturbances caused by hooves prints is assumed to support the colonization of target species in restoration projects (Wessels et al. 2008, Mitlacher et al. 2002, Couvreur et al. 2004). Sheep disperse high amount of seeds in their fleece (Fischer et al. 1996), but cattle and horses disperse orders of magnitude more seeds via dung than via their fur (Couvreur et al. 2004). Mouissie et al. (2005) found that cattle disperse approximately 2.6 Million seeds per animal per year per dung. Seed density in horse dung ranges from 280 to 525 seedlings per litre (Cosyns & Hoffmann 2005). On the other hand, current studies demonstrated that measured germination from dung under glasshouse conditions often over-estimates likely rates of establishment in the fields (Pakeman & Small 2009). Moreover, other studies highlight the potential threat of invasive plant spread, for example weed and grass input into Scottish heather moorland by cattle dung (Welch 1985). Schwabe & Kratochwil (2004) and Süss et al. (2004) emphasize that seed input from non-target communities into target communities caused by migratory grazing negatively affected biodiversity for inland sand ecosystems. Mouissie et al. (2005) showed that in grazing systems with high and low productive parts mainly seeds of common species were dispersed from high productive parts to low productive parts and not in reverse. The authors of that study recommend integrated grazing with only target plant communities and not with plant communities on fertile soils rich in non-target ruderal species as performed in our study. In contrast to these studies we could not find negative effects on species assembly caused by seed input from ruderal species of the newly abandoned fields into the nearby old species-rich pastures although certainly many seeds of ruderal species were consumed by the animals and consequently dispersed by dung. Surprisingly, in reverse many target species from the old species-rich pastures colonized the former arable land. The distribution pattern of target species is strongly connected to animal track pattern. This can be explained by three processes. First of all the old pastures have significantly less nutrient content and therefore ruderal species are less competitive (site-condition filter). Secondly, the year-round grazing by Heck-cattle and wild horses obviously suppressed the establishment of ruderal species on the old pastures. The continuous decrease of ruderal species even on the former arable land supports

that explanation. And thirdly, the animals create niches for establishment by producing small-scale disturbances which are obviously particularly needed by the less-competitive target species. Altogether the connection of old species-rich pastures with the newly abandoned arable land proved to be very successful regarding the dispersal and establishment of target species. Gerken et al. (2008) also observed that target species like *Isolepis setacea*, *Peplis portula* and several species of mosses and lichens followed the animal tracks.

4.4. Implications for practice

Our studies show that on former arable land immediate grazing with large herbivores is possible and leads to a successive development of species-rich grassland communities with low nutrient status. The integration of old pastures into the grazing system considerably enhances colonization of native grassland species, especially alongside animal tracks. Seeding of a commercial seed mixture is not only needless, but above all impedes the establishment of native grassland species. The transfer of species-rich hay accelerates the colonization rate of several grassland species, which were not able to colonize the former arable land spontaneously. Nevertheless, rising of the groundwater table is most important for the development of species-rich floodplain grasslands since highest cover values of target species were found on regularly wet sites.

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Biodiversity Management by Water Buffalos in Restored Wetlands

Biodiversitätsmanagement mit Wasserbüffeln in renaturierten Feuchtgebieten

Gerhard Wiegleb and René Krawczynski

Abstract

The use of water buffalos for landscape maintenance started ten years ago in Germany. Now, more than 2,100 buffalos are kept by about 90 breeders, and first results concerning their usefulness for landscape management are available. Buffalos are mainly used on particularly wet sites which cannot be grazed by cattle or other domestic animals. Although grazing of wetlands, river banks and water bodies is still controversial, early results from literature and our own research clearly indicate the beneficial impact of moderate grazing on such sites for birds, amphibians, vegetation and insects. This paper presents a short literature review and the first results of the BUBALUS project at Brandenburg University of Technology (BTU) and general experience from other projects.

Keywords: *Grazing behaviour, wallowing, dung, food webs, vegetation structure*

Zusammenfassung

Seit etwa zehn Jahren gibt es in Deutschland den verstärkten Trend, Wasserbüffel zu halten. Inzwischen gibt es mehr als 2.100 Wasserbüffel bei mehr als 90 Haltern. Erste Ergebnisse ihrer Eignung als Landschaftspfleger in Feuchtgebieten sind nun verfügbar. Die Büffel werden überwiegend auf besonders nassen Standorten eingesetzt, die für die Haltung von Rindern oder anderen Haustieren nicht geeignet sind. Obwohl die Beweidung von Nassstandorten, Ufern und Gewässern noch immer umstritten ist, zeigen die verfügbaren Ergebnisse den Nutzen für Vögel, Amphibien, Insekten und Vegetation.

Dieser Artikel gibt eine kurze Übersicht zu relevanter Literatur sowie erste Ergebnisse des BUBALUS Projektes der Brandenburgischen Technischen Universität Cottbus (BTU) sowie generelle Erfahrungen aus anderen Projekten.

Schlüsselwörter: Fraßverhalten, Suhlen, Dung, Nahrungsnetze, Vegetationstruktur

1 Introduction

Over the last two decades, a concept of holistic biodiversity conservation has developed that aims to restore degraded ecosystems (see Bunzel-Drüke et al. 2008 for a review). In a natural system, processes such as flooding (Gerken 2006), fire and grazing (Schley & Leytem 2004) create structures and micro-habitats for many endangered species. Fires and floods have been and continue to be suppressed, and grazing is the only natural process which can be simulated without conflicting with other socioeconomic interests (Bunzel-Drüke et al. 2008, Overmaars 2001, Gerken & Görner 1999). Traditionally, herbivores such as sheep and goats were used for grazing in heath lands or dry grasslands. It was only in the late 1980s and 1990s that management of wetlands such as floodplains or bogs through the use of horses and cattle became more common (Bunzel-Drüke et al. 2008), and it was only very recently that, for the first time in the history of German biodiversity conservation, horses and cattle have been allowed to graze year-round in a deciduous forest complex (Gerken et al. 2008).

However, woodland pasturing is still strictly forbidden in most parts of Germany and has been since about 1850. Current research results will not change this easily (Gerken et al. 2008). Although not explicitly forbidden, grazing of wet sites or water bodies is viewed extremely critically and avoided. Despite traditional views, grazing in some wet sites along has been studied (Barth et al. 2000, Kazoglou & Papanastasis 2001, Krüger 2006, Gerken et al. 2008, Krawczynski et al. 2008). Results show that grazing at such sites is beneficial for biodiversity conservation. Under wet conditions, however, grazing with traditional herbivores such as sheep, goats, horses and even cattle might not be possible and can even lead to catastrophic results for the animals (Petermamm et al. 2008). There has been a successful attempt to use moose (*Alces alces*) in wetlands to reduce shrubs and trees (Burkhart 2006). But as moose are browsers, unwanted succession of grasses could not be prevented, and handling as well as fencing of moose is not always easy.

During the last 10 years, several projects have begun to use water buffalos (*Bubalus bubalis*) in wetlands. Water buffalos are domesticated animals which can be handled more easily than moose, they are grazers or at least mixed feeders, and no special fencing is needed. Nevertheless, grazing with water buffalos has often been rejected in Central Europe because the animals are perceived as tropical and exotic (Krawczynski et al. 2008).

2 Literature review

2.1 Why grazing of wetlands and reed beds?

Over the last three decades, special focus has been given to conservation and expansion of reed beds (Mook & van der Toorn 1982, van der Toorn & Mook 1982, Ostendorp 1989, Kühl & Neuhaus 1993). Different laws and regulations in all federal states of Germany declare reed beds to be "*especially protected habitats*" (§ 30 BNatSchG). This was mainly due to the assumption that reed beds (similar to beech forests) represent natural vegetation in Central Europe and that protec-

tion of birds such as the marsh harrier (*Circus aeruginosus*) and great bittern (*Botaurus stellaris*) required vast monotonous reed beds. Despite reed bed protection, populations of wetland species including the great bittern (*Botaurus stellaris*), little bittern (*Ixobrychus minutus*), little egret (*Egretta garzetta*) and all species of crake (*Fulica* spp.) except Coot (*Fulica atra*) have declined (Bauer et al. 2005).

Some reed bed birds including the harriers and bittern are nidicolous birds. The nestlings stay in the nest and are fed by the adults who hunt outside the dense reed bed. Crakes, on the other hand, are nidifugous birds. The nestlings leave the nest and look for food in the reed beds. Although reed beds as we know them today are a suitable breeding habitat, they are not a proper feeding habitat for the nestlings. The nestlings are carnivorous and need a larger supply of insects, spiders and mollusks. In monotonous reed stands, diversity of structure and availability of proper food are rather low. Water rails (*Rallus aquaticus*) need enough space to move through vegetation (Bauer et al. 2005). For spotted crake, "*optimal population densities were found in the reed beds after fire*" (Bauer et al. 2005). Krüger (1999, 2006) stresses the importance of open, shallow waters for fishing birds such as herons and muddy sites free of vegetation as feeding habitat for snipes.

Obviously, reed beds in natural landscapes would have a richer structure, otherwise the mentioned birds could not have evolved. Large herbivores including horses, European bison (*Bison bonasus*), aurochs (*Bos primigenius*) and red deer (*Cervus elaphus*) would have grazed in reed beds and created gaps and path systems. In addition to the large herbivores which would structure reed beds by grazing in natural ecosystems, there are a number of insects that also feed on reed and therefore can potentially structure the beds, including lepidopterans such as *Archanara geminipuncta* (Todeskino et al. 1994), flies such as *Lipara lucens* or leaf mining flies of the family *Agromyzidae* and midges such as *Giradiella inclusa* (Tscharntke 1988). It seems, however, that the influence of insects alone is not enough to maintain the reed habitat for the mentioned birds. The complex influence of vertebrate herbivores, insects, water table and competition among *Phragmites*, *Typha* and *Schoenoplectus* should be studied in the future.

Thus, even for the bittern and little egret, it is not sufficient to simply protect reed beds. For conservation of these species, Bauer et al. (2005) have suggested cutting parts of the reed regularly and creating richly structured reed beds. Little egrets can only be helped by preventing reed beds from covering all shallow waters. It has therefore become apparent that monotonous reed beds have to be structured to offer all reed breeding birds with suitable breeding and feeding habitats.

In January and February 2009, two small areas of the reed stands at Herter See in Lower Saxony (Germany) were blown up with dynamite to create pools for amphibians and birds (Anonymous 2009). It is doubtful whether maintaining wetlands with explosives is sustainable or desirable. On the other hand, grazing with livestock in low densities has proved beneficial for birds breeding in reed beds (Gulickx et al. 2007, Kazoglou et al. 2004, Andres & Reisinger 2001). Bauer et al. (2005) have suggested abandonment of grazing as one reason for the local extinction of common spoonbill (*Platalea leucorodia*). Bremer et al. (1999) offer an aerial image of a colony of *Platalea leucorodia*. The breeding sites are in a grazed patch within a dense reed bed. Wallows of wild boar (*Sus scrofa*) have provided sufficient habitat for water rails (Bauer et al. 2005). Wallows of water buffalos should do the same.

2.2 What are water buffalos?

Water buffalos are only distant relatives of cattle (Fig. 1). Their evolutionary lines separated about 5 million years ago. Therefore cattle and buffalos cannot interbreed as is the case with cattle/bison/yak (for more explicit information see Alexiev 1998 and Krawczynski et al. 2008).

Water buffalos are not only adapted to warm climates. Palaeontological research, especially in China, has shown that water buffalos and Przewalski's horses lived together in northeast China during the last glaciation in cold steppe climate (Tong 2007). Nevertheless, and despite their thick winter fur, buffalos should be given shelter in the form of thickets, reed beds or artificial shelters as is done for cattle.

2.3 Why water buffalos?

In flood plains and similar wetland habitats, cattle and horses can be kept without major problems. In fens, bogs or marsh lands, however, cattle and horses often reach their ecological limits. For example, the Weserumlauftal bei Bodenfelde nature reserve is within the floodplain of the Weser River, and large parts of it are a peat bog. Heck cattle and Exmoor ponies avoid these parts, allowing a succession of dominant plants including *Alnus glutinosa*, *Salix cinerea* and *Carex acutiformis* to form large stands, while less competitive species such as *Menyanthes trifoliata* and *Carex lasiocarpa* have declined or vanished (Gerken et al. 2008). In a marsh land in northwest Germany, 18 Heck cattle were lost in a conservation project in the winter of 2008 because the cattle drowned, became stuck in mud pools or starved as they tried to live on rush (*Juncus* sp.), which were the only plants available in winter (Petermamm et al. 2008). The digestion system of cattle is not adapted to digest rush (Krawczynski et al. 2008) and the animals died despite stomachs full of the plant (Petermamm et al. 2008).

Target conservation species include wading birds, and so the areas should be grazed to provide the structure these birds require, but cattle and horses cannot do the job. Water buffalos are adapted to such conditions and are able to live on rush in winter (Krawczynski et al. 2008). They are well adapted to Central European winters and will grow a thick fur in year-round grazing systems (Krawczynski et al. 2008, Hering et al. 2009).

Although water buffalos generally have no problems with mud and irrigation ditches, in the BUBALUS project, two buffalo cows suffering from infections and fever died in an irrigation ditch in one year. Although they had never had problems with the ditch before and used it for wallowing, they were weakened so much by disease that they were unable to leave the ditch. Two buffalo cows met a similar fate last winter in Saxony-Anhalt (Bley, pers. comment). These cases underline that only healthy buffalos have no problems with muddy terrain. Care should be taken to check the animals' conditions regularly as buffalos suffering from a fever will use any available water to lose body heat. Buffalos which separate themselves from the herd should raise suspicion.

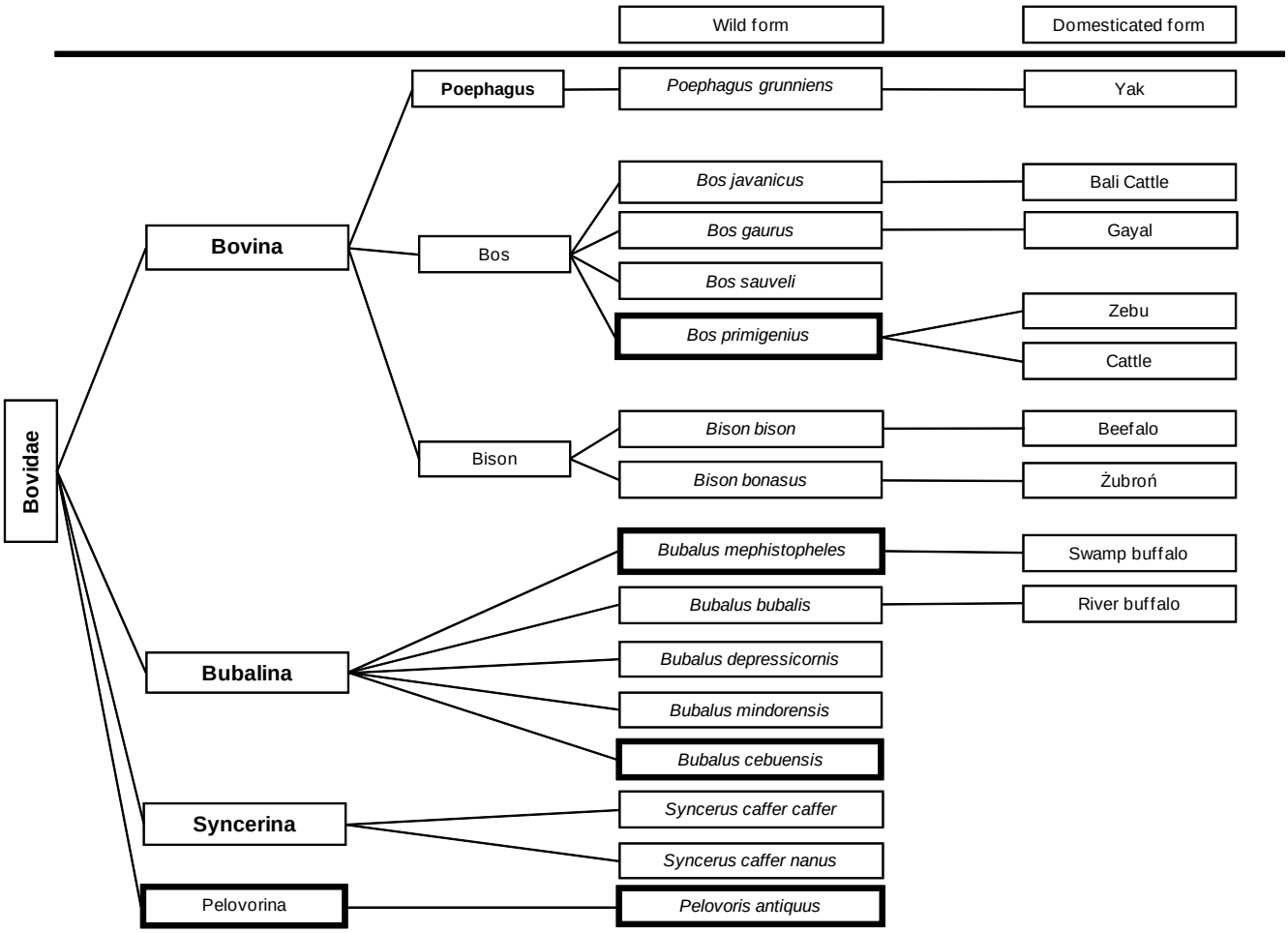

Fig. 1: Relationship between water buffalos and other Bovidae. Heavy black boxes indicate extinct species.

Abb. 1: *Verwandtschaft von Büffeln und anderen Boviden. Die fetten Kästchen markieren ausgestorbene Arten.*

3 Materials and Methods

The area for the BUBALUS project is near the river Spree about 10 km north of the city of Cottbus near the village Dissen (Brandenburg, Germany). Grazing by buffalos started in July 2008. Five buffalo cows and two Konik horses were released into a 7 ha pasture. By summer 2009, two young bulls (Heck cattle) and a stallion (Konik) were also brought to pasture. As the buffalo cows had been in calf when bought, the herd increased to ten buffalos. In total, the study site was grazed by 2.0 livestock units per hectar in summer 2009, which was not optimal. In December 2009 the number of animals was reduced to six (three Koniks and three young female buffalos). In addition to the pasture itself, the animals have access to 0.5 ha of woodland which had been an allée with oaks and alders. The allée has been neglected in the past and a number of young trees, especially *Alnus glutinosa*, now cover its edge and small areas of the meadow. The shrub layer in the allée consists mainly of *Sambucus nigra*. All trees and shrubs higher then 1.30 m (standard height for tree inventory) were inventoried and examined for traces of use by buffalos.

In winter, about one-third of the pasture is covered by water, mainly the southwest part. The existing pools are potential reproduction habitats for several amphibians (see below). However, drought in spring 2008 and spring 2009 led to the pools drying up in May and April, respectively. To ensure a water supply for the animals, a watering hole was dug: the bank was removed from the irrigation ditch “Grenzgraben” on the east side of the meadow to allow the animals to drink there (Fig. 2).

Vegetation consisted of typical plant communities for barren wet pastures. Three species of rush (*Juncus conglomeratus*, *J. effuses*, *J. inflexus*) covered about half of the area. Drier parts contained large amounts of *Cirsium arvense*. The pools were totally covered by *Glyceria fluitans*.

4 Results

4.1 Buffalo wallows

The reason water buffalos go wallowing is that they have problems withstanding high temperatures. This is due to their skin which is about six times as thick as that of cattle with about one-sixth as many sweat glands (Sambraus & Spannl-Flor 2005). If no water is available, they seek the shade of trees, but they prefer wallowing. When no permanent pools are around, they use temporary pools after rain to wallow. Through their wallowing, they deepen the pools and create sites where water will be available longer than in surrounding untouched pools. Our original five buffalos dug four wallows in three months (27, 50, 90 and 152 m^2 in size). By August 2009, the buffalo herd had increased to ten animals, and one more wallow were created.

The wallows are free of larger vegetation and offer habitat for smaller plant species such as *Myosurus minimus* or *Triglochin palustre*. We expect species adapted to flood plains and temporary water bodies such as tadpole shrimp (*Triops cancriformis*) to appear in the wallows. Mallards (*Anas platyrhynchos*) visit the wallows and might act as dispersal agents for plants and other organisms. After one year of buffalo grazing, *Ranunculus peltatus* appeared in one of the less often frequented pools. At the regularly used wallows, *Rorippa palustris* appeared in large numbers when the wallows fell dry.

Before the buffalos began grazing in spring 2008, no tadpoles were found in any of the pools. Although a number of amphibian species (common newt [*Triturus vulgaris*], red bellied toad [*Bombina bombina*], common toad [*Bufo bufo*], common frog [*Rana temporaria*] and edible frog [*Rana* kl. *esculenta*]) were found in the pools, there was no apparent reproduction. In 2009, however, there were tadpoles found in one of the less frequently used wallows. Red bellied toads use the wallows more frequently than other amphibians. Unfortunately, due to the dry April of 2009, the pools all fell dry by the end of that month. Only the most intensively used wallow kept water for a few more days. The drying pools and wallows no longer provided reproduction habitats for amphibians, but the deep hoof prints offered moist daytime conditions. All amphibian species living on the meadow except *Triturus vulgaris* have been found using the hoof prints as daytime shelter. It is known however that *T. vulgaris* also uses hoof prints (Gerken et al. 2008). We have observed the same for yellow bellied toad (*Bombina variegata*) in hoof prints of domestic cows and natterjack toad (*Bufo calamitata*) in hoof prints of red deer.

4.2 Buffalo dung and food webs

From Australia it is known that introduction of exotic animals can cause severe ecological problems because their droppings may not decompose. This affected breeding of cattle and water buffalos. Adapted dung beetles from Europe and Africa had to be introduced to Australia to solve the problem (Low 2001). In Europe, buffalos have been part of the fauna for probably the last million years (Krawczynski 2010). Early research indicates that buffalo dung in Central Europe is decomposed by the same species of micro flora (e. g., *Coprobia granulata*, *Ascobolus furfuraceus*, *Sporormiella minima*, *Pilobolus kleinii*) and dung beetles (e. g., *Geotrupes vernalis*, *Sphaeridium scarabaeoides*) as cattle dung. Song birds including red backed shrike (*Lanius cullurio*), meadow pipit (*Anthus pratensis*), whinchat (*Saxicola rubetra*) and yellow wagtail (*Motacilla flava*) breed and hunt on the buffalo pasture. The occurrence of dung beetles and flies from early spring into late November makes the buffalo pasture an ideal feeding habitat for insectivorous birds and bats. Starlings (*Sturnus vulgaris*) not only use insects which are roused by grazing buffalos but also ride on the buffalos and hunt for horse flies.

White storks (*Ciconia ciconia*) have frequently been using the buffalo pasture as feeding habitat. They not only hunt for amphibians and small mammals but also for large insects such as *Stethophyma grossum*. Black storks (*Ciconia nigra*) and grey herons (*Ardea cinerea*) also patrol the wallows (Fig. 3). Even a white tailed eagle (*Haliaeetus albicilla*) was captured by an automatic camera sitting next to a wallow. Red kites (*Milvus milvus*) and marsh harriers use the pasture as hunting habitat.

4.3 Buffalos and vegetation structure

Buffalos are able to digest plants which cattle cannot, e. g. rush, sedges and alder (*Alnus glutinosa*). It is sometimes explicitly stated that buffalos do NOT eat these plants (Sambraus & Spannl-Flor 2005). Indeed, buffalos prefer to feed on more tasty plants but have to take in more rough forage than cattle. We observed in year-round grazing systems that buffalos tend to feed on sedges in autumn and rush in winter, but they will feed on alder leaves whenever these are available. To get at the canopy of young alder trees which are already out of reach, buffalos push the young trees over and feed on the leaves while holding the tree down with their weight. They share this habit with cattle and European bison. For a list of plants eaten or avoided by buffalos see Krawczynski et al. (2008). New observations indicate that *Schoenoplectus tabaernimontani* is avoided by buffalos and that shrub like *Salix cinerea* and *S. aurita* are preferred over tree like *S. fragilis*.

Buffalos appear to have a unique comfort behavior. They not only rub their 600–1,000 kg bodies against large trees but they also brush their heads and horns against younger trees and bushes. First results from the BUBALUS project indicate that *Alnus glutinosa*, *Sambucus nigra* and *Viburnum opulus* are strongly preferred for brushing. Only initial theories are available to explain that behavior, and more research is needed. However, by reducing the shrub layer and understory in woods as well as reducing *Alnus glutinosa* succession in meadows, the buffalos offer a more suitable micro climate for xylobiont species such as *Protaetia lugubris* or *Osmoderma eremita*. Moreover, the newly available sunny, dead twigs and branches are breeding habitats for beetles such as *Clytis arietus*. *C. arietus* was observed mating in spring 2009 in large numbers on twigs and bushes after the buffalos had killed these plants off.

By suppressing the dominant rush, sedges and reeds, buffalos make way for smaller, less competitive plants such as *Isolepis setacea*, *Carex demissa* or the green algae *Botrydium granulatum*. In temporary pools dominated by *Glyceria fluitans*, the buffalos reduced the cover, and species such as *Ranunculus peltatus* appeared. Before grazing, the *G. fluitans* cover was about 95 to 100 %.

4.4 Influence on woody species

Buffalos use the woody species in three ways: browsing, rubbing and brushing. There is no evidence that the buffalos strip bark as horses or cattle do. For rubbing, older trees are chosen which will stand the weight of an adult buffalo. As there was no visible damage to trees from rubbing, only browsing and brushing were studied in detail.

When buffalos browse on trees, they use their tongue to strip off the leaves. If leaves are out of reach (~ higher then 1.80 m), the animals run the young trees over, pushing them under their bellies. Similarly to bison and cattle, buffalos are able to browse the canopy of trees up to 6 m of height. Younger trees or shrubs are preferred for brushing. Browsing has been observed on the following species of trees and shrubs: *Salix cinerea* (50.0 % of all specimens), *Alnus glutinosa* (33.2 %), *Salix fragilis* (28.6 %), *Quercus robur* (26.7 %), *Fraxinus excelsior* (15.0 %). *Sambucus nigra* and *Viburnum opulus* did not appear to have been browsed in spring and summer. By late autumn, however, young *S. nigra* had obviously been browsed, but we were not able to tell which of the

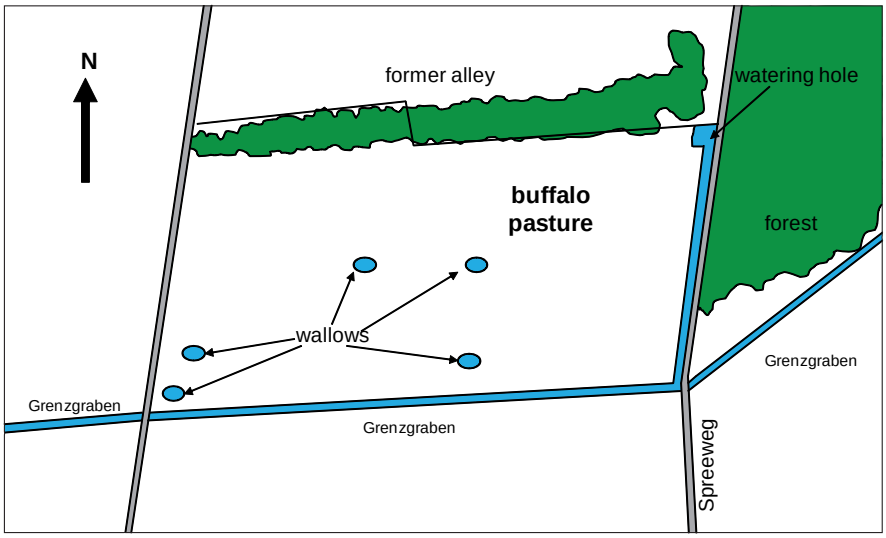

Fig. 2: Schematic map of the buffalo pasture (7.5 ha).

Abb. 2: *Schematische Karte der Büffelwiese (7,5 ha).*

three herbivore species had done so. Our observations in woodland pastures in Lower Saxony and Thuringia showed that Heck cattle and horses do browse *S. nigra*.

Brushing is done only with the heads and the horns. The following species of wood were heavily used for brushing: *Viburnum opulus* (100 % of specimens), *Sambucus nigra* (93.5 %), *Alnus glutinosa* (79.4 %) and *Salix cinerea* (66.7 %). Less frequently used were *Quercus robur* (45.0 %), *Salix fragilis* (42.9 %) and *Fraxinus excelsior* (25.0 %). *Sorbus aucuparia* was not brushed at all.

5 Conclusions

Water buffalos can occupy their evolutionary niche in Central Europe. They are well-adapted to semi-open landscapes consisting of a mosaic of water bodies, marginal vegetation, wet meadows, and woods. Similar to other European herbivores, their use in low densities can be beneficial for biodiversity conservation. Birds, amphibians and insects in particular will benefit from buffalo impact on vegetation structure and species composition. However, many questions still remain unanswered as scientific research has only just begun.

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Fig. 3: A black stork (*Ciconia nigra*) patrols a buffalo wallow. Photo taken by an automatic camera.

Abb. 3: *Ein Schwarzstorch (*Ciconia nigra*) patrouilliert entlang einer Büffelsuhle. Die Aufnahme entstand mit einer Fotofalle.*

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Niedermoor- und Gewässerrenaturierung im Naturpark Drömling (Sachsen-Anhalt)

Restoration of fen and waterbodies in the Drömling Natural Park (Saxony-Anhalt)

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Abstract

The Drömling Natural Park is the largest fen area in Central Germany. The management and development plan defines the re-wetting of fens, the preservation and development of extensively used wetlands and the improvement of the ecological status of water bodies as the main aims. In 11 areas, re-wetting already started or will start in the near future. Habitat quality of canals and ditches was enhanced by building shallow water zones and careful management. Function of canals and ditches changes stepwise from drainage to irrigation. Furthermore, new shallow ponds were created. This contribution presents examples for implementation of measures and first results of scientific evaluation.

All the measures help to maintain and enhance aquatic and amphibic biodiversity and conservation value. A high total number of species correlates well with the occurrence of endangered species. 50 of such Red Lists species were found among aquatic macroinvertebrates and 20 among aquatic macrophytes. These values are above average compared to other fens in Germany. However, the maintenance of diverse landscape and water body structure demands high management efforts. A rising problem for native diversity is the appearance of invasive neozoons.

Keywords: *fen, re-wetting, ditches, ponds, macroinvertebrates, diversity*

Zusammenfassung

Der Naturpark Drömling ist das größte Niedermoorgebiet in Mitteldeutschland. Die Wiedervernässung des Moorkörpers, der Schutz und die Pflege des extensiven Grünlandes und die Verbesserung des ökologischen Zustandes der Gewässer sind als Hauptziele im Pflege- und Entwicklungsplan festgeschrieben. In 11 Teilgebieten hat die Wiedervernässung bereits begonnen bzw. ist in Kürze geplant. Durch Umgestaltungsmaßnahmen wie Uferabflachung und Anlage von Flachwasserzonen sowie Einschränkung der Unterhaltungsmaßnahmen konnten die Lebensbedingungen für Flora und Fauna in den Gräben und Kanälen deutlich verbessert werden. Während die Gräben und Kanäle früher zur schnellen Entwässerung der Flächen im Frühjahr genutzt wurden, dienen sie heute auch dem Wasserrückhalt und der Bewässerung in Trockenzeiten. Eine Reihe von Flachgewässern vorwiegend für die amphibische und Avifauna wurden in den letzten Jahren neu geschaffen. Alle diese Maßnahmen fördern die Vielfalt der Lebensräume und damit den Naturschutzwert des Gebietes, so dass auch zahlreiche geschützte und gefährdete Arten auftreten. Es konnten 50 Arten von Makroinvertebraten und 20 Pflanzenarten der Roten Listen nachgewiesen werden; wesentlich mehr als in anderen Niedermoorgebieten Norddeutschlands. Ein zunehmendes Problem ist das Auftreten von Neozoen. Der Erhalt der Vielfältigkeit der Landschaft und der Gewässerformen erfordert jedoch einen gewissen Unterhaltungsaufwand.

Schlüsselwörter: Niedermoore, Wiedervernässung, Gräben, Flachwasser, Makroinvertebraten, Diversität

1 Einführung

Der Naturpark Drömling besteht seit 1990 auf einer Fläche von 27.800 ha. Die mit der Ausweisung verbundenen Zielstellungen waren u. a. die Bewahrung naturnaher Ökosysteme der Nass- und Feuchtstandorte und die Renaturierung von Niederungswäldern und Mooren durch eine Anhebung der Grundwasserstände zur ganzjährigen bzw. zeitweiligen Wiedervernässung von Teilflächen.

Der ursprüngliche Anteil der Naturschutzgebiete von 4.500 ha konnte mit der Ausweisung des NSG „Ohre-Drömling“ (2005) auf 10.300 ha erweitert werden. Hier soll in der Kernzone auf 840 ha eine ganzjährige Vernässung erreicht werden. Ganzjährig flurnahe Wasserstände mit winterlichen Überflutungen und Nutzungsbeginn ab Juli werden in den Nässezonen auf 2.960 ha angestrebt.

Mit dem Naturschutzgroßprojekt „Drömling/Sachsen-Anhalt“ (Naturschutzgroßprojekt, Phase I: 1992–2003) wurden die wissenschaftlichen und wasser- sowie eigentumsrechtlichen Grundlagen zur Erreichung der Projektziele

- Erhaltung des großflächigen Moorkörpers,
- großflächige Überstauung und allgemeine Anhebung des Wasserstandes,
- Verbesserung der Wasserqualität,
- langfristige Entwicklung der Gewässerstruktur hin zu größerer Diversität,
- Aushagerung des Grünlandes und Schaffung von Lebensbedingungen für vom Aussterben bedrohte Tier- und Pflanzenarten

gelegt. In der Phase II des Naturschutzgroßprojektes (2008–2012) sollen die wasserbaulichen Maßnahmen wie Neu- und Umbau von Stauanlagen, Verlegung von Grabenanschlüssen und Neuanlage von Gewässern realisiert werden.

2 Untersuchungsgebiet

Der Drömling ist ein ehemaliges Niedermoorgebiet, das im Zuge mehrerer Kultivierungsetappen seit dem 18. Jahrhun-

Tab. 1: Veränderte Funktionen verschiedener Grabenformen.

Tab. 1: *Changed functions of different types of ditches.*

ursprüngliche Funktionen	neue Funktionen
kleine Entwässerungsgräben: Entwässerung landwirtschaftlicher Flächen zur Beweidung, Befahrung, Ackernutzung **Kanäle („Vorfluter"):** Schnelles Abführen großer Wassermengen im Frühjahr, Einstau zur Bewässerung landwirtschaftlicher Flächen im Sommer **Moordammgräben:** Parzellierung und Aufhöhung der Kulturflächen **Abflusslose Teichgräben:** Vergrößerung der nutzbaren Flächen, Schaffung zusätzlicher Verdunstungsflächen	Stabilisierung des Bodenwasserhaushaltes Bewässerung zur Wiedervernässung von Teilgebieten, dadurch Aktivierung der Senkenfunktion des Niedermoores und Neubildung bzw. Wachstum des Moorkörpers Habitatfunktion Biotopverbund Entwässerung zur Gewährleistung der landwirtschaftlichen Nutzung (Befahrbarkeit) Tourismus und Umweltbildung

dert bis in die 1980er Jahre hinein entwässert wurde. Heute existiert hier ein stark verzweigtes Gewässersystem mit einer Gesamtlänge von ca. 1.725 km (Braumann 1993). Dabei kann zwischen verschiedenen Graben- und Gewässerformen unterschieden werden, deren ursprüngliche Entwässerungsfunktion sich für die Umsetzung der Naturschutzziele gewandelt hat (Tab. 1). Natürliche Standgewässer fehlen weitgehend. Die im Zuge der großflächigen Überstauung entstehenden wiedervernässten Bereiche und neu angelegte Flachgewässer dienen als Lebens- und Rückzugsraum für viele amphibische Tier- und Pflanzenarten, vor allem für Moorarten und die Avifauna.

3 Maßnahmenkomplexe

3.1 Wiedervernässung

Eine ganzjährige bzw. zeitweilige Vernässung ist auf einer Fläche von 3.800 ha geplant. Solche Flächen sollten im öffentlichen Eigentum sein, da eine wirtschaftliche Nutzung nicht mehr möglich ist. Im Naturpark Drömling befanden sich im Jahr 1992 über 90 % der vorgesehenen Flächen in Privateigentum. Die Eigentumsverhältnisse stellten neben fehlenden wasserrechtlichen Genehmigungen zum Betrieb von Stauanlagen in den Gräben und Kanälen die Hauptprobleme für die Umsetzung des Naturschutzgroßprojektes dar. Durch den Zweckverband Drömling, das Land Sachsen-Anhalt, die Stiftung Stork-Foundation, den Verein „Aktion Drömlingschutz" sowie Kompensationsmaßnahmen konnten Flächen erworben werden. Mit Stand 2009 befinden sich knapp 6.000 ha in öffentlichem Eigentum. Im Jahr 2006 erlangten die Erlaubnisse für ca. 80 Stauanlagen Rechtskraft. Die Staurechte liegen bei der „Naturparkverwaltung Drömling".

Für 11 Kern- und Nässezonen des NSG „Ohre-Drömling", für die wasserrechtliche Verfahren zur Wiedervernässung (höhere Stauziele als bisher) erforderlich sind, sind bereits 8 Verfahren abgeschlossen, die übrigen sollen bis Ende 2009 abgeschlossen werden. Grundlage für die Genehmigungsverfahren bildeten umfangreiche Stauversuche zur Ermittlung von oberen bzw. unteren Stauzielen bzw. Stauzeiträumen, um gezielt Flächen vernässen zu können. Im Ergebnis der Stauversuche konnten die aus Höhen- und Wasserbewirtschaftungsmodellen gewonnenen Modellergebnisse zur Wiedervernässung überwiegend bestätigt werden. Die Wasserrechtsverfahren wurden von einer umfangreichen Öffentlichkeitsarbeit begleitet und unter Einbeziehung der Schaukommissionen des Unterhaltungsverbandes „Obere Ohre" durchgeführt.

Wasserbauliche Maßnahmen zur technischen Umsetzung sind (gebietsspezifisch):

- Rekonstruktion vorhandener Stauanlagen,
- Rückbau von Stauanlagen und Ersatz durch Stützschwellen,
- erdbautechnischer Verschluss von Grabenmündungen,
- Rückbau von Verrohrungen,
- vereinzelt Neubau von Gräben

Bereits ganzjährig wiedervernässt ist der „Breitenroder-Oebisfelder Drömling" (Kernzone des NSG), nachdem ein Planfeststellungsverfahren nach § 31 Wasserhaushaltsgesetz (WHG) i. V. m. § 120 Wassergesetz des Landes Sachsen-Anhalt (WG LSA) abgeschlossen wurde. In diesem Gebiet kann sich Erlenbruch- und Erlen-Eschenwald ungestört entwickeln (Abb. 1). Dieser Prozessschutz erlaubt eine natürliche Eigendynamik, der Totholzanteil kommt bereits den natürlichen Verhältnissen nahe.

3.2 Anlage von Grabentaschen und Uferabflachung an Teichgräben

Kleinere Gräben, Kanäle und Teichgräben im Naturpark Drömling sind trotz eingeschränkter Strukturvielfalt bereits Orte hoher Biodiversität (Langheinrich et al. 2004, 2007). Das zeigt sich an einem hohen Anteil an Rote Listen- und FFH-Arten. Die verschiedenen Gewässertypen dienen als Ersatzlebensraum für Arten aus vom Verschwinden bedrohten Primärlebensräumen wie z. B. organischen Bächen, Söllen oder Weihern.

Teichgräben sind mehrere hundert Meter lange, 6–10 m breite lineare Gewässer mit einem Trapezprofil, die im Zuge von Meliorationsmaßnahmen entstanden sind. Durch morphologische Umgestaltungen wie Anlage von Grabentaschen, Uferabflachung und Schaffung kleiner Inseln wurde die amphibische Zone einiger dieser Gräben auf einer Gesamtlänge von 4,5 km verbreitert (Kausche 2008). Die Teichgräben

stellen artenreiche Lebensräume für Fauna und Flora dar. An Teichgräben konnten 201 Arten von Makroinvertebraten, darunter 13 Arten der Roten Listen Sachsen-Anhalts und 149 Pflanzenarten, davon 6 Arten der Roten Listen Sachsen-Anhalts, nachgewiesen werden. Allein an einem dieser Teichgräben (Abb. 2) konnten 24 Arten der 43 im Naturpark Drömling vorkommenden Libellen nachgewiesen werden (Langheinrich 2007).

Diese Größenordnungen belegen die Habitat- und Refugialfunktion der Teichgräben, die durch die Umgestaltungsmaßnahmen gesichert und erweitert werden konnte.

3.3 Neuanlage von Gewässern

Die Anlage und Pflege neuer Flachgewässer erfolgt im Naturpark Drömling unter dem primären Aspekt des Arten- und Biotopschutzes. Diese Gewässer sind durch meistens geringe Nährstoffgehalte (Trophie) gekennzeichnet.

3.3.1 Kleiner Weiher im nordwestlichen Drömling

Das Gewässer wurde im Jahr 2001 mit einer Fläche von ca. 1 ha und maximalen Tiefe von 0,8 m angelegt (Abb. 3). Die Artenzahlen der Makroinvertebraten stiegen von 13 im Jahr 2002 auf 33 im Jahr 2005. Dominierende Gruppen sind *Odonata*, *Coleoptera*, *Mollusca* und *Heteroptera*. Eine geringe Strukturvielfalt, nur spärlich ausgeprägte submerse Vegetati-

Abb. 1: Erlenbruchwald in der Kernzone des Naturparks Drömling (Foto: NP Drömling).

Fig. 1: *Alder swamp in the core zone of the Natural Park Drömling.*

Abb. 2: Umgestalteter Bereich eines Teichgrabens (Foto: U. Langheinrich).

Fig. 2: *Re-modelled sector of pond-like ditch.*

on und die durch die fehlende Beschattung hervorgerufenen Algenmassenentwicklungen führen zu den im Vergleich zu anderen Gewässern geringeren Artenzahlen.

3.3.2 Flachwasserzone bei Piplockenburg

Im Jahr 2001 wurde die 40 ha große Flachwasserzone bei Piplockenburg als Ausgleichs- und Ersatzmaßnahme für den Ausbau des Mittellandkanals (MLK) angelegt. Über ein Einlassbauwerk ist das Gewässer an den MLK angeschlossen (Abb. 4). Das insgesamt 70 ha große Areal hat sich inzwischen zum wichtigen Rast- und Brutplatz für verschiedene Vogelarten wie Kiebitz, Goldregenpfeifer, Kranich, Saat- und Blässgänse entwickelt.

Im Rahmen umfassender zweimaliger Untersuchungen im Jahr 2009 wurden 70 Taxa von Makroinvertebraten nachgewiesen. Es handelt sich vorwiegend um Indikatoren einer mäßigen Gewässerqualität. Bemerkenswert ist der Fund der gefährdeten *Sphaerium solidum* (Dickschalige Kugelmuschel, Rote Liste Deutschland und Sachsen-Anhalt 1). Über den MLK gelangen Neozoen wie *Atyaephyra* sp. (Süßwassergarnele) und *Dikerogammarus villosus* (Großer Höckerflohkrebs) in das Gewässer. Die Ufervegetation besteht zu 70 % aus Großseggenried mit starker Dominanz von *Juncus effusus* sowie dem fleckenweisen Vorkommen von *Carex hirta*, *C. pseudocyperus*, *C. vesicaria* sowie vorgelagerten Bülten von *C. paniculata*. Mit einem Deckungsgrad von 20 % bildet das *Glycerietum maximae* die dominierende Röhricht-Gesellschaft. Kleinflächig ausgeprägt sind das Phragmitetum australis, das Typhetum latifoliae, das Phalaridetum arundinaceae und das Eleocharitetum palustris. Submerse Pflanzen treten durch Algendominanz kaum auf, die Gesellschaft des Potamogetonetum pectinati ist in Flachwasserzonen mäßig ausgeprägt.

Abb. 3: Weiher im nordwestlichen Drömling (2005) (Foto: U. Langheinrich).

Fig. 3: *Pond in north-western Drömling (2005).*

Abb. 4: Flachwasserzone bei Piplockenburg (Foto: Fa. Möbius i. A. Wasserstraßenneubauamt Helmstedt).

Fig. 4: *Shallow water area near Piplockenburg.*

Angesichts der Größe und hydromorphologisch vorteilhaften Gestaltung des Gewässers sind die vergleichsweise geringe Biodiversität und auch Biomassedichte der vorgefundenen Fauna im negativen Sinne bemerkenswert. Eine Rolle spielen hier neben dem eutrophierungsbedingten weitgehenden Fehlen submerser Makrophyten auch die starke Dominanz der genannten Neozoen.

4 Schutzwert der Gewässer

Der Drömling ist ein bedeutendes Refugium für gefährdete Pflanzen- und Tierarten von Niedermoorlebensräumen, insbesondere auch von -gewässern. Hier wird das für die Gruppe der aquatischen Makroinvertebraten nachgewiesen, mit denen sich die Autoren seit 1992 besonders intensiv befasst haben. 50 Rote-Liste-Arten aus dieser Gruppe wurden gefunden (Tab. 2), von denen einige ihren mitteldeutschen Vorkommensschwerpunkt mit hoher Wahrscheinlichkeit in diesem Gebiet haben. Hierbei handelt es sich um die Wasserkäfer-Spezies *Dytiscus latissimus*, *D. semisulcatus*, *Haliplus varius*, *Hydrophilus piceus* und *H. atterimus*. *D. latissimus* ist dabei eine extrem vom Aussterben bedrohte Art, von der in Mitteleuropa nur noch wenige Funde vermeldet sind (Hendrich & Balke 2000). Sie bevorzugt – ähnlich wie die anderen aufgeführten Arten – klare, makrophytenreiche Standgewässer.

Neben den Käfern sind es besonders die Libellen, die die Schutzwürdigkeit der Gewässer begründen. Es wurden 43 Arten, darunter 14 gefährdete, nachgewiesen. Ein Blick auf die ökologischen Ansprüche dieser Arten ergibt ein sehr differenziertes Bild. Zum ersten kommen Arten vor, die leicht fließendes, pflanzenreiches und klares Wasser bevorzugen (*Coenagrion mercuriale*, *C. ornatum*, *Calopteryx virgo*), zum zweiten solche, die für Moorgewässer typisch sind (*Ceriagrion tenellum*, *Aeshna juncea*, *Somatochlora flavomaculata*), zum dritten Arten mäßig pflanzenreicher Gewässer (*Brachytron pratense*, *Sympetrum pedemontanum*) und schließlich aber auch Pionierarten neu geschaffener Flachgewässer (*Ischnura pumilo*, *Orthetrum coerulescens*).

Für die umgestalteten und neu angelegten Gewässer dokumentiert Kausche (2008) 20 Pflanzenarten der Roten Liste Sachsen-Anhalts, darunter mit *Veronica anagalloides* und *Ranunculus hederaceus* zwei vom Aussterben bedrohte Spezies. Die aquatischen Makrophyten mit den von ihnen geformten Gesellschaften sind ihrerseits in den Gewässern des Drömlings der wichtigste habitatbildende Faktor für Makroinvertebraten.

5 Diskussion

Die Ziele des Pflege- und Entwicklungsplanes

- Erhaltung des Niedermoorkörpers durch optimale Steuerung des Wasserhaushaltes,
- Erhalt- und Entwicklung der Lebensgemeinschaften des Feuchtgrünlandes,
- Entwicklung naturnaher, ungenutzter Wälder und
- Wiederherstellung typischer Landschaftselemente (Flutmulden, Kleingewässer u. a.)

lassen sich nicht ohne Widersprüche und Kompromisse erreichen. Für die Erhaltung und vor allem für die Regeneration des Niedermoorkörpers sind die vollständige Vernässung und die Aufgabe jeglicher Gewässerunterhaltung optimal (Succow & Joosten 2001). Diese würden aber in wenigen Jahrzehnten zum vollständigen Verschwinden von Offenlandstandorten und offenen Wasserflächen und den an diese gebundenen Arten und Lebensgemeinschaften führen. Dies ist im Drömling aus eben jenem Grund, aber auch aus Akzeptanzgründen, nicht gewollt. Somit beschränkt sich die „konsequente“ Niedermoorregeneration auf das Totalreservat, während alle anderen Offenlandbereiche und Gewässer weiter extensiv bewirtschaftet oder unter naturschutzfachlichen Prioritäten gestaltet und gepflegt werden. Wie die Ergebnisse zeigen, ist diese Strategie unter dem Gesichtpunkt des Artenschutzes sehr erfolgreich. Die Resultate bestätigen eindrucksvoll die „Field of – dreams“ Hypothese der Rena-

Tab. 2: Gefährdete Makroinvertebraten-Arten in den Gewässern des Drömling:
(1) Langheinrich & Lüderitz 2007, (2) Langheinrich et al. 2004, (3) eigene Untersuchungen 2009, unveröffentlicht.

Tab. 2: *Endangered macroinvertebrate species in water bodies of the Drömling Natural Park.*

	RL LSA	RL D	Teichgräben (1)	Gräben und Kanäle (2)	Flachwasser (3)
Coleoptera					
Agabus biguttatus	3			x	
Bidessus unistriatus	3	V	x		
Cybister lateralimarginalis	3	3	x		
Dytiscus latissimus	1	1		x	
Dytiscus semisulcatus	2	2	x		
Gyrinus paykulli	3	V	x		
Haliplus obliquus		3	x		x
Haliplus varius	1	1	x		
Hydrophilus atterimus	2	2	x		
Hydrophilus piceus	2	2	x		
Hydroporus rufifrons		2	x		
Laccophilus variegatus (poecilius)		3	x	x	x

	RL LSA	RL D	Teichgräben (1)	Gräben und Kanäle (2)	Flachwasser (3)
Odonata					
Aeshna juncea	2	3	x		
Brachytron pratense	V	3	x	x	
Calopteryx virgo	2	3	x		
Ceriagrion tenellum	1	1		x	
Coenagrion mercuriale	1	1		x	
Coenagrion ornatum	1	1		x	
Coenagrion pulchellum	V	3	x		
Cordulegaster boltoni	3	3		x	
Ischnura pumilio	2	3		x	
Orthetrum coerulescens	2	2	x		
Somatochlora flavomaculata	3	2	x		
Sympecma fusca		3	x		
Sympetrum flaveolum		3	x		
Sympetrum pedemontanum	2	3	x		
Trichoptera					
Beraea pullata	3			x	
Grammotaulius nitidus	3	3		x	
Limnephilus fuscicornis	2			x	
Nemotaulius punctatolineatus		1	x		
Oligostomis reticula	3	3	x		
Phacopteryx brevipennis		3		x	
Bivalvia					
Anodonta cygnea		2	x	x	
Pisidium obtusale	3	V	x		x
Pisidium pseudosphaerium	1	1		x	
Pisidium pulchellum	1	1		x	
Sphaerium solidum	1	1			x
Unio pictorum		3	x	x	x
Gastropoda					
Anisus spirorbis	V	2	x		
Aplexa hypnorum		3	x		
Bithynia leachi		2		x	
Gyraulus leavis	1	1		x	
Planorbis carinatus		3		x	
Stagnicola corvus		3		x	x
Stagnicola turricula		3		x	
Valvata studeri		1		x	
Viviparus contectus		3	x		
Viviparus viviparus	2	2		x	
Ephemeroptera					
Ephemera glaucops		3			x
Heptagenia flava		3		x	

turierungsökologie: *If you build it, they will come* (Palmer et al. 1997). Hinsichtlich des aquatischen Makrophyten- und Makroinvertebratenreichtums übertrifft der Drömling andere untersuchte Niedermoorgebiete (Fiener Bruch/Sachsen-Anhalt; Großes Bruch/Sachsen-Anhalt u. Niedersachsen; Dümmer-Niederung/Niedersachsen) bei weitem (Langheinrich et al., in Vorbereitung). Obwohl die Unterschiede z. T. auch mit anderen Faktoren wie dem höheren Trophiegrad und der intensiveren Nutzung der anderen Gebiete zu erklären sind, ist die differenzierte Pflege und morphologische Umgestaltung der Gewässer zweifellos ein Ausschlag gebender Faktor. Dazu kommen die Lage am „Grünen Band", der früheren deutsch-deutschen Grenze, das heute als das längste Biotopverbundsystem Mitteleuropas gilt sowie im Überlappungsgebiet der beiden großen Flusseinzugsgebiete Elbe (über die Ohre) und Weser (über die Aller), für die der Drömling eine Talwasserscheide darstellt. Beide Gebietseinbindungen ermöglichen das Zuwandern zahlreicher, z. T. gefährdeter Arten (Gerstner & Leupold 2009).

Die Aufrechterhaltung der vielfältigen Gewässermorphologie ist wie die Pflege von Feuchtwiesen kein kostenloses Unterfangen. Bei den neu angelegten Kleingewässern und den umgestalteten Teichgräben sind nach knapp 10 Jahren schon starke Verkrautungs- und Verlandungserscheinungen zu beobachten, die eine periodische Pflege notwendig machen. Das ist der entscheidende Unterschied z. B. zu renaturierten Fließgewässern, die man nach der Renaturierung weitestgehend sich selbst überlassen kann.

Wie unsere Untersuchungen ferner zeigen, gehen problematische Entwicklungen auch am Drömling nicht vorbei. Die Ausbreitung invasiver Neozoen wie des Höckerflohkrebses vollzieht sich über Verbindungsgewässer wie den Mittellandkanal und führt zu einer merklichen Beeinträchtigung der Biodiversität. Ob die Herstellung der uneingeschränkten ökologischen Durchgängigkeit für künstliche Gewässersysteme immer anstrebenswert ist, bleibt deshalb zweifelhaft.

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Assessment and restoration of artificial ponds in the Palatinate Forest

Bewertung und Entwicklung künstlicher Stehgewässer im Biosphärenreservat Pfälzerwald

Wolfgang Frey, Holger Hauptlorenz, Holger Schindler and Gero Koehler

Abstract

The survival of the approximately 1,000 artificial ponds in the Pfälzerwald (Palatinate Forest) biosphere reserve is endangered as they continue to be abandoned, but a large number of them have conservation and historical value. An overall management concept is needed as the high costs for restoration and the requirements of the EU Water Framework Directive regarding river continuity will make it impossible to maintain all of the ponds. Most of the ponds are migration barriers for fish and aquatic invertebrates. The assessment methods presented here are based on readily available data for the evaluation of the ecological and cultural-historical importance of the ponds, their implications within the landscape, and their (often negative) impact on stream ecology. The assessment of the condition of the ponds' manmade structures leads to conclusions about the urgency for action. The assessment classes are linked with recommendations for action. In the synopsis of all assessments, management concepts emerge for the individual ponds, and priority lists of ponds can be generated that point out where actions are preferential.

Keywords: *artificial ponds, eco-morphological assessment, migration barrier, historical structures, landscape and recreation, management concept*

Zusammenfassung

Aufgrund zunehmender Nutzungsaufgabe an den etwa 1.000 künstlichen Stehgewässern im Biosphärenreservat Pfälzerwald und ihrer gleichzeitig oft hohen naturschutzfachlichen bzw. kulturhistorischen Bedeutung ist ein Managementkonzept notwendig geworden. Dem Erhalt der Anlagen stehen hohe Sanierungskosten sowie die Anforderungen der EU-Wasserrahmenrichtlinie, für eine biologische Durchgängigkeit der Fließgewässer zu sorgen, entgegen. Die meisten Anlagen stellen nämlich unüberwindliche Wanderbarrieren dar. Die vorgestellten Bewertungsverfahren, basierend auf einfach zu erhebenden Merkmalen, beurteilen die ökologische und die kulturhistorische Bedeutung der Anlagen, die Bedeutung für das Landschaftsbild sowie ihre (negativen) Auswirkungen auf das Fließgewässersystem. Die Bewertung des baulichen Zustands ergibt Aussagen über die Dringlichkeit des Handelns. Die einzelnen Bewertungsklassen sind mit Handlungsempfehlungen verknüpft. In der Zusammenschau der einzelnen Empfehlungen leiten sich Maßnahmen für die einzelnen Gewässer ab sowie Priorisierungen von Teichen, an denen vorrangig Handlungen erfolgen sollen.

Schlüsselwörter: Teiche, Weiher, ökomorphologische Bewertung, Wanderhindernis, historische Bauwerke, Landschaftsbild, Erholung, Managementkonzept

1 Introduction

In the Palatinate Forest there are practically no natural bodies of standing water, but there are more than 1,000 artificial ponds (Koehler & Gramberg 2004). The ponds were originally built for fish or for hydropower, but are increasing being abandoned. Only a few are currently used for fish breeding, recreation, and water sports. In some cases, the related secondary biotopes have developed high ecological value, as shown in Figure 1.

Mainly because of the effects of pollution, the forest administration has chosen not to renew the land leases of a high percentage of ponds (Hahn & Friedrich 2000), leading to abandonment, and the responsibility for the ponds thereby reverts to the forest administration or the municipality. These public owners don't have the resources to maintain all of the bodies of water, and some of these biotopes have been or will be lost. Many of the remaining ponds are in danger of disappearing within the next years.

On the other hand, these unused ponds can still have a negative influence on the associated watercourse, particularly on the movement of animals. No management concept exists for these barrier structures, particularly in terms of the requirements of the EG Water Framework Directive (EU 2000).

Roweck et al. (1988) conducted a very detailed investigation of 19 ponds in the Palatinate Forest with a special focus on vegetation and offered proposals for management and maintenance. Beyond this work, only monographs about individual ponds within this landscape exist. Recommendations for the management of standing bodies of water in the low mountain regions of Germany are very general (e. g., Rahmann et al. 1988) or deal only with specific impacts such as periodic draining of ponds (e. g., Zeitz & Poschlod 1996).

In 2004 the Department of Hydraulic Engineering and Water Management at the University of Kaiserslautern proposed a 'concept for the ecological assessment and development of ponds in the Palatinate Forest' (Hauptlorenz et al. 2007). The Deutsche Bundesstiftung Umwelt (DBU) decided to support this project financially from 2007 to 2010.

There are three main goals of the project:

- Development of an assessment system taking into account the cultural-historical value, the function for recreation, the scenic landscape value, the ecological quality, and the influence of the ponds on the river system.

- Creation of a management concept and a decision-support system based on the assessment.
- Planning and realization of first measures on chosen examples.

2 Data collection

A base data collection protocol was developed to guide the on-site survey. Its parameters are shown in Table 1. In the years 2007 and 2008, 235 ponds were documented using the protocol.

In addition to the parameters in Table 1, vegetation, dragonflies, und benthic invertebrates were documented. Vegetation and dragonflies were chosen as indicators for the ecological quality of a pond in support of the development of the eco-morphological assessment system. Benthic invertebrates collected in the watercourse up- and downstream of the ponds were used to get information about the effects of the ponds on life conditions of the streams. The number of ponds in which each aspect of data collection was undertaken is shown in Table 2.

The ecological quality of the streams and the real and potential watercourse interconnectedness were determined according to existing morphological assessments. A literature search was made to determine the cultural and historical importance of the ponds.

All of the base information was merged and prepared for a database to be used for the subsequent analysis and assessments.

3 Morphological and hydrochemical description

The surface areas of the ponds range from a few square metres up to 12 ha. The dimensions reflect their uses and are presented in Table 3. The height of the dam walls mostly ranges from 2 to 4 m and the maximum water depths are 1–2 m. The most common outlet structure is shown in Figure 2. Some of the outlets were designed to support hydropower, mill, or “drift” usage and consist of an overfall or a tube (Tab. 4). Drift refers to the practice of rafting small pieces of timber. To do this, the watercourses were built into channels with bricked walls during the 19th century, and ponds were built along them to drive the floating system.

More than 80 % of the ponds are centered in the watercourse, and therefore are of high relevance for the stream systems (Tab. 5). Considering this in combination with the structure of the most common outlet (Fig. 2), it is clear that the ponds have a strong influence on the interconnectedness of the streams.

Almost all of the watercourses of the Palatinate Forest are located on sandstone (bunter). Only a thin strip in the east shows the influence of calcium carbonate. The variegated sandstone is lacking in bases and nutrients. The pH values range mostly from 5 to 7, and the conductivity is about 100 µS.

The ponds with low pH and low conductivity are mostly dystrophic and are located in forests. Ponds in meadows have higher pH and conductivity values and are rarely dystrophic. The intensity of fish breeding is connected with even higher pH and conductivity values. The highest values are found in ponds that contain saline runoff from roads and in ponds that are located in the calcium carbonate area where viticulture is practiced.

4 Assessment of the ponds

Existing assessment systems for standing water bodies are focused on nature protection aspects. In most cases there are only general proposals for an assessment (e. g., Schoknecht et al. 2004), and the assessment systems are restricted to natural lakes (e. g., LAWA 1998). Assessment approaches for small artificial bodies of water can be found in Mayer et al. (2003) for an area in the state of Brandenburg but not for the low mountain regions of Germany.

Fig. 1: Secondary biotope with high ecological value at an abandoned pond.

Abb. 1: *Ökologisch hochwertiges Sekundärbiotop an einem aufgegebenem Weiher.*

Tab. 1: Parameters of the data collection protocol.

Tab. 1: *Parameter des Erhebungsbogens.*

Main parameters	Sub-parameters
Pond morphology	Dimension, location, supply, water body, banks
Man-made structures	Inlet, outlet, dam wall, floodwater overfall
Use	Kind and intensity, infrastructure
History	Historical use, age, historical construction
Description of the biotope	Aggradation, shading, vegetation, special structures
Surroundings	Type of forest, land use, settlements, adjacent biotopes, riparian zone
Stream biotope	Stream morphology, passability, adjacent migration barriers
Hydrological chemistry	pH, O_2 concentration, temperature, conductance, trophic condition

Tab. 2: Number of ponds in which data were gathered.

Tab. 2: *Anzahl der Erhebungen.*

Investigations	Investigated ponds
Base data collection	235 of about 1000 ponds
Vegetation	200 of the 235 base data collection ponds
Dragonflies	32 of the 235 base data collection ponds
Macrozoobenthos	11 test points upstream and downstream of 5 different ponds or pond groups

Tab. 3: Typical uses of ponds of different dimensions.

Tab. 3: *Ausdehnung der Wasserflächen und typische Nutzungen.*

Size	Use	Percentage
> 1 ha	Old fish ponds, waterpower ponds, recreation	3 %
0.1 to 1 ha	Old fish ponds, mill ponds	38 %
< 0.1 ha	Drift ponds, new fish breeding ponds	59 %

Tab. 4: Outlet structures.

Tab. 4: *Auslauf-Bauwerke.*

Structure type	Typical use	Percentage
As in Fig. 2, additionally other structures possible	All fish ponds	74 %
Only overfall or tube	Hydropower, mill, and drift ponds	25 %
None remaining or designed with no outlet		1 %

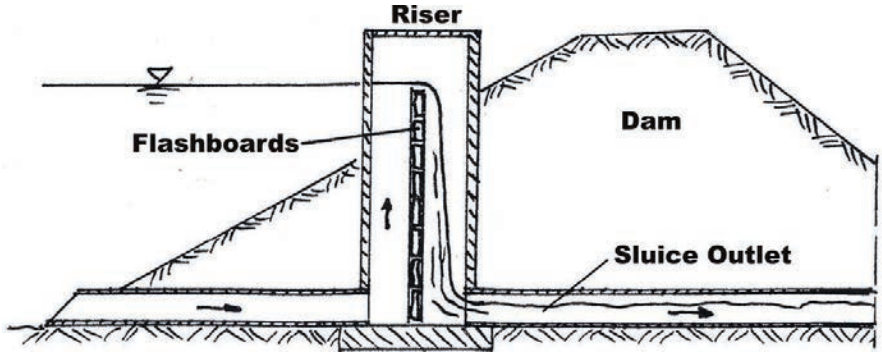

Fig. 2: Principle of the most common outlet construction.

Abb. 2: *Prinzip des häufigsten Auslauf-Bauwerk-Typs ("Mönch").*

Tab. 5: Position of the ponds in relation to the watercourse.

Tab. 5: *Lage der Weiher im Gewässersystem.*

Type	Description	Percentage
Centred	Centred in the watercourse, holding back all of the water, the watercourse is interrupted	82 %
Bypass	Pond and watercourse are located in a parallel connection, holding back some of the water, the watercourse is continuous (bypass channel)	13 %
Spring supply	Pond is located next to the watercourse, supply is only from backed-up or piped springs; the natural spring biotopes have been disturbed or destroyed	5 %

Rahmann et al. (1988) recognized the necessity of considering the following aspects in a management concept for small bodies of standing water: the historical facts and scenic landscape conditions as well as concerns regarding nature protection, agriculture, recreational and professional fishing, and tourism. Additionally the effects of the ponds on the ecological state of the stream according to the Water Framework Directive must be taken into account. Based on this, five assessment systems were created:

1. Condition of the structures
2. Eco-morphological assessment
3. Influence on the watercourse
4. Cultural and historical assessment
5. Scenic landscape und recreation impacts

Each assessment uses the data collection protocol as the main database supplemented with additional data such as historical facts. All five assessment systems are independent from each other, and in all but the first, the ponds are rated on a five-point scale from very high to very low.

4.1 Condition of the structures

The dam walls and the outlets of the ponds exist in different conditions. The current condition of the structures was assessed as intact, damaged, or ruined (Fig. 3). Damaged dam walls endanger the whole pond and the area below. Damaged outlets degrade the pond.

4.2 Eco-morphological assessment

A crucial difficulty in developing an ecological assessment is that there is no natural model for the ponds due to their artificial origin. Therefore we used habitat limiting structures, the diversity of natural structures, and the naturalness of banks and surroundings as assessment parameters as shown in Figure 4.

The assessment scheme was evaluated with the help of biological investigations, primarily the comprehensive vegetation surveys. Correlations between the individual parameters of the data protocol and parameters of ecological quality generated from the biological investigations (such as number of Red List species, Red List vegetation communities, total number of dragonfly species) have been tested. No correlati-

exhaust constructions \ dam wall	intact	damaged	ruinous	not specified
several constructions all intact	39	3		
one construction intact	104	9		2
several constructions two intact	2			
several constructions one intact	18	3		
no intact construction	31	18	1	1
not specified	1	1	1	1

A no restoration required
B restoration of an exhaust construction
C restoration of the dam wall
D restorations strongly required

Fig. 3: Condition of the structures in the 235 observed ponds and conclusions for their restoration.

Abb. 3: *Zustand der Bauwerke der 235 untersuchten Weiher und Folgerungen für deren Sanierung.*

on, for example, was found between the grade of aggradation and any of the biological parameters, so this parameter was not used for the eco-morphological assessment. Also the "impression of the surveyor" regarding the ecological quality on site was used as guidance for emphasizing relevant parameters for this assessment.

The detailed assessment scheme can not be presented here as it is very complicated. Some parameters, such as oxygen and pH, are only relevant when they exceed critical values. Others are assessed in combination with each other (if-then relation). Some of the degradation parameters are assessed pessimistically, only the worst are included in the overall assessment.

Corresponding to the Water Framework Directive assessment, the eco-morphological value is classified into five levels: very high, high, moderate, low, and very low. The results of the eco-morphological assessment are shown in Figure 5. Most of the investigated ponds have a moderate or low ecological value.

4.3. *Influence on the watercourse*

As mentioned above, ponds centred in the watercourse act as migration barriers. The water quality can also be disturbed under certain conditions. In addition, investigations showed that even slightly eutrophic ponds degrade invertebrate communities in streams. Another influence that must be taken into account is the loss of the stream biotope caused by backwater. Thus, the passability of the man-made structures, the interconnectedness of the stream system with and without the pond, the trophic state, and the morphological quality of the stream are used as parameters to assess the influence of the pond on the watercourse. All parameters can be determined from the observed attributes in the data collection protocol.

The execution of the developed assessment method at the 235 investigated ponds led to a fairly homogeneous distribution among five quality classes with a plurality rated as moderate (Fig. 6). To better understand this, it is necessary to look at the individual assessment components to understand what aspect led to the rating and how significant it is what is also essential for deriving measures. In 87 % of all cases, there was an impassable structure, but mostly this was not a crucial aspect for the stream system. Due to the upstream

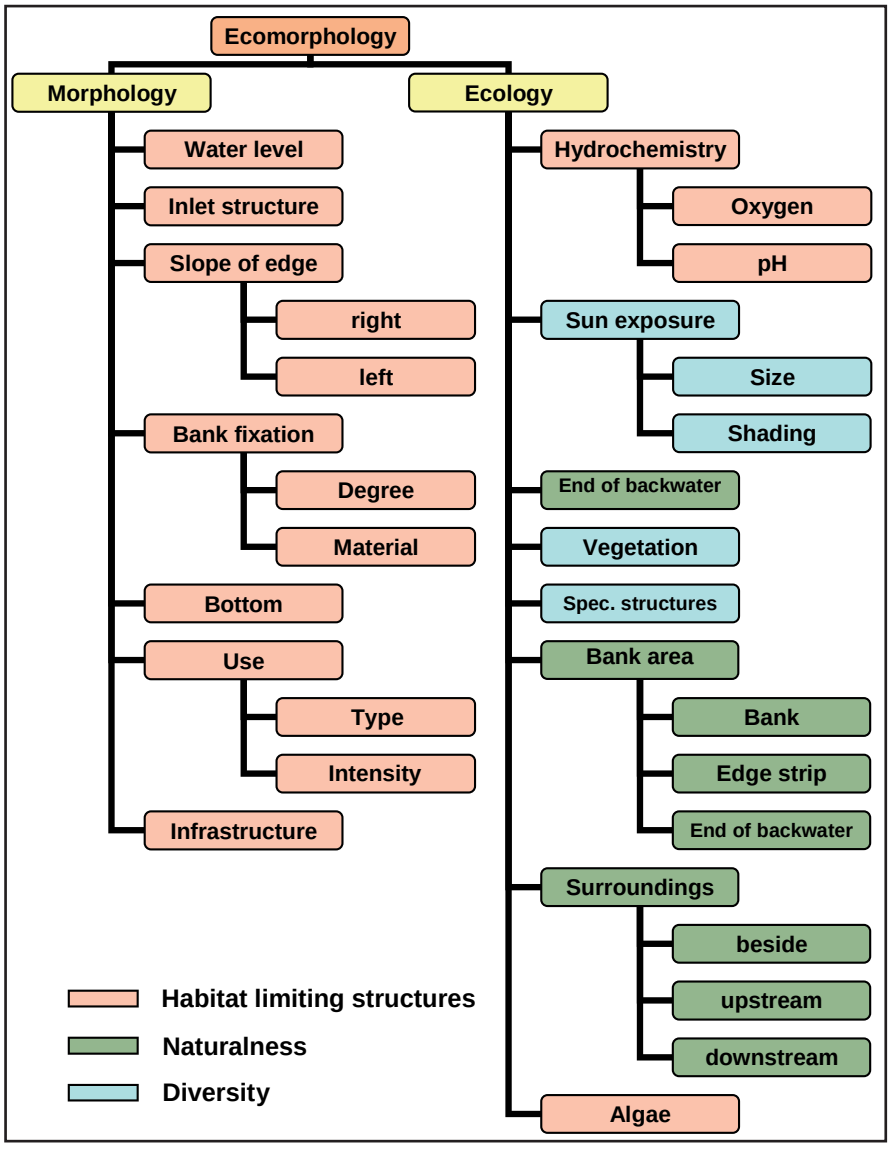

Fig. 4: Eco-morphological assessment structure.

Abb. 4: *Zusammensetzung der ökomorphologischen Bewertung.*

location of the ponds and the presence of other existing barriers, the interconnectedness wouldn't improve significantly in three-quarters of cases if the pond was removed.

4.4. Cultural and historical assessment

The history of the development and use of the ponds is diverse. Four main groups can be differentiated (Tab. 6).

The assessment system uses the age of the pond and the existence of significant cultural-historical structures as parameters. A third parameter is the history of the pond and asks if an individual pond has its "own story" (historical events, regional legends, outstanding use, or change of use), a "common story" of a special group of ponds such as drift ponds, or no special history.

Most of the observed ponds have only a low or very low cultural-historical value. Considering this, there is a growing need to preserve the few ponds with high or very high historical importance (Fig. 7).

4.5 Scenic landscape value and recreation

The landscape assessment takes into account that the most important usage for the ponds in the future will be passive recreation. The Palatinate Forest is famous for its hiking. The assessment considers the spatial diversity, the spatial perception, and the accessibility, estimated from observed attributes such as expanse of the water body, shading, vegetation, hiking trail proximity, special structures, and pond arrangement.

Most of the ponds show a high or moderate importance in scenic landscape terms (Fig. 8).

4.6 Collective assessment and decision support

Each of the five assessment systems leads to different classes and different recommendations for action, e. g., the assessment of the condition of structures results in conclusions about the urgency of restoration measures, and the five

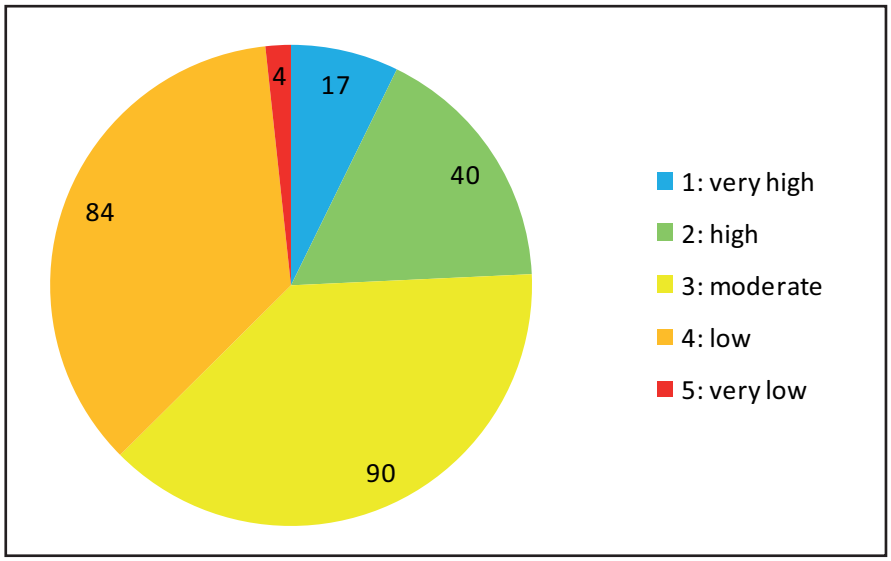

Fig. 5: Distribution of the eco-morphological values of the 235 observed ponds.

Abb. 5: *Verteilung der ökomorphologischen Bewertungsklassen auf die 235 untersuchten Weiher.*

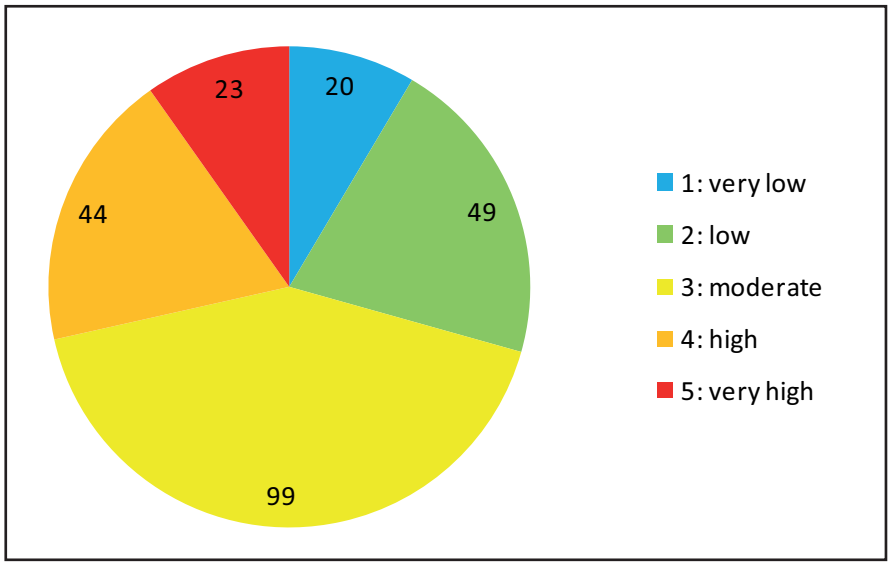

Fig. 6: Distribution of the degree to which the pond influences the watercourse in the 235 observed ponds.

Abb. 6: *Verteilung der Auswirkungen auf das Fließgewässer an den 235 untersuchten Weihern.*

classes of the eco-morphological assessment result in the proposals shown in Table 7.

By assembling the recommendations resulting from the five assessment systems together, a management concept for each individual pond can be generated. The eco-morphological assessment, the influence on the watercourse, the cultural-historical assessment, and the landscape and recreation assessment lead to decision support regarding the preservation or the removal of the pond and measures for improvement. The assessment of the condition of the structures leads to conclusions about the urgency of action when

Tab. 6: The four main uses of the ponds in the Palatinate Forest.

Tab. 6: *Die vier Hauptgruppen der Teichnutzung im Pfälzerwald.*

Use	Description
Old fish ponds	Their existence can be documented to medieval times in some cases. They are positioned in the centre of the watercourse and can be very large. Most of the ponds belong to this group.
New fish ponds	In most cases, some of the water is diverted from the watercourse to small ponds positioned alongside the stream. Sometimes the supply is only by springs, in particular at the edges of wide valleys. These ponds were mostly built in the 20th century.
Mill ponds	Built for hydropower, these ponds are mostly positioned in the center of the watercourse and the mill has been activated by a delivery channel or tube from the pond.
Drift ponds	Used for floating small pieces of timber, these ponds were built with sandstone at the beginning of the 19th century. They were abandoned at the end of the 19th century.

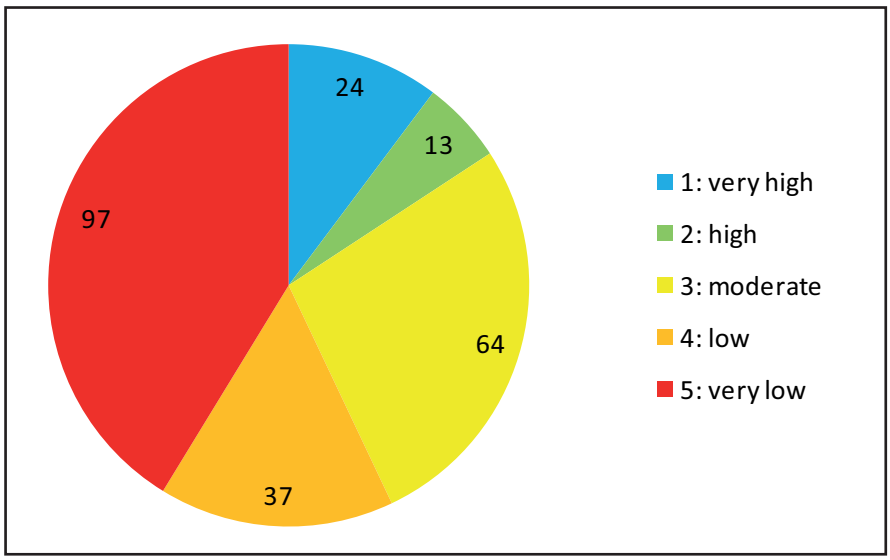

Fig. 7: Distribution of the cultural-historical values of the 235 observed ponds.

Abb. 7: *Verteilung der kulturhistorischen Bewertungsklassen auf die 235 untersuchten Weiher.*

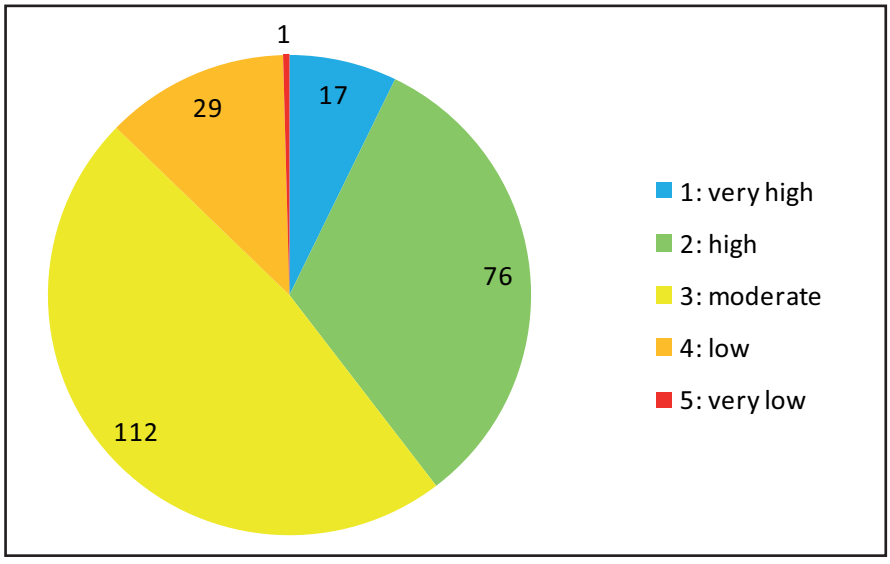

Fig. 8: Distribution of the landscape values of the 235 observed ponds.

Abb. 8: *Verteilung der Landschaftsbild-Bewertung auf die 235 untersuchten Weiher.*

Tab. 7: Decision support derived from the eco-morphological classes.

Tab. 7: *Aus der ökomorphologischen Bewertung resultierende Entscheidungshilfen.*

Class	Management decision support	Measures for upgrading
1 Very high	Conservation of the pond, preservation has highest priority	None necessary
2 High	Conservation of the pond, preservation essential	Ecological support reasonable, but not a priority
3 Moderate	Conservation and preservation desirable	Ecological support measures desirable
4 Low	Not necessary	If preservation is desired for other reasons, ecological support should be provided
5 Very low	Pond can be shut down if there are no other arguments for conservation (decay permitted or removal required depending on other assessments)	If pond preservation is desired (for some other reasons), ecological support measures would likely not be cost-effective

preservation is recommended based on the other assessments.

In addition, a calculated comparison between the eco-morphological value and the influence on the watercourse can be performed. Such an "ecological matrix" compares the ecological values of the pond and of the stream and tries to determine if the backwater is more of a hindrance or more of an enrichment from the ecological point of view. An "anthropogenic matrix" combining the cultural-historical assessment and landscape/recreation value ranks the relevance of the pond for human interests. This may be a further important reason – beyond the ecological argument – for the conservation of the pond.

5 Management Concept

The management concept will be derived from the results of the assessments as explained above and modified based on the existing rights and usages. The main goal is the conservation and maintenance of historically and ecologically valuable ponds. Undesirable uses should be identified and corrected (e. g., intensive fish breeding, retention basin for road drainage), and new options for use can also arise. The ecological value or the value for recreation can be enhanced with mostly low cost measures (e. g., removal of spruce or Douglas fir) whereas in the case of damaged structures, the question of restoration versus decay or removal must be answered.

Possible measures for improvement include the following:

- **Installation** of a **bypass channel** next to the pond (conversion from a centred to a bypass pond)
- **Installation** of a solid **overfall** with rough-textured chute down to the tailwater to improve passage for stream-dwelling organisms
- Medium-term **maintenance and support** of ponds (e. g., conservation of structures, stocking regulation, improvement of the surrounding)
- **Restoration** of damaged structures
- Lowering of water table or **removal** of ponds

Decisions regarding the individual ponds will be made in coordination with local authorities, owners, and users (forestry, municipality, environmental authorities, water management offices, fishing associations, fish farmers, private owners), who can make use of our recommendations for the observed ponds. For the larger number of ponds that have not yet been investigated, the data collection protocol and the assessment systems will enable the stakeholders to reach appropriate decisions.

To realize the first measures based on our management concept, we are currently in negotiation with municipalities and forest administration. One anticipated measure, for example, is the rehabilitation of a damaged dam to maintain a historical drift pond with an existing sandstone outlet (Fig. 9). The planning should include the construction of a fish pass to assure the biological passability of the structure.

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Fig. 9: Drift pond dam from the 19th century with historical outlet structure (right side) and damage requiring restoration (left side).

Abb. 9: *Damm eines Triftweihers aus dem 19. Jahrhundert mit erhaltenem historischen Auslassbauwerk (rechts) und sanierungsbedürftigem Schaden (links).*

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Restoration of some small loess streams – a contribution of organic farming to nature conservation and management

Renaturierung kleiner Lössbäche – ein Beitrag der Ökologischen Landwirtschaft zum Naturschutz

Ulrich Braukmann, Bastian Rupp, Werner Haaß, Ulf Stein and Achim Schütte

Abstract

As a part of the interdisciplinary research project "Integration of nature protection goals with organic farming: an the example from the Hessian "state domain" [Staatsdomäne] area Frankenhausen", different restoration measures have been carried out within this site, 15 km north of Kassel. Since 1998, intensive conventional agricultural practices have been substituted with organic farming here. One intention of the agricultural restructuring was to realise nature protection goals in cooperation with sustainable organic agricultural production.

The hydrologic portion of the project addresses both the implementation of restoration measures in rivers and streams and their scientific monitoring. Starting in July 2007, several restoration measures were carried out in the hydrologic systems of the Jungfernbach and Esse streams within the Frankenhausen site. Both systems are formed by typical loess streams (catchment size about 9 km²) which had been heavily degraded for several hundred years by intensive agriculture. The most important restoration measures were removal of a piped section of a tributary of the Jungfernbach at Totenhof, restoration of biological passability by removal of weirs and substitution of narrow pipes under farm paths, relocation of a section of the Jungfernbach from the edge of the floodplain to its original location in the centre, widening of narrow sections and partial raising of the deepened stream bed by means of rough ramps (stone bars) and racks made of oak wood or iron.

These physical restoration measures were accompanied by a scientific monitoring programme comprising morphological, hydrochemical and biological (aquatic macrophytes, aquatic macroinvertebrates, fish and amphibians) aspects.

The aim of this study was to document the original ecological conditions, the restoration measures and the early ecological effects on the stream sections for the first six months following restoration as a basis for further ecological monitoring.

The restoration measures effected clear morphological changes in cross-section and passability. The chemical condition of the streams showed slight changes in some aspects following the restoration, e. g. a reduction of phosphorus, magnesium and potassium concentration. Other than macrophytic algae in the newly shaped sections, aquatic macrophytes did not develop over the winter season before the end of the monitoring phase in April 2008. Within the newly shaped stream sections of a small tributary and of the Jungfernbach, up to 14 aquatic macroinvertebrate taxa started to colonise the new habitats 6 months after restoration.

*Fish fauna were very poorly represented in the streams and included only a few specimens of brown trout (*Salmo trutta*). This did not change markedly after restoration, possibly due to the isolation of the population caused by impassable weirs downstream of the investigation area.*

Keywords: *Organic farming; loess streams; stream restoration; morphological, chemical, biological monitoring; biodiversity; evaluation of ecological success; integrated nature conservation*

Zusammenfassung

In einem interdisziplinären „Entwicklungs- und Erprobungs-Vorhaben" der Universität Kassel „Die Integration von Naturschutzzielen in den Ökologischen Landbau am Beispiel der Hessischen Staatsdomäne Frankenhausen" wurden unterschiedliche Naturschutz-Maßnahmen auf dem Domänengelände durchgeführt. Seit 1998 wird die Staatsdomäne Frankenhausen, die ca. 15 km nördlich von Kassel liegt, ökologisch bewirtschaftet. Ein Aspekt bei der Umstellung auf ökologische Landwirtschaft war die Umsetzung von naturschutz-orientierten Maßnahmen, die in Kooperation mit dem landwirtschaftlichen Betrieb umgesetzt wurden.

Ein gewässerökologisches Teilprojekt umfasste unterschiedliche Entwicklungsmaßnahmen an und in Bächen des Jungfernbach- und Esse-Systems auf dem Gelände der Staatsdomäne ab Juli 2007. Beide Bachsysteme (Einzugsgebietsgröße jeweils ca. 9 km²) werden von typischen lössgeprägten Bördenbächen gebildet. Löss-Gebiete zählen zu den durch intensive Landwirtschaft am tiefgreifendsten veränderten Gebieten Deutschlands. Folgende wesentliche Renaturierungsmaßnahmen wurden auf dem Domänengelände umgesetzt: Entfernung der Verrohrung, Offenlegung und Neugestaltung eines Nebenbaches des Jungfernbaches am Totenhof, Rückverlegung eines Jungfernbach-Abschnitts vom Rand der Aue in seine ursprüngliche Lage im Zentrum der Aue nach historischen Angaben, Wiederherstellung der biologischen Durchgängigkeit durch die Entfernung von Wehren und den Ersatz von unpassierbaren Wege-Durchlässen durch voluminösere Durchlässe mit durchgängiger Sohle, partielle Aufweitung enger Querprofile und Anhebung der Gewässersohle durch Stein-Riegel und Sohlrechen aus Stahl oder Eichenholz.

Die Maßnahmen wurden von einem wissenschaftlichen Monitoringvorhaben begleitet. Hauptaspekte der wissenschaftlichen Begleitung waren morphologische, hydrochemische und biologische Untersuchungen aquatischer Makrophyten, des Makrozoobenthos, der Fischfauna und der Amphibien. Sie dienten der Erfassung des ökologischen Status quo der Gewässer vor Durchführung der Maßnahmen und der Doku-

mentation der ökologischen Situation der Gewässer im Anschluss an die Maßnahmen als Basis für die Beobachtung der künftigen Gewässerentwicklung.

Die Renaturierungsmaßnahmen induzierten markante Veränderungen der morphologischen Situation der ehemals zu engen und tiefen Querprofile und verbesserten die biologische Durchgängigkeit auf dem Domänengelände. An den Sohlrechen fand während der Folgemonate nach der Renaturierung wegen zu geringer Wasserführung nur ein geringer Totholztransport und damit noch keine erkennbare Sohlanhebung statt.

Die chemischen Qualitätsparameter zeigten bei einigen Wasserinhaltsstoffen (z. B. bei Phosphor, Magnesium und Kalium) einen Rückgang der Konzentrationen, der seine Ursachen im Verzicht auf mineralische Düngung mit diesen Stoffen in der ökologischen Landwirtschaft haben könnte.

Bei den Wasserpflanzen traten in den neu gestalteten Gewässerabschnitten unmittelbar nach den Renaturierungsmaßnahmen Pionierbestände makrophytischer Algen wie *Spirogyra*, *Cladophora* und *Vaucheria* auf. Über die Herbst- und Wintermonate nach Abschluss der Maßnahmen im Oktober 2009 bis zum Ende der Monitoring-Phase im April 2008 konnten sich noch keine Makrophytenbestände in den neu gestalteten Gewässerabschnitten entwickeln.

Im Gegensatz hierzu fand in diesem Zeitraum eine rasche Ansiedlung von 14 Wirbellosen-Taxa im Jungfernbach und 13 Taxa im kleinen, offengelegten und neu gestalteten Bach am Totenhof statt. In diesem Nebengewässer siedelten sich zahlreiche für Lössbache charakteristische Makroinvertebraten bachaufwärts aus dem Jungfernbach heraus an.

Die sehr spärliche Fischpopulation, die aus wenigen Bachforellen in einem einzigen Gewässerabschnitt bestand, veränderte sich infolge ihrer räumlichen Isolation durch unterhalb des Untersuchungsraums gelegene Wehre nicht nennenswert.

Schlüsselwörter: Ökologische Landwirtschaft; Lössbäche; Gewässerrenaturierung; morphologische, chemische, biologische Erfolgskontrolle; Biodiversität; Naturschutz

1 Introduction

The “Aquatic Ecology” project described in the following contribution is part of the interdisciplinary research project (development and testing programme [“E+E-Vorhaben”]). ”Integration of nature protection goals with organic farming: an the example from the Hessian ”state domain” [“Staatsdomäne”] area Frankenhausen“ conducted by different institutes of the University of Kassel. The Frankenhausen site is situated on land that has been leased from the federal state of Hessen by the University of Kassel since 1998 to allow the intensive conventional agricultural practiced there to be replaced by organic farming. Physical measures were financed by the Hessische Landgesellschaft. Scientific monitoring was financially supported by the German Federal Nature Conservation Agency (BfN).

The project consists of two major components:

1. An operative programme [“Hauptvorhaben”] to carry out different tangible restoration and development measures, e. g. restoration of streams and rivers in the region
2. A scientific monitoring programme [“Wissenschaftliches Begleitvorhaben”] to assess the ecological success of the realised measures.

The development and test programme started in spring 2006. The implementation of the first restoration measures took place in summer 2007. Scientific monitoring ended in April 2008.

The scope of the operative programme of the aquatic part of the project is to improve hydromorphological habitat conditions for aquatic and semi-aquatic plants and animals; these actions are supported by measures in the floodplain to provide more room for the sustainable ecological development of the streams within the Frankenhausen site. The measures were designed to comply with the goals and practices of organic farming and to serve as examples which might be implemented in other comparable organic farms.

The scope of the scientific monitoring programme was twofold. First, the status quo of aquatic macrophytes, invertebrates and fishes before and shortly after restoration was documented. Second, the recolonisation by benthic macroinvertebrates of newly restored stream sections was investigated. Another goal was to identify typical plant and invertebrate taxa which could be used as target species to monitor the ecological success of restoration measures in similar streams.

Typical streams of the German *Börde* landscape – an agriculturally fertile area marked by flat terrain, loess soils, and few trees – show the following features:

- Their bed materials are mostly fine-grained from input of loess.
- The watercourses have generally been straightened.
- The watercourses have often been shifted close to the edge of the floodplain.
- Their beds have mostly been deepened either by hydraulic engineering or as a consequence of straightening and vertical erosion.
- As a consequence of deepening, streams and their floodplains are often separated. Semiaquatic transition zones between the aquatic and terrestrial areas are usually missing.
- The surrounding flood plain area is frequently drained by dense drainage systems for agricultural purposes.
- In many cases open arable land is situated close to the banks. Unmaintained riparian buffer strips are often narrow or totally missing.
- A permanently high input of silt, nutrients and pesticides is common to loess streams in conventionally cultivated Börde areas.
- Dead wood, an important structural component of stream beds, is often removed for maintenance reasons.

For these reasons, particularly the ongoing input of silt which generally leads to a severe sealing and homogenisation of the stream bed, loess streams usually show a comparatively low biological diversity.

Important prerequisites for the ecological development of aquatic communities in loess streams include the following:

- Good chemical quality
  - No pesticides near the banks
  - Reduced input of silt
- Natural structures of the stream bed and bank
  - Higher structural diversity through the inclusion of dead wood.

Centuries of intensive agriculture have resulted in conditions that are increasingly incompatible with natural streams and their floodplains. In such areas the realisation of stream restoration measures is extremely difficult. In loess areas, much more than in other regions, land for restoration purposes is largely unavailable owing to their fertile soils, which are valuable for agriculture. Therefore stream restoration measures were undertaken within the Frankenhausen site, where organic farming is practised, to provide a model for comparable farming in other regions of Germany.

2 Area of investigation

The Jungfernbach, situated about 15 km north of Kassel, is part of the stream system of the Esse which flows into the river Diemel, a tributary of the river Weser (Fig. 1). Their catchment is located in a typical *Börde* landscape. Great parts of it are covered with fertile loess soils. The floodplains of the Jungfernbach and Esse system have been significantly altered by agriculture. The Jungfernbach has a total length of about 6 km, an average slope of 1.27 % (Weber 2000) and a catchment area of 9 km^2. Mean width of the stream bed is 1 to 3 meters, mean annual flow is 1.7 m^3/s, mean five-year flow 3.5 m^3/s, and current velocity ranges between 0.1 and 0.4 m/s. Bed and banks of the Jungfernbach are not stabilised, but in most sections have been significantly straightened, and the stream bed has mostly deepened down to 2–3 m below the surface of the riparian area. Within the Frankenhausen site, the Jungfernbach and its tributaries belong to the category of loess hill streams, which are rich in fine stream bed material and of moderate slope.

According to Pottgiesser & Sommerhäuser (2004, 2008), the investigated streams resemble type 6: "*small fine-substrate-dominated calcareous highland streams*" and type 18: "*small loess and loam-dominated lowland streams*". In natural alder floodplain forests, small loess brooks may develop towards type 11: „*small, organic-substrate-dominated rivers*" (Pottgiesser & Sommerhäuser 2004).

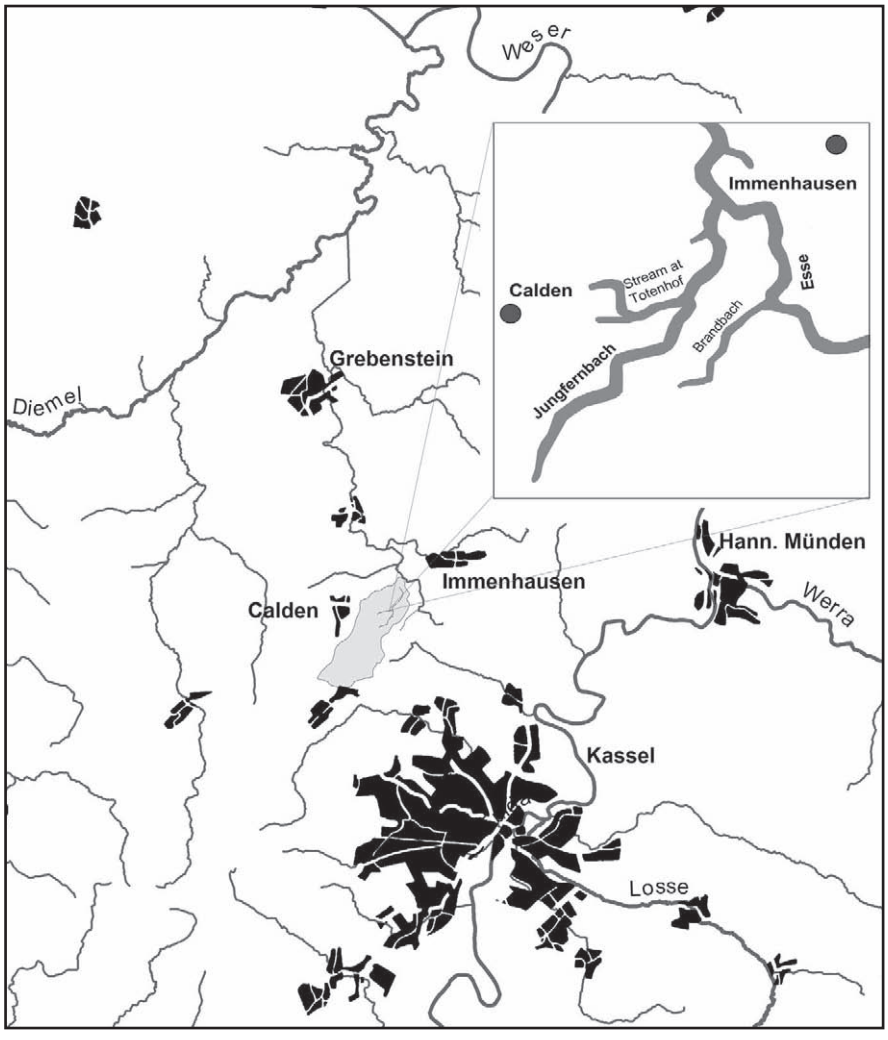

Fig. 1: Study area and map of water quality of the Jungfernbach system according to the saprobic system. All sections are classified as moderately polluted (quality class II, results for streams outside the Jungfernbach system according to HLUG 2000).

Abb. 1: *Untersuchungsgebiet und Karte der Gewässergüte des Jungfernbach-Systems gemäß Saprobiensystem. Alle Abschnitte sind mäßig belastet (Güteklasse II, Ergebnisse außerhalb des Jungfernbach-Systems nach HLUG 2000).*

A reference section of this stream type was found within the area of the Jungfernbach nature reserve. It has a length of about 200 m and is the only section of the Jungfernbach with a moderate structural quality according to LAWA (2000). This section (type 11) was used as the reference condition (*Leitbild*) for the restoration of other morphologically degraded parts of the Jungfernbach. In its semi-natural reference section, the Jungfernbach presents a meandering course without anthropogenic depth erosion of the stream bed. Here the average depth of the stream bed is about 30 to 50 cm. Within the reference section the stream passes through a nearly natural alder floodplain forest. It differs significantly from the downstream sections, which have been heavily modified by former agricultural use. They are deepened down to 3 meters, mostly straightened and bordered by narrow, patchy, wooded riparian buffers. These sections are more or less severely morphologically degraded and predominantly show a bad structural quality (Fig. 2).

As a typical loess-loam stream, the Jungfernbach and all other investigated stream sections are characterised by layers of mud of varying thickness covering their beds. Bed sediments are dominated by silt, loess, loam and fine-grained sand. Pebbles and cobbles rarely occur. Under natural conditions dead wood forms the most important coarse structures to serve as suitable habitats for benthic macroinvertebrates.

Due to nearly permanent input of loess particles from the catchment, the coarse structures like stones, leaves, twigs etc. are often silted over. Siltation leads to a severe uniformity of the stream beds, resulting in a biological diversity which is much lower than in stony mountain streams. Due to permanent turbidity caused by the silt, loess streams generally contain few water plants. Intensive cultivation of corn, sugar beets or even wine in the catchment usually leads to an increased impact of nutrients and pesticides. Thus loess streams, especially in wine-growing areas, are actually among the most degraded and biologically impoverished moving-water ecosystems in Germany and in comparable areas of Central Europe.

2.1 *Water and structural quality of the Jungfernbach system*

Water quality of the Jungfernbach and Esse systems is classified as class II, moderately polluted, in all water courses, according to the saprobic system (DIN 2003) and LAWA (1998). Compared to the biologically defined water quality, the hydromorphological quality of the streams, evaluated according to the German habitat assessment system (LAWA 2000), is much worse. Just 3 % of the total water course of the Jungfernbach is moderately degraded and classified as class 3, meeting the regulatory goals to be achieved. Most of the length of the stream (83 %) is classified as distinctly to heavily degraded, and 14 % is completely degraded. That result is typical and representative for most German loess streams. Figure 2 gives an overview of the hydromorphological condition (structural quality) of the streams specified above.

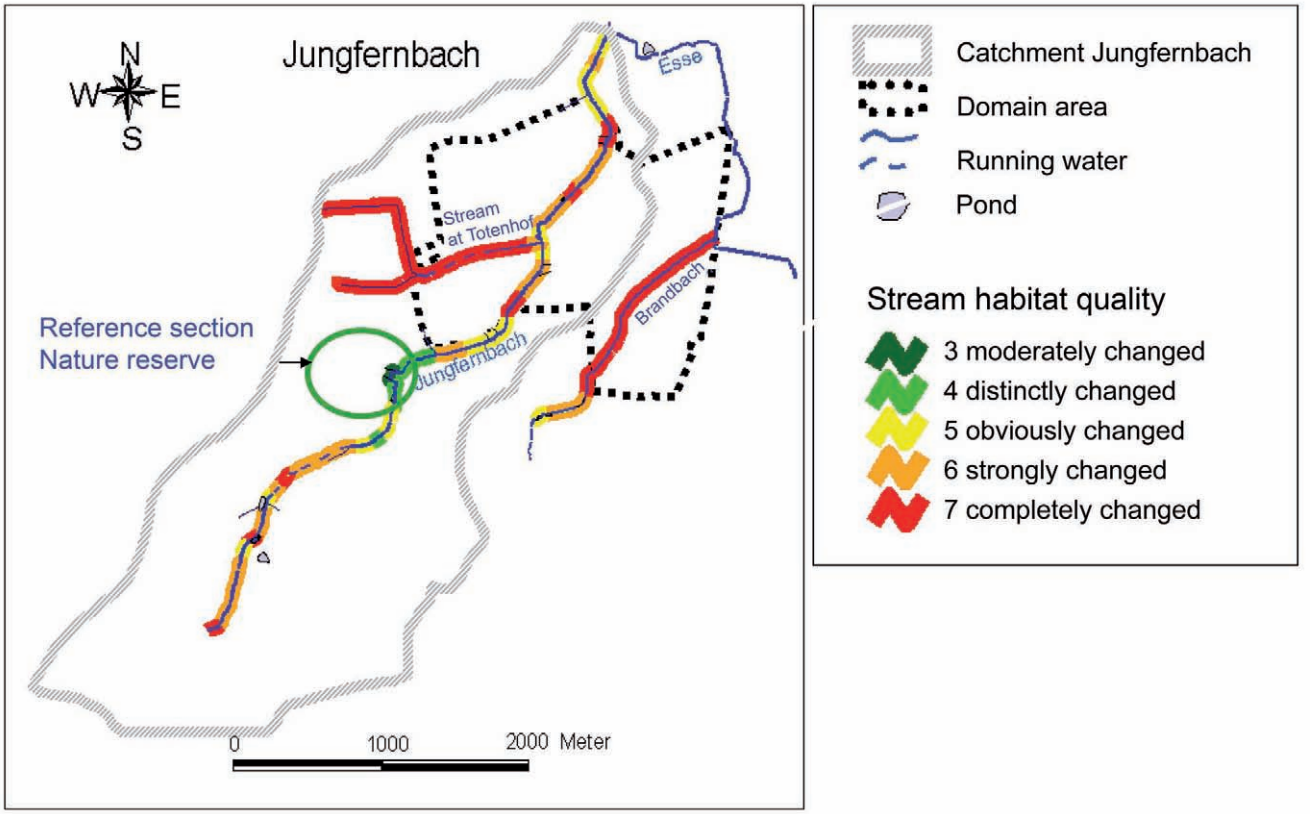

Fig. 2: Stream habitat quality of the Jungfernbach system before restoration. Only a small 200 m section within the nature reserve can be described as moderately impaired. All other sections are significantly worse. (Figure according to Weber 2000, after HMULF 2000)

Abb. 2: *Gewässerstruktur-Güte des Jungfernbach-Systems vor der Renaturierung: Lediglich ein kurzer Abschnitt von 200 m Länge (im Naturschutzgebiet) ist mäßig beeinträchtigt. Alle anderen Abschnitte sind schlechter eingestuft. (Abbildung nach Weber 2000 und HMULF 2000)*

Figure 3 presents (a, b) a near-natural reference condition of a characteristic organic-substrate-dominated loess stream like the Jungfernbach within the nature reserve and (c–f) some typical aspects of the morphological degradation of the loess streams and agricultural ditches within the Frankenhausen site.

3 Operative programme

3.1 Restoration measures in the stream systems of Jungfernbach and Esse

The restoration measures were planned and conducted by the planning consultancy "Büro für Ingenieurbiologie und Landschaftsplanung" (BIL, Witzenhausen) in cooperation with the University of Kassel, Department of Water Ecology and Management.

The first steps for the ecological development and improvement of the stream systems were carried out in the Frankenhausen farm area. The land there has been leased from the federal state of Hessen by the University of Kassel since 1998 to allow the intensive conventional agricultural practices to be replaced by organic farming. One aim of the agricultural restructuring of the site was to allow the goals of nature conservation to be pursued in close cooperation with sustainable organic production.

3.1.1 Goals of the measures

A major goal of the restoration measures was to develop and support both the natural conditions of the streams and their biodiversity, thereby complying with the economic and ecological intentions of organic farming. Another aim was the creation and development of natural areas, particularly in floodplains with supraregional bioptope connections.

The basic ecological goals of the project can be defined as follows:

- Reestablishment of passability for fish and macroinvertebrates
- Restitution of the inherent dynamic of the water bodies and a near-natural morphology; promotion of dead wood as an important structural parameter within the scope of water maintenance measures
- Reversal of vertical erosion
- Reduction of sediment and nutrient input from the catchment
- Development of a riparian buffer consisting of typical floodplain vegetation
- Support for development of greater zoological diversity

The first proposals for natural development of the watercourses within the site were developed in 2001 (Braukmann et al. 2002) based on a diploma thesis by Weber (2000). Further investigations were carried out in 2004 and 2005 (Wolf et al. 2005). More detailed planning was conducted by the planning office BIL (Haass 2008). After authorisation by the regional council of Kassel, the following measures were implemented between July and October 2007:

- The Jungfernbach was relocated from the edge to the centre of the floodplain.
- The deepened beds of Jungfernbach and Brandbach were partly raised by stone barriers. Rakes made of wood or iron bars, all passable for organisms, were installed to support an accumulation of dead wood.
- Passability of most stream sections was improved by removing existing weirs and narrow pipes under paths.
- A piped section of the ditch at Totenhof was daylighted and restructured.
- Riparian buffers and areas for succession were extended up to 20 meters on each bank.
- Several ponds and pools were created.

Figure 4 gives an overview of restoration measures carried out at the Frankenhausen site.

The following paragraphs provide a detailed overview of the restoration measures carried out in the different project streams (see also Fig. 4).

Jungfernbach: In some sections the bed was raised to about 1 meter by sills (*Grundschwellen*) consisting of regional limestone material. In other sections, coarse racks of oak wood or iron bars were installed to support natural raising of the bed through accumulation of dead wood.

Biological passability was improved by a number of measures including removal of weirs and the substitution of impassable pipes with larger ones that were dug into the natural substrate.

In the area of the nature reserve, the straightened course of the Jungfernbach was relocated from the edge of the floodplain to its original position in the middle. A new shallow bed with the potential for dynamic development and early inundation was created and protected against vertical erosion with sills made of limestone.

The drainages in the floodplain were closed. A new unperforated intercepting sewer along the border between arable land and grassland was located in the grassland area to maintain drainage of the adjacent agricultural areas which continue to be cultivated. This drain pipe was also necessary because the stream bed was raised in this section. The aim of this measure was to establish a wetland area as a suitable habitat for dragonflies, amphibians and wading birds The excavated earth was partly used to fill the former bed at the edge of the floodplain and to create back water, including areas of standing water. Below the stream relocation, the bed was partly protected against vertical erosion and raised 0.5 to 1 meter with sills and coarse iron racks.

Close to the Jungfernbach, four ponds of different depths were established for amphibians.

Small creek near Totenhof: The piped section of the small creek near Totenhof was daylighted for a length of about 400 m. A new shallow bed was established. The bottom was

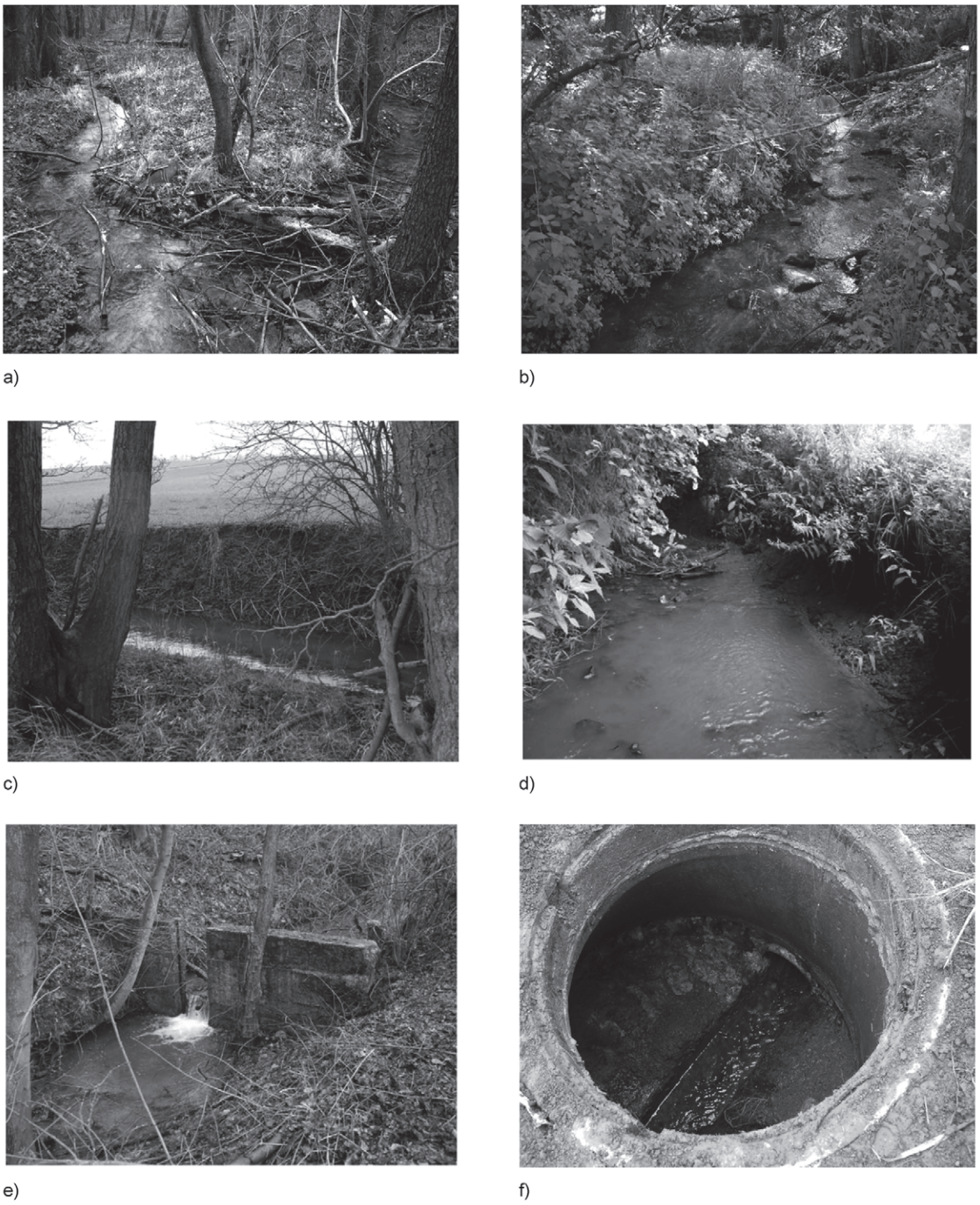

Fig. 3: **a**), **b)** Semi-natural section of the Jungfernbach stream. Reference condition of a typical loess stream with shallow stream bed and minimal vertical erosion, strongly curved to meandering, surrounded by a natural alder floodplain forest. Relevant bed structures are dead wood, some coarse sediments and larger stones; stream shows characteristics of an organic-substrate-dominated subtype. **c)** Artificially deepened stream bed resulting from straightening. Typical section without clearance for dynamic development, no riparian buffers, sharp boundaries between aquatic and terrestrial ecosystems, and no amphibian areas. **d)** Characteristic permanent turbidity caused by the input of loess-loam particles. **e)** Obstacles to ecological passability for aquatic animals caused by an old weir. **f)** Piped stream section at Totenhof; this section was daylighted and rebuilt (see Fig. 5 a, b) (Photos: a, b) Braukmann, c) to f) Rupp).

Abb. 3: ***a), b)*** *Naturnaher Abschnitt des Jungfernbaches; Referenzabschnitt eines typischen Löss-Baches mit flachem Bachbett, geringer Tiefenerosion, kurvigem bis mäandrierendem Verlauf in einem Schwarzerlen-Eschen-Bachauenwald; bedeutende Bettstrukturen sind: Totholz und einige größere Steine; Gewässer zeigt Aspekte eines organisch geprägten Gewässertyps;* ***c)*** *Unnatürlich stark eingetieftes Bachbett infolge ehemaliger Begradigung, typischer Abschnitt ohne Möglichkeit einer dynamischen Eigenentwicklung, keine Uferrandstreifen, scharfe Grenze zwischen aquatischem und terrestrischem Bereich, keine amphibische Zone;* ***d)*** *Typische permanente Trübung infolge des Eintrages von Löss-Partikeln;* ***e)*** *Wanderungshindernis für aquatische Organismen, verursacht durch ein Wehr;* ***f)*** *Verrohrter Abschnitt des Baches am Totenhof; dieser Abschnitt wurde geöffnet und neu gestaltet (vgl. Abb. 5 a, b) (Fotos: a, b) Braukmann, c-f) Rupp).*

partly protected against erosion with sills of local limestone. Below the daylighted part of the stream, the very steep borders were flattened on both sides, and the bed was stabilised and raised about 0.5 m with rough ramps. Narrow pipes below farm paths were replaced with wider ones to enable biological passability.

Stream edges were partly replanted with alders. Beside the daylighted stream section, a pond with a surface area of 320 m² and a depth of 1.5 m with shallow edges in places was created.

Brandbach: The severely deepened bed of the Brandbach was raised about 0.6 m with eight rough stone ramps. A pipe was replaced with a wider passage. In this section, alders were also replanted. Drainages were removed and some ponds were established.

Near the **Esse creek** an earthen wall was relocated 10 m away from the stream in order to develop a broader riparian area. A small headwater in the area of the Mühlberg grassland was opened and structured as a small shallow creek.

All restoration measures were carried out with the goal of improving structural and biological diversity. The aims were to support biotope connectivity, restore biological passability, and increase the amount of natural floodplain vegetation. Most of the measures improved the water regime by raising the groundwater level. Finally, all measures are expected to have a positive visual impact on the monotonous loess landscape.

Some of the most important measures are illustrated in Figure 5.

3.1.2 Outlay for the restoration measures

Gross construction expenses for the restoration measures carried out for the ecological upgrading of the water bodies amounted to 157,000 EUR (according to Haass 2008). These costs also include measures such as development of several new ponds in the floodplain of the streams.

4 Scientific monitoring

An important aim of the scientific monitoring was to gain basic knowledge of the abiotic and biotic parameters which might be influenced and changed by the restoration measures of the aquatic ecosystems within the operative programme of the project.

Another aim of the scientific monitoring was to assess the ecological condition of the stream sections before and shortly after restoration to obtain a baseline for future monitoring in the coming years. Furthermore, the study was to document the ecological effects of the hydromorphological restoration, particularly the raising of the stream bed, on the aquatic and amphibian communities. The recolonisation process of benthic organisms in restored sections of the Jungfernbach (section 7 in Fig. 6) and the small daylighted and newly shaped creek at Totenhof were also to be documented (sections No. 5 and 12 in Fig. 6).

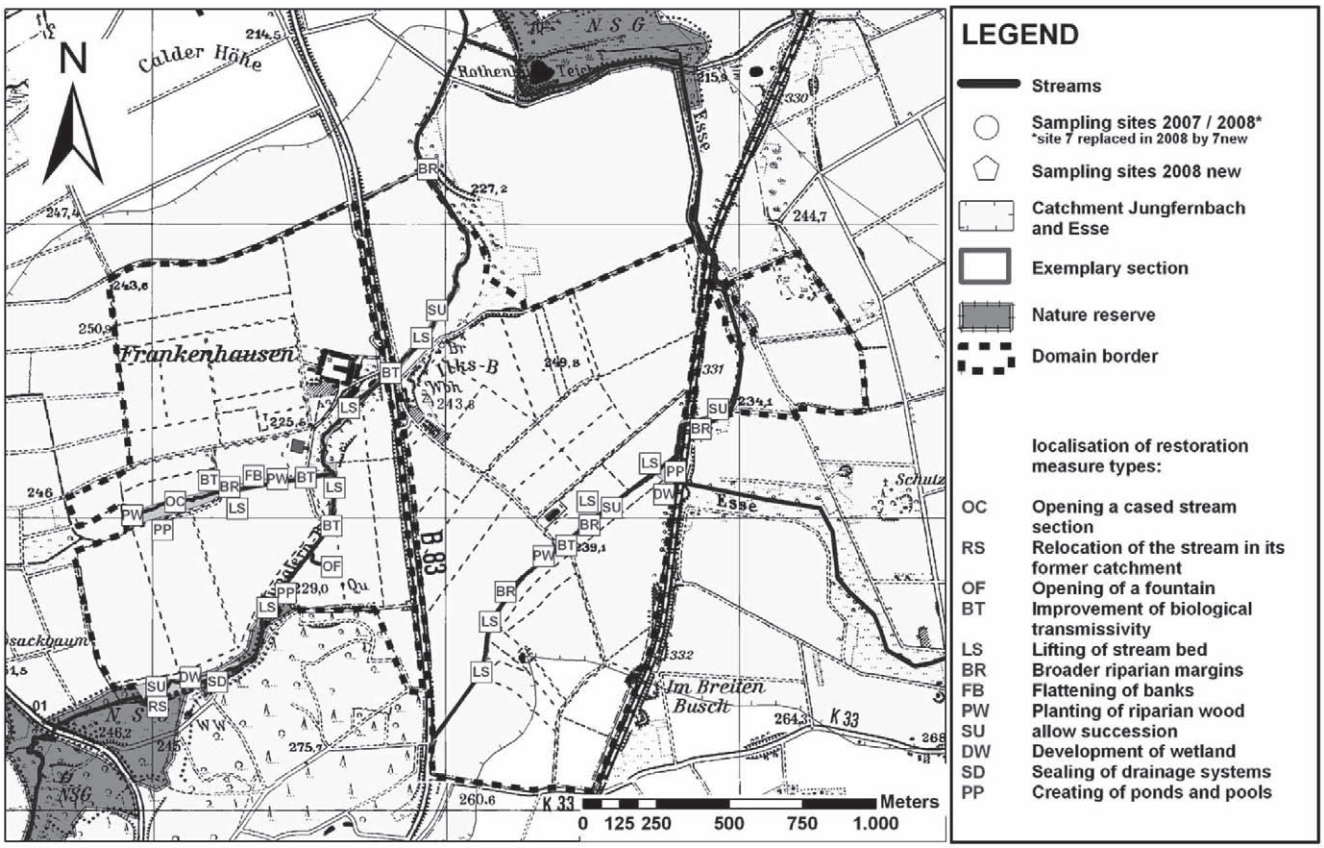

Fig. 4: Overview of main restoration measures in the Jungfernbach and Esse watershed at Frankenhausen site.

Abb. 4: *Übersicht über die wichtigsten Renaturierungsmaßnahmen-Typen im Jungfernbach- und Esse-System auf dem Gebiet der Staatsdomäne.*

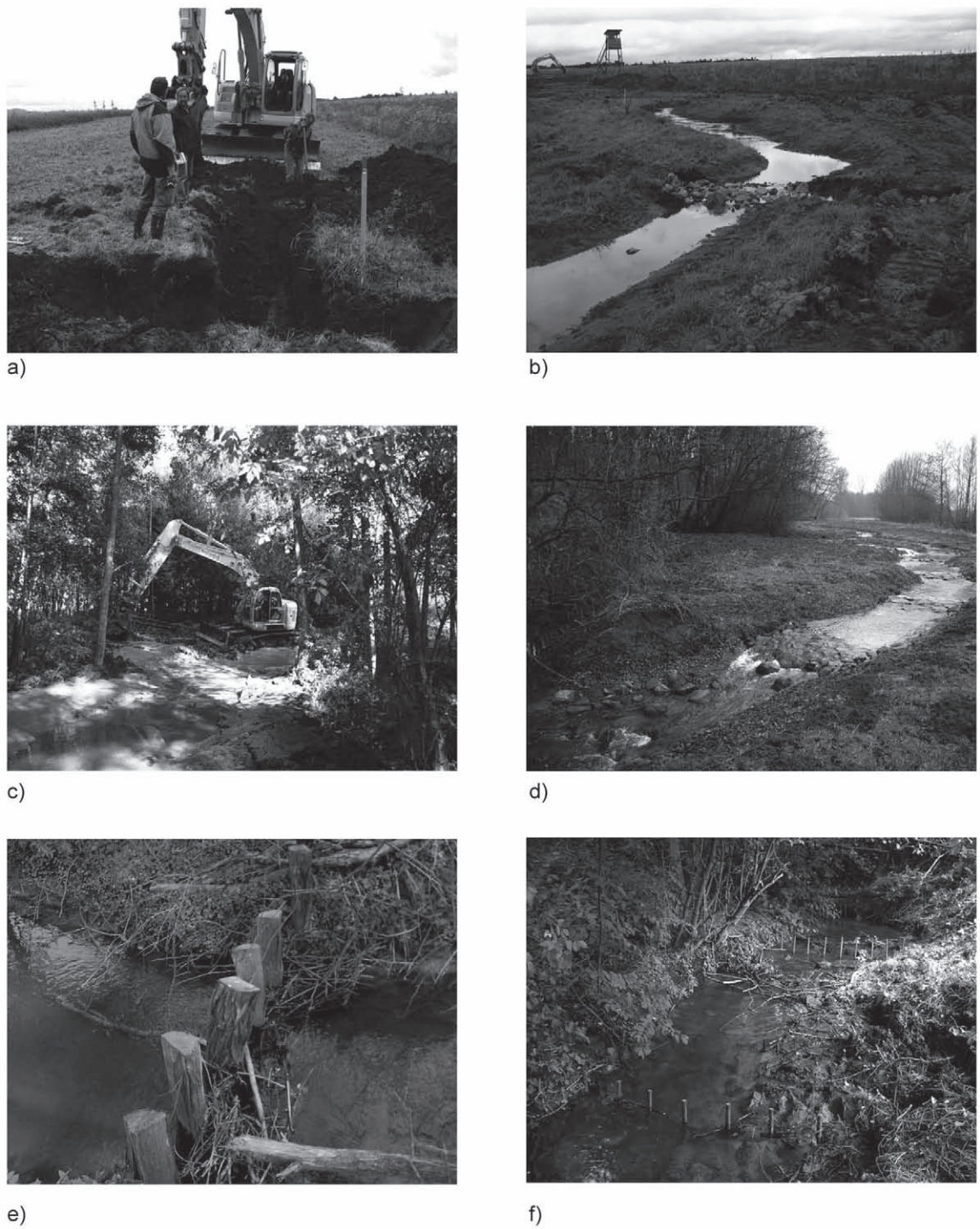

Fig. 5: Main restoration measures: **a)** Daylighting of the formerly piped brook at Totenhof; **b)** Newly built brook at Totenhof. Goals included restitution of biological passability and of a flat bed structure with the potential for dynamic development and early inundation; **c)** Relocation of the Jungfernbach into the middle of the flood-plain; **d)** Newly built section of the Jungfernbach, the shallow bed has been partly stabilised by stone bars; **e)** Lifting of the stream bed by racks made of wooden bars; **f)** Lifting of the stream bed by groups of iron bars (Photos: a, e) Rupp; b, c) Haaß; d, f) Braukmann).

Abb. 5: *Haupt-Renaturierungsmaßnahmen: **a)** Öffnen des verrohrten Baches am Totenhof; **b)** Neu strukturierter Bach am Totenhof – Ziele: Wiederherstellung der biologischen Durchgängigkeit und eines flachen Bachbetts mit dem Potential einer dynamischen Eigenentwicklung und frühzeitiger Ausuferung; **c)** Rückverlegung des Jungfernbaches in die Mitte der Aue; **d)** Neu gestalteter Abschnitt des Jungfernbaches, das flache und breite Bett wurde partiell mit Steinriegeln gegen Tiefenerosion gesichert; **e)** Anhebung der Bachsohle, initiiert durch Eichenholzstäbe; **f)** Anhebung der Sohle durch Stahlstäbe (Fotos: a, e) Rupp; b, c) Haaß; d, f) Braukmann).*

The scientific monitoring consisted of the following aspects:

- Assessment of the morphological conditions and probable changes resulting from restoration measures in 12 sections which are representative for typical loess streams, particularly:
  - Raising of the stream bed
  - Shifting of bed and bank structures
- Chemical monitoring of organic pollution, nutrients, and geochemistry
- Biological monitoring of the status quo and development of:
  - Aquatic, amphibian and terrestrial vegetation (in the riparian area)
  - Macroinvertebrates, amphibians and fish

The most important aspects of the scientific monitoring programme were as follows:

- Typification of the Jungfernbach
- Preliminary studies: four sections of the Jungfernbach were investigated in 2001 to enable the following:
  - Evaluation of the structural quality
  - Chemical and biological investigations
  - Determine reference conditions and development objectives
- The main studies were carried out in the following sites:
  - In 2007: eight sections in the Frankenhausen area, one reference section in a nature reserve, two sections of the Esse
  - 2008: nine sections in the Frankenhausen area, one reference section, and two sections of the Esse

Figure 6 shows where the sites were established for the morphological, chemical and biological monitoring programme.

4.1 Methods

4.1.1 Morphological monitoring

Morphological investigations included surveying and mapping of the composition of substrates and bed structures as well as the temporal changes in these components due to the restoration measures carried out. Morphological studies also analysed the spatial and temporal development of typical cross-sections. Morphological investigations were carried out from 2007 to April 2008 in 10 representative stream sections within the investigation area.

4.1.2 Chemical monitoring

Chemical monitoring covered water temperature, oxygen content and saturation, pH, electrical conductivity and total hardness. These were measured directly in the field.

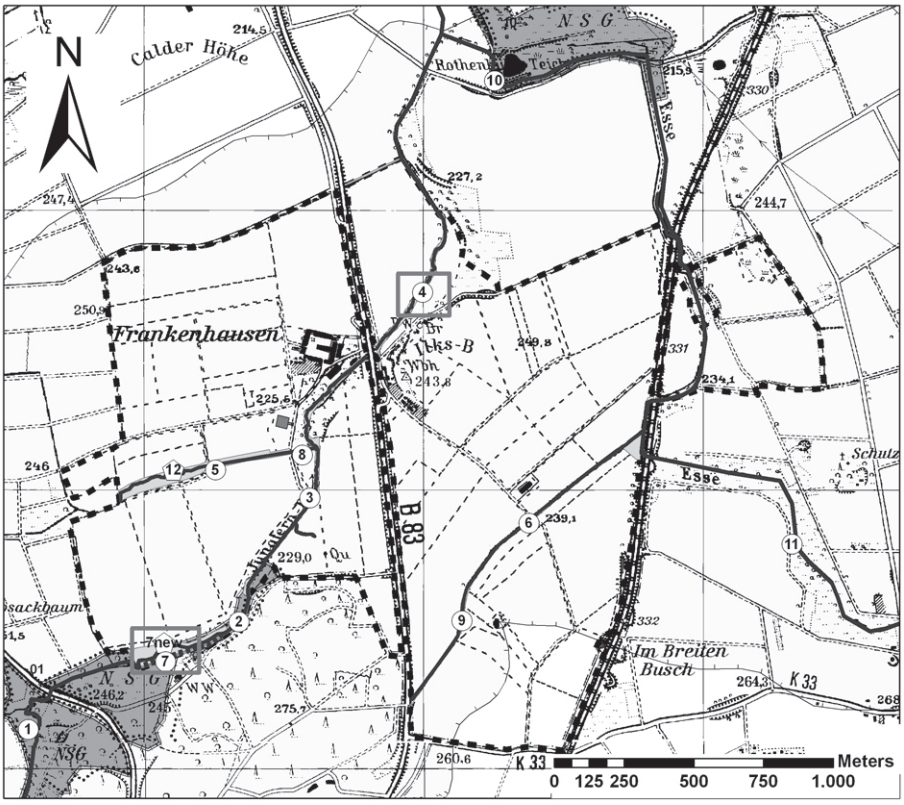

Fig. 6: Sampling sites in the investigation area; for the legend, see Figure 4.

Abb. 6: *Untersuchungsstellen im Renaturierungsgebiet – Legende siehe Abb. 4.*

The following chemical pollution and nutrient indicators were measured: biological oxygen demand (BOD_5), dissolved organic carbon (DOC), nitrate-nitrogen, ammonium-nitrogen and ortho-phosphate-phosphorus. For the characterisation of geochemical and water quality parameters, calcium, magnesium, potassium, sodium, chloride and sulphate were measured in the laboratory. Measurements were carried out according to DEV (1992).

In 2007 measurements in the field took place every 2 months and twice in the lab. In 2008, after completion of restoration, chemical parameters were measured four times.

4.1.3 Biological monitoring

Biological studies presented below include assessments of aquatic macrophytes, aquatic macroinvertebrates, fish and amphibians. Aside from amphibians, these groups are generally used as biological quality indicators in the European Water Framework Directive (WFD 2000).

Aquatic macrophytes

Monitoring of aquatic macrophytes was carried out according to LUA NRW (2003) on 11 representative sections. Water plants were identified according to van de Weyer (2003), and estimation of abundance according to Londo (1974).

The actual vegetation was compared with the natural vegetation of the reference condition. Each macrophyte site was related to an adequate ecological quality class based on disturbance indicators particularly considering shading of the water course by riparian trees following LUA NRW (2003).

Macroinvertebrates

Macroinvertebrates are reliable indicators of oxygen-consuming organic pollution. They also indicate habitat disturbances and degradation of morphological conditions in the watercourses (Braukmann & Biss 2004 und Lorenz et al. 2004).

Investigations were carried out in 10-m lengths of representative sections of the streams using substrate-oriented multi-habitat-sampling based on AQEM (2005), modified by Hübner (2007). A total sample of 1 m^2 consisted of 10 subsamples of 0.1 m^2 each. Sampling took place three times per year (March/April, July/August and October) in 2007 and 2008 to obtain the widest spectrum of species composition. Samples were sorted and organisms were determined to be alive in the field according to Braukmann (2000) and Hübner (2007). A more detailed determination of the subsamples was undertaken in the lab.

Fishes

Fishes were studied by electro-fishing once a year between 2006 and 2008 in 50-m stream sections. In each sample, the species were determined, and the fish were counted, sorted according to length class. The number of escaping individuals per section was estimated in the field.

Amphibians

Qualitative observations of adult amphibians, their eggs and their larvae took place eight times at 2-week intervals from the beginning of March to the middle of July in 2007 and 2008 in the newly created ponds near Totenhof and close to the Jungfernbach. Sampling site data were noted following Schlüpmann (2005).

4.2 Results

4.2.1 Hydromorphology

The assessment of the substrate structures revealed a widespread, and in some places, massive coverage of the stream bed with fine silt which had washed in from the surrounding loess area at nearly all sites. A very small amount of dead wood and other coarse material was observed. Natural limestone boulders were similarly very rare. Investigations of the cross sections in 2007 had indicated a strong vertical erosion of the stream beds which was an important reason for stream bed lifting. In part, these measures showed first small effects in the following year. The changes in cross-section and substrate composition of section 7 are illustrated in Figure 7 as an example.

4.2.2 Water chemistry

All investigated sites showed chemical characteristics typical of carbonate streams with electrical conductivity values well above 300 µS, the threshold range between silicate and carbonate stream types (Braukmann 1997). The Jungfernbach system is characterised by generally higher values than the Esse (Fig. 8). All sites show low pollution levels by oxygen-consuming organic substances as characterised by BOD_5 values shown in Figure 8. BOD values in 2007 met the German chemical quality class I-II standards (according to LAWA 1998), except those from the sites Jungfernbach 2 and Esse 10, which were classified as class II.

DOC values in the Jungfernbach system were also generally lower than in the Esse. A maximum DOC value of 12 mg/L was registered at Jungfernbach 1. Median DOC in the Jungfernbach was 2 mg/L, whereas in the Esse it was about 4 mg/L. Based on their median BOD concentrations, all sites of the Jungfernbach can be classified as chemical quality class II, and the Esse as class II-III (according to Braukmann 2000). Thus the Jungfernbach is less contaminated with organic pollutants than the Esse.

Phosphorus concentrations of the Jungfernbach in 2007 generally could be assigned to quality class II, meeting the required regulatory quality target. In 2008 partly higher values at Jungfernbach 2, 4 and 7 (reaching class II-III) and at Jungfernbach 1 (class III) were measured.

The regulatory target of quality class II for nitrate-N was not achieved. The lowest values were measured in the Esse. The Jungfernbach presented higher values and was classified as class II-III. Ammonium-N values were rather low, within quality class I-II.

A broader, less intensively used riparian area should lead to better nutrient loads in the future. The range of some major chemical parameters characterising typical loess streams is shown in Figure 8.

4.2.3 Biology

The results of biological surveys of aquatic macrophytes, macroinvertebrates, fishes and amphibians are presented below.

Aquatic Macrophytes

Based on their aquatic vegetation, the watercourses in the project area can be divided into three characteristic loess stream types:

- Macrophyte-free type (streams less than 10 m in width)
- *Berula erecta* community type
- Helophyte type.

In 2007, immediately after the restoration measures had been completed, only a few or no macrophytes were found in the modified sections. The macrophyte-free type also dominated in unrestored shaded sections. This corresponds well to the naturally vegetation-free type of loess streams. In unshaded or just moderately shaded unrestored sections, the *Berula erecta* community or the helophyte type prevailed. Therefore all sites, except site 3 of the Jungfernbach, were characterized as good or very good quality according to LUA NRW (2003). Section 3 of the Jungfernbach was unshaded and heavily dominated by *Phragmites australis* which covered the whole bed of this brook area. This section belonged to the helophyte type and therefore also corresponded to one of the typical phenotypes of loess streams (LUA NRW 2003).

Other than in a few patches of the newly restored sections, the indicators of increased nutrient load *Cladophora* and *Vaucheria* algae were not observed in notable densities in most stream sections.

Through April 2008, only slight changes were observed compared to the situation in 2006 or 2007 before restoration. In the relocated and newly shaped watercourse of the Jungfernbach, patches of *Spirogyra* spp., *Vaucheria* spp. and *Lemna minor* were observed. Also *Equisetum palustre* and *Polygonum amphibium* were found in this section. In the newly created unshaded section of the small brook at Totenhof, green algae such as *Cladophora glomerata* developed in moderate quantities. Otherwise, in 2008, only riparian grasses grew from the borders into the middle of the bed of this narrow water body. During this initial stage, very small patches of *Berula erecta* and *Epilobium hirsutum* could be found in the watercourse.

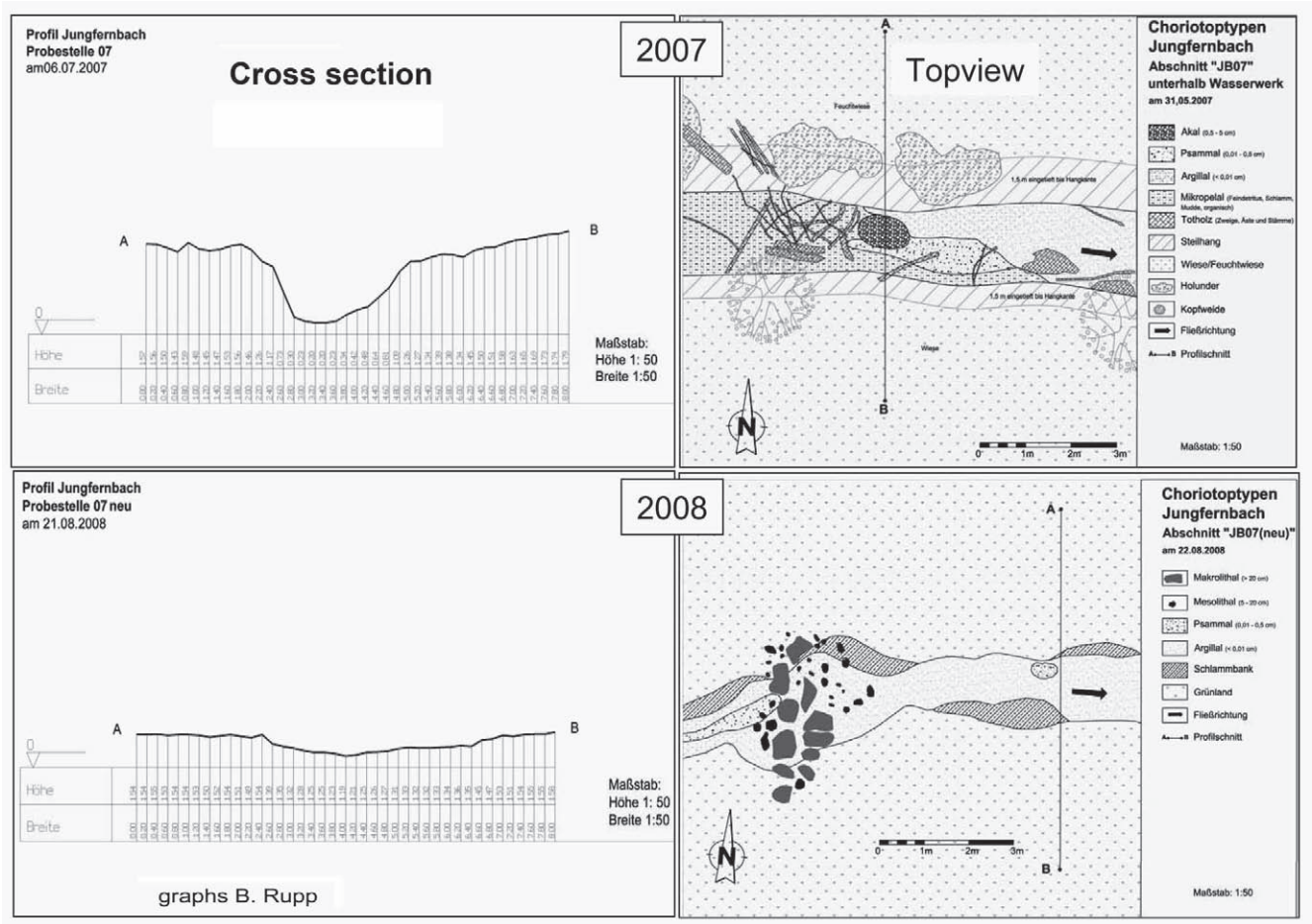

Fig. 7: Jungfernbach, section 7, left: altered cross-section, right: substrate structure, above: before, below: after restoration. The initial stage of the newly built stream bed (left) shows a lower substrate diversity because no dead wood had drifted into this section shortly after restoration.

Abb. 7: *Jungfernbach, Abschnitt 7, links: Veränderung des Querprofils, rechts: Substrat-Struktur, oben: vor, unten: nach der Renaturierung. Das Initialstadium des neu gestalteten Bachbetts (links) zeigt noch eine geringe Substrat-Diversität, da kurz nach der Renaturierung noch kein Totholz in diesen Abschnitt eingetragen wurde.*

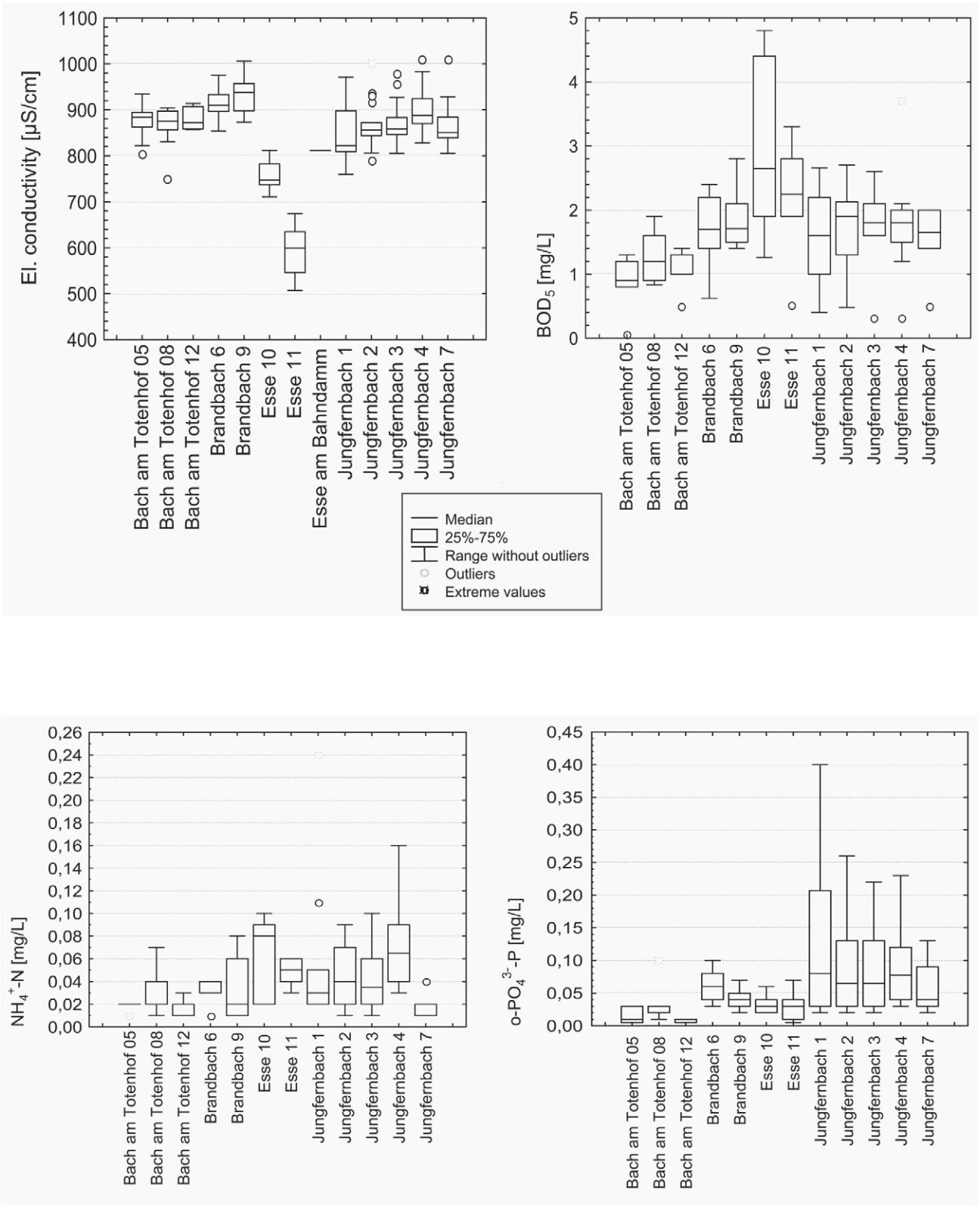

Fig. 8: Chemical quality parameters:
a) Electrical conductivity and biological oxygen demand over 5 days (BOD_5).
b) Ammonium-nitrogen (NH_4^+-N) and ortho-phosphate-phosphorus (o-PO_4^{3-}-P).

Abb. 8: *Chemische Qualitätsparameter:*
a) *Elektrische Leitfähigkeit und Biochemischer Sauerstoffbedarf (BSB_5).*
b) *Ammonium-Stickstoff (NH_4^+-N) und Ortho-Phosphat-Phosphor (o-PO_4^{3-}-P).*

In its initial stage, the newly shaped, unshaded Brandbach also showed areas where algae including *Vaucheria* began to spread shortly after restoration.

Macroinvertebrates

Macroinvertebrates were studied intensively over the period before, during and after the restoration measures were undertaken. As examples, the results are outlined for two streams, the Jungfernbach and the small, newly established creek at Totenhof. Figures 9 and 10 give an overview of the taxa of those sections that spread most steadily and dominated in areas where the greatest morphological changes took place.

In total, 70 macroinvertebrate taxa were found in the Jungfernbach. The macroinvertebrate community of this stream is characterised by a high dominance of gammarids (*Gammarus pulex* and *G. fossarum*). Regular occurrence of the sediment-dwelling midge species *Ptychoptera paludosa*, which prefers shallow silty areas of slowly flowing watercourses, was typical. In shady sections, larvae of the chironomid *Micropsectra* form dense, highly abundant populations. Other characteristic species of fine-grained stream beds include the mayflies *Ephemera danica* and *Electrogena uyhelyii*, which were found here in low numbers. Nevertheless, both species can be regarded as target species for the development of near-natural, unpolluted loess streams with fine sediment beds. The species are also characteristic of streams with a sufficient amount of coarse and stable structural elements, such as dead wood. Other target taxa for this stream type are the caddisflies *Sericostoma* spp., *Halesus* spp., and the beetles *Limnius perrisi* and *L. volckmari*. All are sensitive to oxygen deficits, which can easily occur in slightly polluted brooks with a large amount of fine sediment and slow current.

Figures 9 and 10 each show a list of the most consistent and dominant taxa in the Jungfernbach and the creek at Totenhof. Over the period of 2007–2008 in the Jungfernbach 29 taxa (out of 70 in total) occurred in more than 25 % of all sections of the Jungfernbach, in the creek at Totenhof 20 taxa (out of 39 in total) were present in more than 25 % of all sections of the creek at Totenhof.

Recolonisation of the newly created stream sections by benthic macroinvertebrates at sections No. 7 (Jungfernbach) and No. 12 (creek at Totenhof) (Fig. 6) in its daylighted upper part, took place rapidly 6 months after the end of restoration. In the newly structured section of the Jungfernbach 14 invertebrate taxa were found and 13 taxa in the formerly piped section of the creek at Totenhof. This result suggests that loess streams with a naturally low biodiversity (due to low flow and low substrate diversity) are also highly dynamic systems with a good potential for recovery under suitable water quality conditions.

The further development of benthic macroinvertebrates, especially the establishment of sensitive target taxa, typical for morphologically regenerated and chemically unpolluted loess streams, should be monitored in the coming years when more natural floodplain conditions will have developed and more dead wood will have accumulated.

Fishes

In the years of electro-fishing from 2006 to 2008, just one species, the brown trout *Salmo trutta fario*, could be found, and then only in a single section, No. 2 (Fig. 6). This section is located in the nature reserve and is characterised by a relatively high structural diversity in shaded surroundings with reduced siltation. The results of the fish monitoring are shown in Figure 11.

Brown trout is the characteristic species of the upper trout region of streams (epirhithral according to Illies (1961). Because the species spawns in gravelly areas, it has very limited opportunities to reproduce successfully in heavily silted loess streams like the Jungfernbach. The small population of brown trout found in section 2 in the Jungfernbach seems to be isolated and slightly reproductive. Immigration from below, particularly from the Esse, is impossible due to impassable weirs.

Amphibians

The newly created ponds had not yet been accepted as spawning habitats in April 2008. Other than the European toad (*Bufo bufo*), just one other amphibian specimen, an Alpine newt (*Triturus alpestris*), was found after an exhaustive search. Also no spawn or tadpoles were observed in any of the new ponds shortly after restoration. One reason may be that restoration ended late in the year in October after the end of the migration and spawning phase of amphibians.

5 Contribution of organic farming to restoration success in loess streams

The catchment area of the Jungfernbach upstream from the investigated area is mainly cultivated as meadow. Therefore impact from pesticides is not to be expected. Organic farming within the Frankenhausen site excludes pesticides.

Other typologically comparable loess streams in intensively cultivated catchment areas, e. g. the areas of conventional viniculture in Rheinland-Pfalz, have been studied cursorily to compare the influence of such crops on benthic macroinvertebrates in loess streams. Stream morphology and benthic invertebrates were studied in a morphologically semi-natural section of the Dörrenbach, a small loess stream in southern Rheinland-Pfalz below the village Dörrenbach. Morphologically, the Dörrenbach stream is very similar to the Jungfernbach. The following macroinvertebrate taxa were found in the Dörrenbach: *Polycelis nigra*/*tenuis* (rare), *Glossiphonia complanata* (rare), *Gammarus pulex* and *Gammarus roeselii* (both abundant). Insects were completely absent. The investigated section was downstream of a large vineyard, which partly bordered the brook. Based on these circumstances, pesticides are the obvious reason for the clear lack of aquatic insects.

In the upper catchment of the Jungfernbach, no comparable agricultural cultivation such as of corn or wine is present. In its reference section within the nature reserve, the Jungfernbach shows a much higher biological diversity with many insects.

This leads to the conclusion that the improvement of morphological structures within and along the streams and rivers by restoration measures can only offer ecological success as defined, for example, by the presence of macroinvertebrates as bio-indicators, if the water quality is sufficient and if

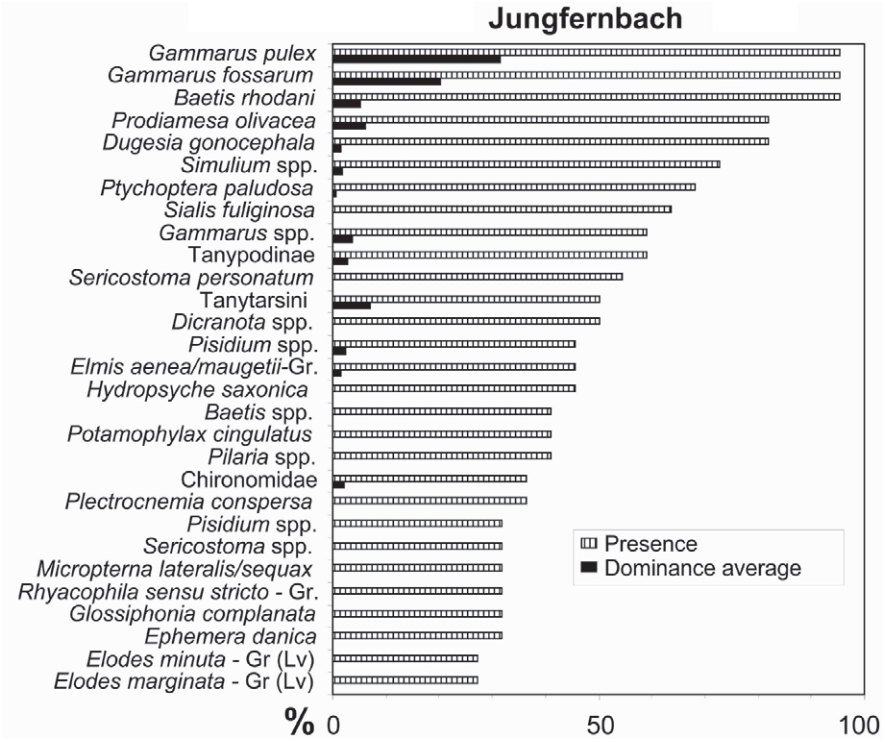

Fig. 9: Jungfernbach: 15 macroinvertebrate taxa present in ≥ 25 % of all studied sections out of a total of 70 taxa.

Abb. 9: *Jungfernbach: 15 stetige Taxa des Makrozoobenthos (Stetigkeit ≥ 25 %) von insgesamt 70 Taxa.*

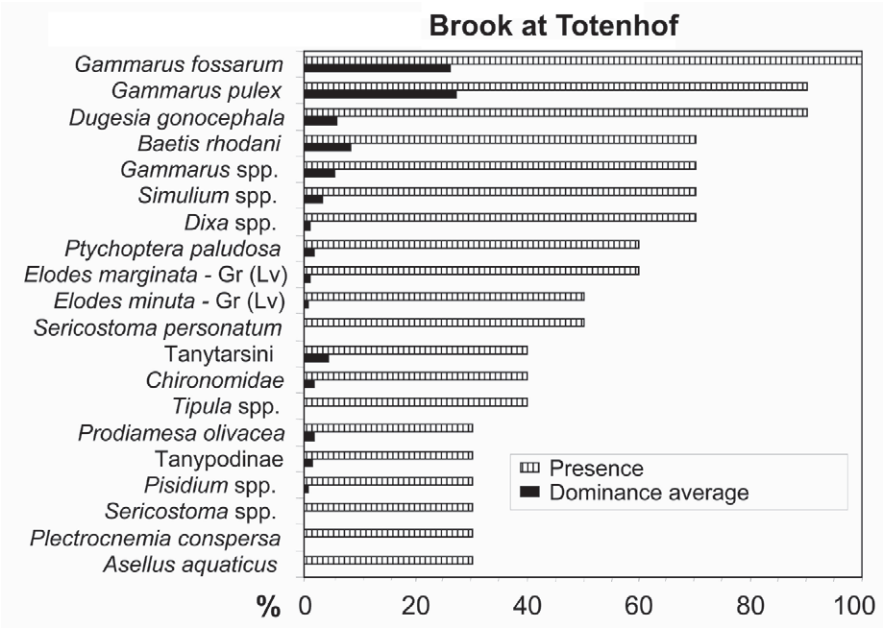

Fig. 10: Brook at Totenhof: 21 of the taxa present in ≥ 25 % of all studied sections out of a total of 39 taxa.

Abb. 10: *Bach am Totenhof: 21 stetige Taxa des Makrozoobenthos (Stetigkeit ≥ 25 %) von insgesamt 39 Taxa.*

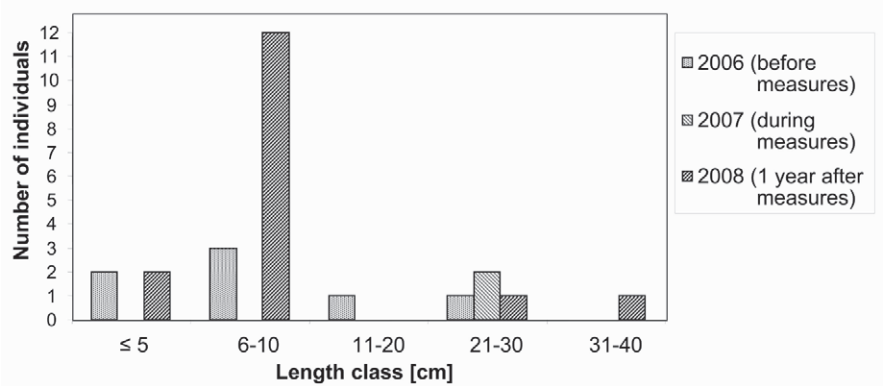

Fig. 11: Results of electro-fishing 2006–2008; 2006 (before), 2007 (during), 2008 (6 months after restoration); number of brown trout in section 2.

Abb. 11: *Ergebnisse der Elektrobefischung von 2006 bis 2008; 2006 (vor), 2007 (während), 2008 (6 Monate nach der Renaturierung); Anzahl Forellen in Abschnitt Nr. 2.*

no pesticides are introduced into the water. Pesticides may prevent any ecological success that could arise through the addition of structural improvements. In this context the importance of farming without pesticides in floodplain areas has to be emphasised as an essential foundation for a successful ecological improvement of loess streams.

6 Summary of first results less than 1 year after restoration

Morphological, chemical and biological efficiency monitoring, carried out in the years before, during and 6 months after the end of restoration revealed the following results:

The morphological situation showed a positive development.

Passability was markedly improved. The structures put in place to effect raising of the stream beds had not shown visible results as of April 2008 due to low flow after restoration.

The physicochemical status showed no significant changes. A comparison between the investigation periods 2001–2005 and 2007–2008 shows a slightly reduced concentration of phosphorus, magnesium and potassium at nearly all sites. Since in organic farming these substances are not used as mineral fertiliser the abandonment of these fertilisers might be a reason for the deminished concentration of the mentioned water constituents.

Considering the biological status, macrophytes showed a few individual settlements, and a rapid development of algae was obvious in the first initial development of the modified stream sections.

Macroinvertebrate communities changed only marginally in the initial phase of stream development, and target taxa were still underrepresented. In newly created sections, a rapid colonisation by up to 14 invertebrate taxa was observed 6 month after restoration.

The fish population showed minimal changes as well with brown trout continuing to be the only species present. Almost no reproduction took place because of isolation of the population due to barriers downstream.

7 Conclusions and perspective

1. The scientific monitoring programme ended in April 2008, 6 months after restoration. Early ecological success was evident, but the monitoring period was much too short to capture effective biocoenotic changes. More natural communities may be expected once the restored streams have developed further towards the envisaged stream type surrounded by a natural floodplain forest. Therefore, further monitoring for 10 years or more (cf. Koenzen et al. 2009) is essential to describe and survey long-term ecological effects.

2. A further restoration programme should be carried out incorporating the whole catchment of the stream systems of Jungfernbach and Esse. Because of existing weirs at the mouths of those streams, both systems should be given highest priority for restoration, in particular the sections containing the weirs.

The highest priority should be given to restoration measures in the catchment, especially in the floodplains adjacent to the water bodies. Here measures that are compatible with stream and river quality should be undertaken. A holistic approach seems necessary, particularly a change in agricultural land use leading to a large-scale conversion of arable land, which is vulnerable to floods and erosion, to grassland near the stream borders. In floodplain areas without cattle husbandry, where grass can no longer be used as green fodder, alternatively biomass from the grassland could be used for bio-energy production.

In rural areas being cultivated very intensively with agriculture, such as *Börde* areas or the northern German lowlands, suitable measures for improvement of biodiversity are especially important. Here a reduction in the nonpoint-source import of soil particles, nutrients and above all pesticides must be considered. Appropriate measures include reduction of spraying close to rivers and lakes, appropriate disposal of pesticides on farms, broader riparian buffers along streams and rivers with less intensive, unfertilised grassland management and, last but not least, conversion of conventional agriculture to organic farming in floodplain areas.

Acknowledgements

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Investigations towards the restoration of wetlands in the Tijuana Estuary with special regard to brackish and saline ponds

Untersuchungen zur Renaturierung von Feuchtgebieten im Tijuana Ästuar unter besonderer Berücksichtigung von brackwasserhaltigen und salinen Teichen

Ines Tröstler, Volker Lüderitz and Richard M. Gersberg

Abstract

This study represents the first comprehensive biological and hydrochemical investigation of small coastal ponds in the saltmarsh dominated Tijuana Estuary, southern California (U.S.). Special attention is given to the brackish water biotopes.

Different salinities and considerable fluctuations in water level characterized these shallow ponds and restrict the biological settlement. Fluctuations of salinities ranged from brackish water to hyperhaline water conditions. Due to different salinity levels, the ponds vary in hydrochemistry, macroinvertebrate species composition and plant communities. The macroinvertebrate community of the brackish waters were dominated by Gastropoda*,* Odonata*, and* Coleoptera *containing a mixture of freshwater/brackish water species and marine macroinvertebrates. Typical plants of the brackish habitat were* Typha domingensis *(Southern cattail), and* Scirpus californicus *(California bulrush) associated with* Juncus acutus *(Siny rush). These brackish habitats with a wide range of salinity fluctuations are sparsely colonized but represent a niche for typical highly adaptable species. Especially, it is a biotope for species with a wide range of salt tolerance. Therefore, endangered species occurred besides introduced or invasive species in the ponds of the Tijuana Estuary. This fact has to be taken into account in case of wetland restoration. Due to the freshwater influence, the restoration of brackish habitats focuses on the problem of invasive species.*

Keywords: *Wetland Restoration, Saltmarsh, Coastal pond, Tijuana Estuary, Invasive species, Macroinvertebrates, Management, Conservation, Brackish water*

Zusammenfassung

Die vorliegende Arbeit befasst sich mit der Situation des Tijuana-River-Ästuars im Südwesten Kaliforniens und untersucht insbesondere Flachgewässer mit Brackwassercharakter. Verschiedene Salzgehalte und erhebliche Schwankungen der Wasserstände sind für diese Gewässer charakteristisch und limitieren die biologische Besiedelung. Die Unterschiede in der Salinität reichen dabei von Brackwasserbedingungen bis hin zur Hypersalinität. Aufgrund der verschiedenen Salzgehalte variieren die Gewässer in der hydrochemischen Zusammensetzung, der Makroinvertebratenzusammensetzung und der Pflanzengesellschaften. Die Gruppe der Makroinvertebraten in den Brackwasserbiotopen wird von Schnecken, Libellen und Käfern dominiert, wobei Süß- und Brackwasserarten zusammen mit marinen Invertebraten auftreten. Typische Pflanzen der Brackwasserlebensräume sind *Typha domingensis* und *Scirpus californicus*, verbunden mit J*uncus acutus*-Pflanzen.

Solche Brackwasserbiotope mit ihren stark schwankenden Salzgehalten sind zwar artenarm, aber sie stellen zugleich Nischen für Organismen mit speziellem hohem Adaptationsvermögen insbesondere hinsichtlich der Salztoleranz dar. So wurden bei den Untersuchungen gefährdete, aber auch invasive Arten gefunden. Diese Besonderheit ist bei allen Sanierungs- und Renaturierungsaktivitäten zu berücksichtigen.

Schlüsselwörter: Feuchtgebiete Renaturierung, Salzmarsch, Küstengewässer, Tijuana Ästuar, invasive Arten, Makroinvertebraten, Naturschutz, Brackwasser

1 Introduction

The importance and ecological functions of coastal saltmarshes range from stabilization of fine sediments, serving as a protective buffer and filter between land and sea, over the blending of terrestrial and marine fauna, to refuge for migratory shorebirds and waders (Laegdsgaard 2006). Nevertheless, these habitats have been destroyed and changed. Coastal saltmarshes in southern California have experienced a loss of approximately 75–90 % of their area compared to pre-settlement values (Powell 2006). The degradation of saltmarshes has different causes. Generally, agricultural practices, changes of hydrology, natural processes (flood, sedimentation), urbanization, habitat fragmentation and the invasion of exotic species lead to disturbances and alteration of estuaries (Laegdsgaard 2006). As a result, morphology and ecology of the area were altered; composition of flora and fauna changed, native species became extinct and numerous species are listed as threatened and endangered. Several processes are non-reversible and the restoration is therefore difficult. Generally, restoration efforts focus on weeds removal, fence off areas for protection and natural regeneration (Laegdsgaard 2006), re-vegetation, and transplantation of saltmarsh plants. Elevation, tide, and salinity play important roles for the success of restoration and establishment of salt marsh areas (Laegdsgaard 2006). Furthermore, restoration projects encompass reinstating of hydrological regimes in connection with excavation of sediments and altering of surface features (O' Brien & Zedler 2006). These alterations, however, lead to artificial conditions (O' Brien & Zedler 2006).

Adaptive management is an important method for coastal ecosystem restoration projects (Thom 2000). The method of

adaptive management (experimental tests in a restoration site/ learning by doing, Thom 2000) was and is used for restoration projects in the Tijuana Estuary in California, especially for the actual control and removal of invasive species.

The Tijuana River National Estuarine Research Reserve (Tijuana Estuary) is one of the largest remaining saltmarshes in southern California. It is surrounded by the growing cities of Tijuana, Mexico, Imperial Beach, CA and San Diego, CA. Urbanization and inputs of debris, raw sewage and industrial effluents have led to multiple alterations and a disturbance of this ecosystem. In particular, the rapidly growing city Tijuana, Mexico, with wastewater discharge to the Tijuana River is a major cause of such adverse environmental effects to the estuary. Nevertheless, efforts have been made for restoration and protection of the estuary. The Tijuana Estuary Tidal Restoration Program (TETRP) focuses on the restoration of habitats that have lost area and tidal flushing.

The importance of brackish habitats in the Tijuana Estuary is:

- refuge for animals when the estuary has high tide (Zedler et al. 1992)
- biotope for species which use brackish and salt marsh habitats such as rails (Zedler et al. 1992)

The small brackish and saline coastal ponds in the Tijuana Estuary have not been studied very well so far. Therefore, the aim of this study was to investigate four selected ponds in the Tijuana Estuary and integrate these biotopes into future restoration plans. More specifically, this paper provides an overview of the composition of the macroinvertebrate community, vegetation and hydrochemical conditions of the ponds. Another aim was to find species characteristic for brackish coastal ponds.

The sampling site and sampling points were chosen based on differing varieties of the ponds (vegetation, macroinvertebrates), differing levels of salinity (water body), water depths, availability/accessibility, and missing comprehensive survey of these ponds in the Tijuana Estuary research.

2 Study area

The Tijuana River National Estuarine Research Reserve (TRNERR, Tijuana Estuary) is located in southern San Diego County, California, U.S. (32°35' N, 117°07' W) (Fig. 1), north of the United States – Mexican border at the mouth of the Tijuana River. The marsh-dominated, coastal plain estuary covers approximately 1,024 ha (Zedler et al. 1992). Influenced by marine water from the Pacific Ocean and fresh water from the Tijuana River, the area is a mixture of different habitats, such as dominantly saltmarsh areas, fresh-brackish marsh areas, tidal creeks, open tidal channels and mudflats, sand dunes, beaches, and salt pans. Historically, natural catastrophic events (e. g. 1983 El Niño event, catastrophic flooding) and a variety of human activities (e. g. sewage disposal practices, agricultural uses, military installations, apartment buildings along the beach) shaped the Tijuana Estuary and altered the habitats (Zedler et al. 1992). Presently, the Tijuana Estuary is one of the 27 protected areas of the National Estuarine Research Reserves (NERRs – nationwide network of the U.S.) and was designated a "wetland of international importance" (2005) in the Ramsar list (Ramsar Convention On Wetlands).

The Tijuana region has a mediterranean climate with a mean rainfall of 250 mm per year, which mainly precipitates intermittently between November and April. Long dry summers with little rainfall, and wet winters are characteristically. The mean temperature is 23°C. Mean temperatures range from 7°C in winter to highs of 25°C in summer (O' Brien & Zedler 2006). Extreme conditions in this region are dry years with low rainfall and wet years with winter storms and floods (Zedler et al. 1992). The vegetation in the estuary is influenced by the amount and timing of rainfall and the river discharges into the entire watershed (443,323 ha watershed of the Tijuana River) (Zedler et al. 1992). High evaporation and hot dry desert winds are also important factors for the flora and fauna (Zedler et al. 1992).

Flowrate of the Tijuana River shows considerable fluctuation during most years. The estuary is dominated seasonally by marine hydrology. Occasionally, the area is more strongly influenced by fresh water during flood events (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000, Zedler et al. 1992).

The form of the Tijuana valley at the mouth is flat and wide. The predominant geologic formations are quaternary and recent alluvial and slope wash deposits above sandstones, shale and limestones (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000). These unconsolidated deposits are comprised of clay, silt, sand and cobble-sized particles.

The estuary's north arm in the upper area of the salt marsh was chosen for the present investigation. Biological and hydro-chemical samples were collected from four small, shallow coastal ponds nearby the military landing field (Fig. 1 and 2).

The establishment and development of the coastal ponds is unknown. The military landing field was built in 1953, and a brackish marsh appeared at the terminus of the urban drai-

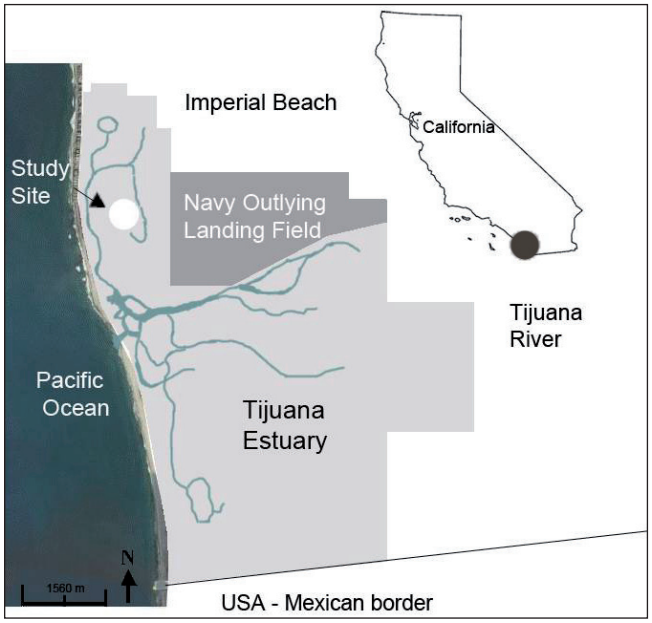

Fig. 1: Location of the Tijuana Estuary in California.

Abb. 1: *Lage des Tijuana Ästuars in Kalifornien.*

nage from this field (Zedler et al. 1992). The sampling sites were located in this area. A photograph of the Tijuana Estuary from 1978 shows gravel excavations which perhaps led to the development of the ponds. These ponds are influenced by the freshwater inflow from the Navy Landing Field especially during the rainy season and they are without opening to the ocean and without surface outflow. Minerals and salts are therefore concentrated in these water bodies. As a result of these environmental conditions, the salinity of the investigated ponds fluctuated from brackish to hyperhaline salinity level (Tab. 2). Pond three was isolated from pond four during the samplings in October, 2006. Nevertheless, pond three and four are connected at higher sea level. The surface soil of the sampling site was covered with a salt crust.

The Comprehensive Management Plan for Tijuana River National Estuarine Research Reserve and Tijuana Slough National Wildlife Refuge (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000) encompasses the following goals for habitat restoration and protection:

I. Goals for the NERR System (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000):

- "*Ensure a stable environment for research through long-term protection of National Estuarine Research Reserve resources;*
- *Address coastal management issues identified as significant through coordinated estuarine research within the NERR System;*
- *Enhance public awareness and understanding of estuarine areas and provide suitable opportunities for public education and interpretation;*
- *Promote federal, state, public, and private use of one or more Reserves within the NERR System when such entities conduct estuarine research; and*
- *Conduct and coordinate estuarine research within the NERR System, gathering and making available information necessary for improved understanding and management of estuarine areas*."

II. Goals of the FWS for the National Wildlife Refuge System (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000):

- "*To preserve, restore, and enhance in their natural ecosystems (when practicable) all species of animals and plants that are endangered or threatened with becoming endangered;*
- *To preserve a natural diversity and abundance of fauna and flora on Refuge lands;* …"

The Tijuana Estuary lost 80 % of its daily tidal prism between 1852 and 1986 as a result of different events (Zedler et al. 1992). Therefore, actual goals for restoring the estuary would aim to both increase the tidal prism and at the same time, combat sedimentation (California Department of Parks and Recreation, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration 2000).

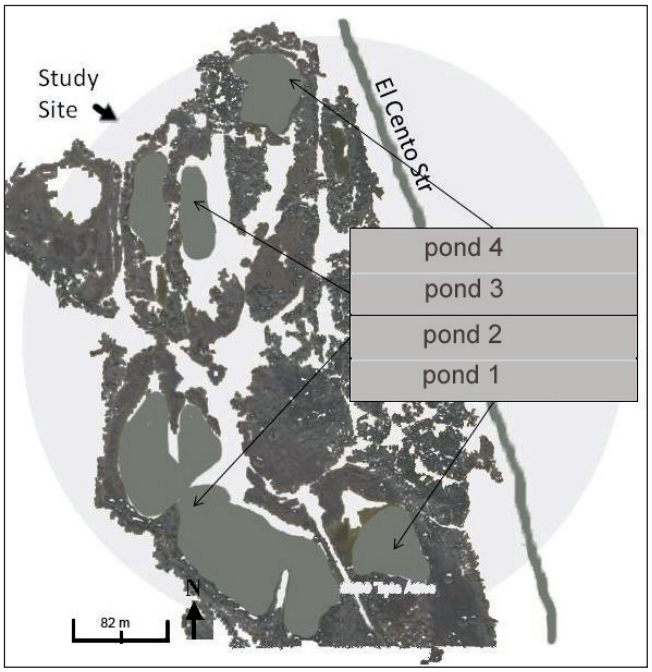

Fig. 2: Map of the study site in the Tijuana Estuary.

Abb. 2: *Lageplan des Untersuchungsgebietes im Tijuana Ästuar.*

3 Methods

In October 2006, one-time samples were collected from the four coastal brackish and saline ponds in the high salt marsh area of the Tijuana Estuary after a dry summer period, when water depth in the ponds ranged between 0.10 m and 0.20 m.

3.1 Biological analyses

Macroinvertebrates were sampled from pond 1, 2, 3 and 4 at several locations of each pond (Fig. 1, 2). A qualitative, multihabitat sampling approach was conducted to characterize the macroinvertebrate communities in the different ponds. A hand net with mesh size 3 mm (diameter [Ø] = 200 mm) was used to collect macroinvertebrates from the aquatic macrophytes, the water column and the bottom substrates (approximately 10 cm depth). Macroinvertebrates were collected at each pond over a period of 4 hours. The abundances of different organisms were estimated based on a seven degree scale (n = number of individuals; **1:** n = 1; **2:** 2 < n ≤ 20; **3:** 21 < n ≤ 40; **4:** 41 < n ≤ 80; **5:** 81 < n ≤ 160; **6:** 161 < n ≤ 320; **7:** 320 < n (Alf et al. 1992)). The organisms were then preserved in ethanol (70 %) for further taxonomic analysis in the laboratory. All macroinvertebrates were identified to the lowest taxonomical level, in some cases to family or genus level and usually species level (Abbott 1974, Borror & White 1970, Burch & Tottenham 1980, Emerson & Jacobson 1976, Hogue 1974, Jensen 1995, Keen & Coan 1974, Milne & Milne 1980, Merritt & Cummins 1996, Morris 1958, Morris et al. 1980, Powell & Hogue 1979, Rehder 1981, Smith & Carlton 1975, Usinger 1956, and White 1983). Identification of dragonfly larvae was improved by identifying adult insects in the field (Manolis 2003).

Parallel to the sampling of macroinvertebrates, plants were mapped in the same locations of each pond in a 10 meter radius around the ponds according to the Braun-Blanquet method (Braun-Blanquet 1932). Species were identified in that area using Lightner (2006). For all ponds, total percent

cover of each plant species was estimated and was judged on a 100 % cover value. Information about plant spreading, degree of endangerment, invasive species and other data were provided by several databases (Global Invasive Species Database 2009, California Invasive Plant Council 2009, Calflora 2009, California Native plant society 2009, USDA PLANTS Database 2009).

3.2 Hydrochemical analyses

Hydrochemical sampling was performed also once at the same time as the biological collection procedure. The standardized hydrochemical methods for analyses are shown below (Tab. 1). Temperature, dissolved oxygen, and pH were measured with a portable hydrolab meter in the field. Samples were filtered (filter size: 0.45 µm) for photometric analyses.

Additionally, salinities were measured bimonthly from September 2008 to April 2009.

4 Results

4.1 Water condition

Ponds 1 and 2 were predominately euhaline/ polyhaline brackish waters while ponds 3 and 4 were characterized by hyperhaline salinity levels. Investigations of the salinity in the ponds of the Tijuana Estuary (Fig. 3) showed a high fluctuation of salinity, particularly in ponds 3 and 4. These considerable fluctuations of salinity ranged from 30 ppt (December 2008) up to 152 ppt (October 2008) in pond 3. Salinity ranged from polyhaline brackish (pond 1) to hyperhaline level (pond 3, 4) in October 2006.

The results of all measurements and hydrochemical analyses are shown in Table 2.

The oxygen contents from pond 1 to pond 4 decreased while salinity increased. The temperature of the ponds ranged from 20.9 to 22.5°C. This temperature in connection with the high organic matter concentration leads to low oxygen levels in the ponds. The electrical conductivity was very high in ponds 3 and 4 reflecting the high salinities. The content of organic matter was relatively high in all ponds (Tab. 2). However, only moderate concentrations of nitrate and ammonia were found.

4.2 Macroinvertebrate communities and vegetation

The macroinvertebrate community of the investigated ponds was characterized by low species diversity (Tab. 3). A total of 24 taxa (16 families) was recorded at all sampling sites. The total number of species at each site ranged from 18 in pond 1 to only 4 in pond 3. Six groups of invertebrates (*Crustacea*, *Gastropoda*, *Heteroptera*, *Odonata*, *Coleoptera* and *Diptera*) were identified, which mainly occurred in pond 1. *Gastropoda*, *Odonata* and *Coleoptera* were most species rich, with four or five species, while other groups contained only one or two different species.

Some dragonflies were sighted but only in flight in the surroundings of ponds 1 and 2, e. g. *Anax junius* mainly occurred in the cattail stands. The survey of all dragonflies of pond 1 and 2 was not possible and has to be completed with further macroinvertebrate collections in spring.

Tryonia imitator, *Anax junius* and *Trichocorixa reticulata* were the most dominant species at sampling sites. Furthermore, *Trichocorixa reticulata* occurred in all ponds with high abundance, especially in pond 4.

Tropisternus salsamentus, *Berosus* sp., *Enochrus* sp., and *Hygrotus* sp. were coleopterans which were collected exclusively in the brackish pond 1 with a salinity of 25.4 ppt. *Ochthebius rectus* and *Ochthebius lineatus* occurred in salinities of 110 ppt (pond 4) and, therefore, seem to prefer higher salinities.

A limited number of different functional feeding groups were found at the sampling site. Overall, the aquatic functional feeding groups with the highest number of species and density were predators and grazers. A high number of grazers resulted from a higher proportion of snails in the macroinvertebrate community at the sampling time. The high number of predators in pond 1 is due to the different dragonfly species and beetle larvae.

Tab. 1: Methods used for hydrochemical analysis.

Tab. 1: *Verwendete Methoden für die hydrochemischen Analysen.*

Parameter	Method
Phosphorus (Orthophosphate) [1)]	ascorbic acid method, APHA Standard methods, range: 0–2 mg/L
Total Phosphorus [2)]	DIN EN ISO 6878: 2004, range: 0.03–4.6 mg/L PO_4
Nitrate [1)]	cadmium reduction method, APHA Standard methods, range: 0–30 mg/L
Ammonia [1)]	phenol-hypochlorite method according to Strickland & Parsons (1972), range: 0.1–10 µg-at/L
Biochemical Oxygen Demand (BOD) [1)]	5-day incubation, APHA Standard methods
Chemical Oxygen Demand (COD) [2)]	DIN 38 409 (H44), range: 5–60 mg/L O_2
Chloride [2)]	titration according to Mohr, DIN 38 405 (D1-1)
Salinity	YSI 85 for pond 1 and 2, refractometer (range of 0–160 ppt) for pond 3 and 4

[1)] Laboratory of the Graduate School of Public Health at the San Diego State University, USA

[2)] Laboratory of the University of Applied Sciences Magdeburg-Stendal, Germany (Samples were frozen during the transport to Germany.)

Tab. 2: Results of hydrochemical and -physical investigations.

Tab. 2: *Ergebnisse der hydrochemischen und -physikalischen Untersuchungen.*

date of sampling:	**10-12-2006**			
parameter	**pond 1**	**pond 2**	**pond 3**	**pond 4**
salinity (ppt)	25.4	34.2	66.4	110.0
oxygen (mg/L)	6.96	5.39	4.29	/
temperature (°C)	20.9	21.4	22.0	22.5
pH - value	8.8	8.4	8.3	8.0
orthophosphate (mg/L)	0.467	0.342	0.306	0.646
nitrate (mg/L)	< 0	0.263	0.185	1.123
ammonia (mg/L)	0.210	0.263	0.212	0.024
date of sampling:	**10-19-2006**			
BOD (mg/L)	23.18	10.65	20.92	27.28
COD (mg/L)	228.5	290.0	291.5	420.5
total phosphate (mg/L)	0.481	0.468	0.900	0.941
chloride (g/L)	15.9	19.8	43.9	58.5
electrical conductivity (µS/cm)	3090	3990	7470	9470

Due to the similar bottom substrate and morphological structure of the ponds only a few types of habitats were found. Pelal (e. g. mud), psammal (e. g. sand), and phytal (e. g. plants) are the common habitat preferences of the macroinvertebrates sampled during this study.

Vegetation

In general, the area was abundantly covered with vegetation. The diversity of plants around the investigated ponds at the sampling sites of the Tijuana Estuary is low to moderate. The plant diversity around pond 1 is higher than the diversity near the other ponds. *Juncus acutus* spp. *leopoldii* (leopold's rush), *Salicornia virginica* (pickleweed), *Distichlis spicata* (saltgrass), and *Jaumea carnosa* (salty susan) are dominant elements of the plant community and occurred in the surrounding of all ponds usually in high abundances. The area around the edge of pond 2 was relatively sparsely covered with vegetation due to a salt crust on the soil.

The plant community of pond 1 was dominated by *Salicornia virginica* (pickleweed), *Typha domingensis* (southern cattail), *Distichlis spicata* (saltgrass), and *Scirpus californicus* (California bulrush).

Typha domingensis and *Scirpus californicus* are common in the surrounding of the ponds and indicate freshwater influences. Therefore, the plant community of the ponds is made up of typical saltmarsh plants (high marsh) and plants of the riparian habitat of the Tijuana Estuary.

Cordylanthus maritimus spp. *maritimus* (Saltmarsh bird's-beak) grew in the high marsh of the Tijuana Estuary. This endangered plant was found in the surroundings of pond 3 and 4. The plant is endangered in California and elsewhere (California Native Plant Society, http://www.cnps.org/; 03.04.2009).

The Leopold's rush is included in CNPS's inventory of rare and endangered plants on list 4.2 (limited distribution) (http://www.calflora.org, 20.08.2009).

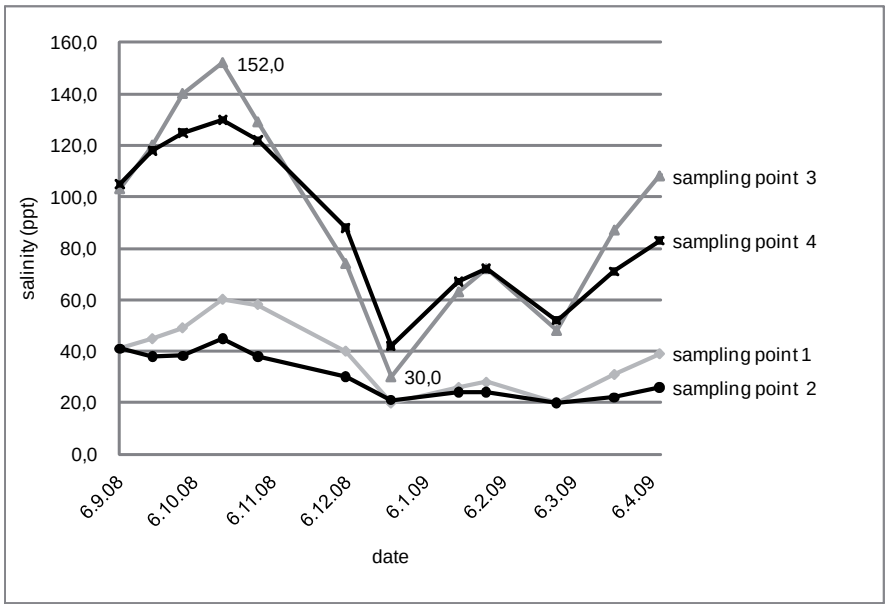

Fig. 3: Time variation curve of salinity in the investigated ponds.

Abb. 3: *Ganglinie des Salzgehaltes in den untersuchten Teichen.*

Tab. 3: Abundances of macroinvertebrate species in the ponds.

Tab. 3: *Abundanzen der Makroinvertebraten in den Teichen.*

Species name	Occurrence	pond 1	pond 2	pond 3	pond 4
Crustacea					
Isopoda	among the *Typha*	3			
Ostracoda	no direct sampling	4	3		
Palaemon macrodactylus	detritus among the *Typha*	4			
Gastropoda					
Acteocina sp.	fine sand, sandy mud, sand		3		
Barleeia californica	mud, sandy mud	3	4		2
Cerithidea californica	mud		4	3	3
Melampus olivaceus	mud	2	4		
Tryonia imitator	sandy mud, fine sand, mud	5	5	4	
Heteroptera					
Trichocorixa reticulata	among the *Typha*, mud, other	4	4	4	6
Odonata					
Anax junius (adult)	in flight, in *Typha* population	5	3		
Enallagma sp. cf. (adult)	in flight and sitting of pickle-weed	2			
Ischnura sp. (larvae)	among the *Typha*	4			
Sympetrum corruptum (adult)	in flight and sitting of pickle-weed or saltgrass	3	2		
Coleoptera					
Berosus sp. (larvae)	mud/roots	2			2
Enochrus cf. sp. (adult)	substrate among the *Typha*	1			
Hydrophilidae sp. (adult)	substrate among the *Typha*	1			
Hygrotus sp. (adult)	substrate among the *Typha*	2			
Ochthebius sp.(adult)	mud/roots -riparian		3		2
Ochthebius rectus (adult)	mud/roots-riparian				1
Ochthebius lineatus (adult)	mud/roots-riparian				1
Tropisternus salsamentus (adult)	substrate among the *Typha*	2			
Tropisternus sp. (adult)	substrate among the *Typha*	1			
Diptera					
Chironomidae	mud	2			
Ephydridae sp. (pupae)	mud/roots			3	

Foeniculum vulgare (Sweet fennel) was introduced in California from Europe and Mediterranean area. It is not native in California. *Foeniculum vulgare* is listed in the 2006 list of the California Invasive Plant Council (Cal-IPC). The invasive impact of this plant is statewide high (http://www.calflora.org, 12.04.2009). This plant is common at the brackish pond 1.

5 Discussion and conclusions

The investigated coastal ponds in the Tijuana Estuary probably arose from gravel mining. Due to freshwater impacts on the ponds and resulting brackish water conditions, the ponds play a large role for the habitat diversity in this marsh region. Moreover, the man-made ponds are important habitats for threatened or endangered species. The ecological functions and the importance of brackish habitats in the Tijuana Estuary are:

- increase of habitat diversity in the estuary
- habitat for typical brackish water species
- refuge for endangered species (endangered salt marsh bird's beak)

The hydrological conditions influence the hydrochemistry in these shallow ponds and can vary dramatically during a year. Important factors are dilution due to rainfall and runoff in wet season, and concentration of salts in the dry season in connection with evaporation. Therefore, it is important to note that the salinity reflects only the hydrological condition. Long-term investigations are necessary to better characterize the water chemistry and biology of the ponds.

The nature and variation of salinity is an important ecological factor and influences the species composition of water organisms and the communities of plants in the ponds.

Tab. 4: Vegetation (cover abundances according to Braun-Blanquet) at the ponds.

Tab. 4: *Vegetation (Deckungsgrade nach Braun-Blanquet) an den Teichen.*

Species name	Common name	pond 1	pond 2	pond 3	pond 4
Juncus acutus ssp. *leopoldii*	Leopold's rush	1	2a	2a	2a
Salicornia virginica	Pickleweed, Virginia glasswort	3	3	2b	2b
Distichlis spicata	Saltgrass	2b	3	2b	2b
Typha domingensis	Southern cattail	2b			
Scirpus californicus	California bulrush	2a	2b		
Jaumea carnosa	Salty susan, Marsh jaumea	1	+	2b	2a
Cuscuta californica; Cuscuta salina var. major	Chaparral dodder; Goldenthread	+		2a	
Limonium californicum	California sea lavender, marsh rosemary	+	+	2a	2a
Foeniculum vulgare	Sweet fennel	+			
Eriogonum fasciculatum	California buckwheat, Eastern Mojave buckwheat	2a		2a	2b
Cordylanthus maritimus spp. *maritimus*	Saltmarsh bird's-beak			R	+
Isocoma menziesii	Menzies' goldenbush	1		2a	2a
Monanthochloe littoralis	shoregrass	2a			

The species composition of pond 1 differed from the other ponds. Besides the *Gastropoda*, *Odonata* and *Coleoptera* were the most conspicuous elements of the invertebrate community. Characteristic brackish macroinvertebrates in the region are *Tryonia imitator* (brackish water snail), *Ostracoda*, *Anax junius* (Green darner), *Tropisternus salsamentus*. *Tryonia imitator*, a small brackish water snail, occurs in shallow, submerged waters and tolerates a wide variety of salinities (Kellog 1980). The snail is threatened and listed in the global and state ranking list of conservation (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/spanimals.pdf, 20.08.2009).

Berosus sp., *Enochrus* sp., *Hygrotus* sp., and *Ochthebius* sp. are important coleopterans of brackish and saline water conditions in the Tijuana Estuary.

The adverse environmental conditions and high salinity level led to a decrease in species richness and lack of fauna, e. g. absence of dragonflies in pond 3 and 4.

Species which preferred the phytal were dominant among *Odonata* and *Coleoptera*. The aquatic plants and the root system of riverine vegetation are biotopes for these organisms, and the occurrence of these habitats is an important factor influencing the occurrence of these macroinvertebrates.

Most species of pond 1 were found in the water body and bottom substrate (a mixture of mud, sandy mud and detritus) of the *Typha domingensis* population. Therefore, the aquatic plant community plays a role in the diversity and composition of macroinvertebrates in the ponds.

Restoration projects start with the establishment of goals. Measures of the success of restoration projects depend on the attainment of the aims.

The following first goals for the protection and restoration of the investigated ponds (based on this investigation) with special regard to the goals of the management plan of the Tijuana Estuary are:

- Protect the brackish water habitat as an important habitat of the Tijuana Estuary for the preservation and restoration of native habitat diversity.
- Increase diversity and populations of endangered plants such as salt marsh bird's beak, typical brackish water species, and shorebirds at the sampling site of the investigated ponds.
- Integrate the brackish ponds in the development of an adaptive invasive species management plan.
- Integrate these research findings and adaptive management into restoration efforts.
- Integrate pond 1 and pond 4 in biological monitoring programs.

The restoration of brackish habitats focuses on the adverse impact of invasive species. The Tijuana Estuary has experienced an invasion of non-native plants. These plants are widespread in the area. Common outcomes are displacement of native plant species and to changes in the food web. The management of invasive plant species of the Tijuana Estuary will be developed and broadened.

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Ecological assessment of streams on La Gomera and Tenerife (Spain) – an approach for an evaluation and restoration tool based on the EU-Water Framework Directive

Ökologische Bewertung von Bächen auf La Gomera und Teneriffa (Spanien) – Ein methodischer Ansatz zur Einschätzung von Renaturierungsmaßnahmen bei der Umsetzung der EU-Wasserrahmenrichtlinie

Volker Lüderitz, Uta Langheinrich, Jose Ramon Arevalo, Robert Jüpner and Angel Fernandez

Abstract

In recent decades, the number of streams on the Canary Islands has decreased dramatically due to the non-sustainable consumption of water for agriculture and tourism. Natural reaches of streams with an endemic macroinvertebrate fauna do, however, still exist in protected areas of Tenerife and La Gomera. Those reaches serve as a reference to develop an assessment method for streams on islands. This method takes into account common parameters such as water quality and hydromorphology, while emphasizing biodiversity and endemism. The latter concepts as they relate to stream conservation are important in both nature conservation and protection of species as many endemic aquatic organisms are endangered.

Keywords: *Canary Islands, streams, assessment, macroinvertebrates, endemics*

Zusammenfassung

In den letzten Jahrzehnten ist die Zahl der Fließgewässer auf den Kanarischen Inseln drastisch zurückgegangen. Ursache dafür ist eine sehr hohe Wasserentnahme für Landwirtschaft und Tourismus, die das nachhaltig nutzbare Dargebot bei weitem überschreitet. Dennoch existieren in besonders geschützten Bereichen der Inseln Teneriffa und La Gomera noch naturnahe Abschnitte von Fließgewässern mit Elementen endemischer Makroinvertebraten-Fauna. Diese Abschnitte dienen als Referenzgewässer für die Entwicklung eines spezifischen Bewertungssystems für Fließgewässer auf Inseln. Dieses System berücksichtigt die üblichen Qualitätsparameter wie Wassergüte und Hydromorphologie, hebt aber die Biodiversität und den inseltypischen Endemismus besonders hervor. Die daraus resultierenden Gewässerentwicklungskonzepte stellen ein entscheidendes Instrument des Natur- und Artenschutzes dar, da viele der endemischen Gewässerorganismen vom Aussterben bedroht sind.

Schlüsselwörter: Kanarische Inseln, Bäche, Bewertung, Makroinvertebraten, Endemiten

1 Introduction

One of the main objectives of the EU Water Framework Directive (WFD) is for all European bodies of water to meet the criteria for ‘good ecological status’ or a ‘good ecological potential’ by the end of 2015. The requirements of this directive, which include the prevention of further deterioration, offer a good basis for implementing integrated strategies to protect water bodies while taking into account the complexity of anthropogenic influences and defining quantitative environmental quality goals.

The small streams on the Canary Islands support an interesting and surprisingly diverse fauna (Malmqvist et al. 1993, Beyer 1993, Malmqvist et al. 1995). Unfortunately, these water bodies are subject to heavy disturbance and loading.

The number of perennial streams has steadily dropped on both Tenerife and Gran Canaria. Between 1933 and 1973, the number of perennial streams on Gran Canaria decreased from 285 to 20 and on Tenerife fewer than 10 streams are recorded now (Nilsson et al 1998).

Threats to the freshwater ecosystems include the decrease in forested areas, the use of subterranean and surface water reservoirs for agricultural irrigation and for tourism, and water pollution by point and non-point sources. To supply irrigation, most streams have been heavily canalized. Nevertheless, the objectives and requirements of the WFD are also valid for the Canary Islands. To support its implementation, detailed planning of restoration measures and renaturalization is necessary. A holistic method of stream assessment is urgently needed to contribute to these requirements (Lüderitz 2004). For the chemical assessment, continental standards can be used, but biological methods should be adjusted for the unique situation of island ecosystems.

Compared to the species diversity on the continent and on large islands such as the British Isles, the number of aquatic species on relatively small islands is limited as is the number of streams themselves. Thus, assessment systems such as the AQEM (**A**ssessment System for the Ecological **Q**uality of Streams and Rivers throughout **E**urope using Benthic **M**acroinvertebrates), which depend on a relatively high species number (Hering et al. 2003, Lorenz et al. 2004), are only suitable to a limited extent.

Island macroinvertebrate assemblages often include a considerable number of endemic species and subspecies. The disappearance of streams and their ongoing canalization can lead to the extinction of such organisms. Thus, endemic taxa in particular have to be considered in every assessment approach.

This paper presents an assessment system based on the occurrence and distribution of aquatic macroinvertebrates improved by hydromorphologic parameters. It was developed

by sampling streams on La Gomera and Tenerife and analyzing data published by other authors (Beyer 1993, Malmqvist et al. 1993, Malmqvist et al. 1995, Nilsson et al. 1998).

2 Materials and Methods

From November 2006 until March 2009, macroinvertebrates were sampled in eight reaches of streams on La Gomera (Fig. 1) and in five reaches of streams on Tenerife (Fig. 2). Four of the reaches on La Gomera are located in or very near to the Garajonay National Park. This National Park is the best remnant of ancient Canary laurel forest (a partial relict of the Tertiary Age forests that have become extinct in Europe due to climatic change) in the Canary archipelago, and several undisturbed permanent streams are still present together with their forest canopy. On Tenerife one reach belongs to a nature reserve. The others are disturbed to some degree by anthropogenic influences, e. g. intensive agriculture, canalization, and damming (Tab. 1).

The reaches were sampled twice (spring and fall). Sampling was conducted over a length of 100 m by means of an extended version of the multi-habitat-sampling technique (Hering et al. 2003, Lüderitz et al. 2004). This method includes all microhabitats (mineral and organic bed substrates, submerged and emergent aquatic plants) within the stretches. An area of 40 m^2 at each site was sampled using a hand net with a mesh size of 0.5 mm. The organisms (except easily identifiable species) were fixed in 70 % ethyl alcohol and identified according to Balke et al. (1990), Bellmann (1993), Freude et al. (1971/1979), Müller-Liebenau (1971), Nybom (1948), Machado (1987), Crosskey (1988) and Waringer & Graf (1997).

Hydromorphological assessment was accomplished by the mapping method of LAWA (2000) and the suggestions by Raven et al. (2002) after an adaptation and calibration to the natural conditions of the Canary Islands (Kumm 2008). The following main parameters were recorded: stream course development, longitudinal profile, cross profile, bed structure, bank structure, and riparian area. These six main parameters were broken down into 25 individual parameters.

The hydromorphological status (*Strukturgüteindex*) was classified into seven quality classes:

- Class 1: unchanged; natural morphology
- Class 2: slightly changed; unimportant changes that clearly do not influence the functionality of the water body
- Class 3: moderately changed; changes in morphology are obvious and have a significant impact on the ecology of the water body
- Class 4: clearly changed; water body shows a clear deviation from its natural status and is straightened and lined up to 50 %
- Class 5: markedly changed; straightening and lining approach 100 %
- Class 6: heavily changed; natural dynamics are prevented by paving and lining of the bank
- Class 7: excessively changed; completely canalized

The morphology was assessed by comparing undisturbed stream reaches in the same landscape unit with the mapped sites.

3 Results

During sampling campaigns from November 2006 to March 2009, a total of 64 macroinvertebrate species were found at 13 sampling sites (Tab. 2). Altogether, 74 species from the investigated groups have been documented in former studies

Tab. 1: Location and characteristics of sampled streams on La Gomera (1–8) and Tenerife (9–13).

Tab. 1: *Lage und Besonderheiten der untersuchten Bäche auf La Gomera (1–8) und Teneriffa (9–13).*

Site	Name/Location	Altitude (m)	Site characteristics and disturbances
1	La Laja	590	Garajonay National Park, natural pine forest, supplies a reservoir
2	La Laja	450	Several small dams, extensive agriculture
3	Chejelipes	250	Several dams and reservoirs upstream
4	El Cedro	910	Garajonay National Park, laurel forest
5	El Cedro	540	Downstream of a waterfall, influenced by agriculture, water scarcity
6	Barranco del Aqua	410	Influenced by agriculture, stream course partially paved and straightened
7	Meriga	970	Small stream in Garajonay National Park, laurel forest; downstream of the site piping of the whole stream
8	El Rejo	650	Small stream in Garajonay National Park, laurel forest
9	Taganana	200	Agriculture and urban sewage loading, partially paved and straightened
10	Igueste	400	Extensive agriculture, water scarcity, low flow rates
11	Masca	450	Intensive tourism, water scarcity
12	Afur	300	Agriculture, low flow rates
13	Barranco del Infierno	500	In the nature reserve, natural morphology over a flowing distance of ~ 1 km, than total canalization

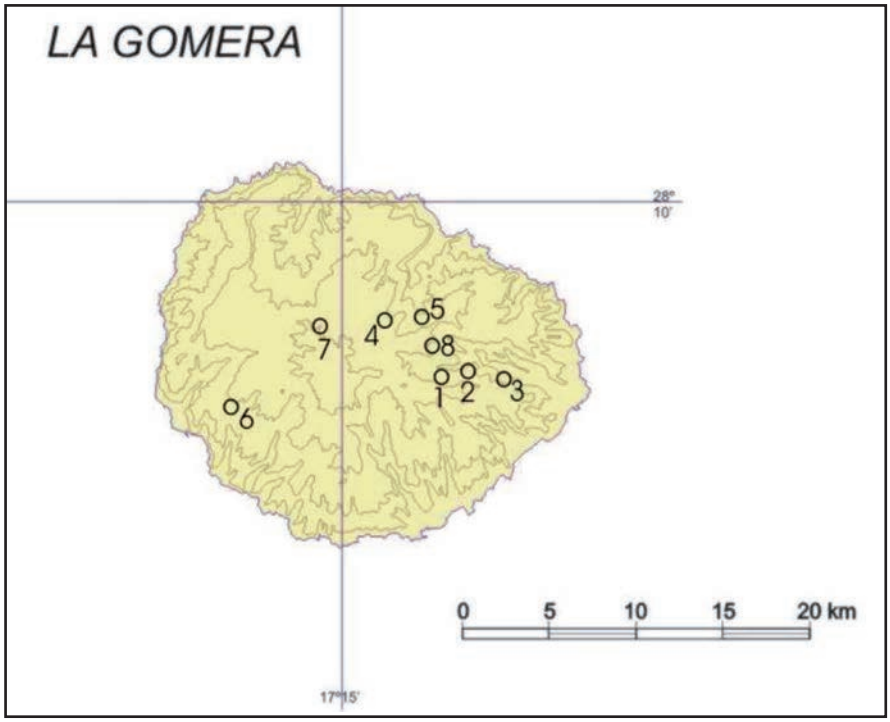

Fig. 1: Sampling sites in streams on La Gomera (Map: Agustin Naranjo Cigala).

Abb. 1: *Untersuchungsabschnitte an Bächen auf La Gomera (Karte: Agustin Naranjo Cigala).*

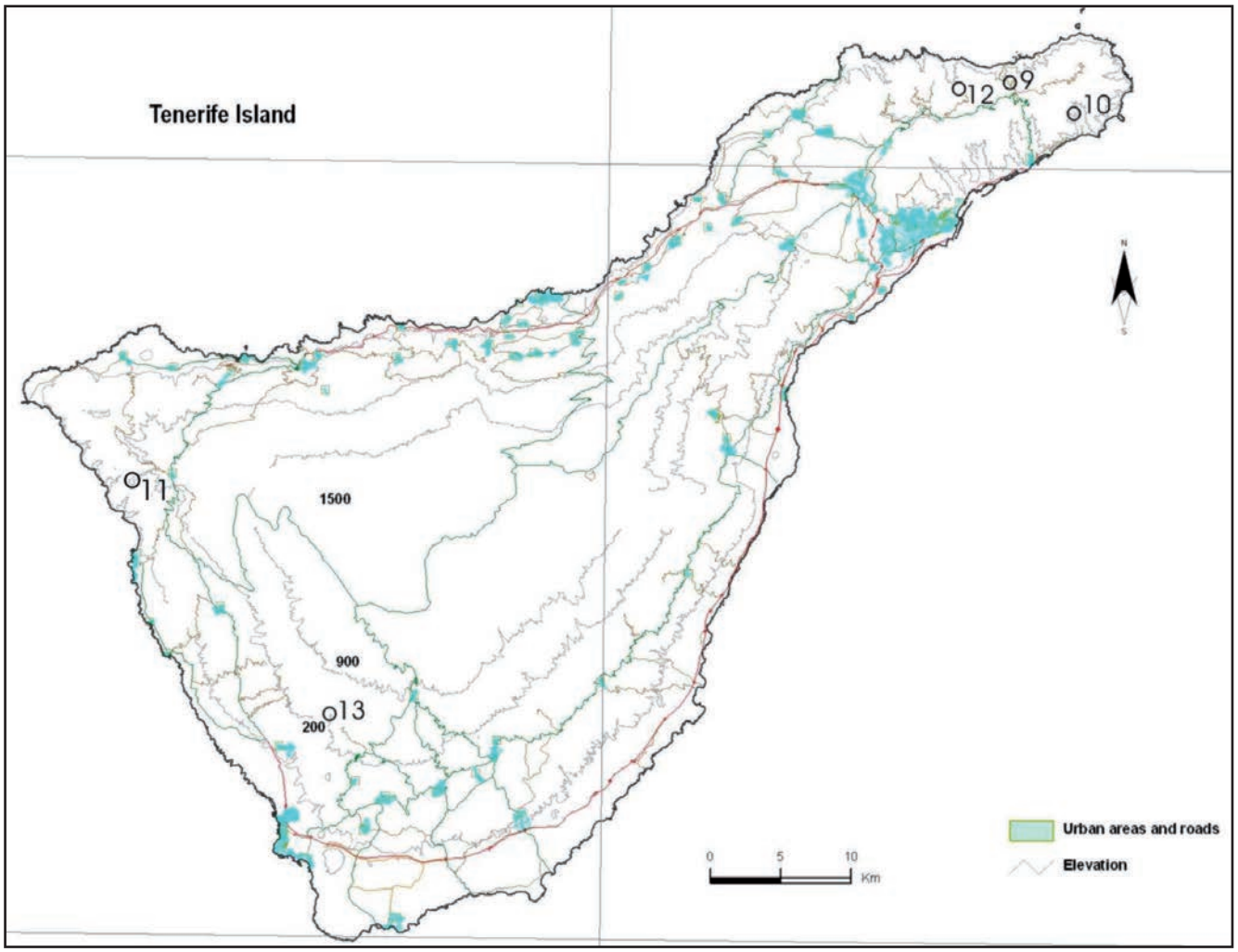

Fig. 2: Sampling sites on Tenerife (Map: Agustin Naranjo Cigala).

Abb. 2: *Untersuchungsabschnitte an Bächen auf Teneriffa (Karte: Agustin Naranjo Cigala).*

Tab. 2: Abundances of macroinvertebrate species found in streams of La Gomera and Tenerife, Canary Islands (1: single individual, 2: rare, 3: not very frequent, 4: common, 5: frequent, 6: very frequent, 7: abundant).

Tab. 2: *Makroinvertebraten in Bächen auf La Gomera und Teneriffa (Kanarische Inseln); Abundanzen (1: Einzelfund, 2: selten, 3: nicht häufig, 4: verbreitet, 5: häufig, 6: sehr häufig, 7: massenhaft).*

Taxonomic group/species	Endemic species or subspecies	Sensitive species	La Gomera								Tenerife				
			1	2	3	4	5	6	7	8	9	10	11	12	13
Odonata															
Anax imperator			4	5								4	4	4	4
Anax parthenope			4	4								3	4		4
Crocothemis erythrea			3	3								4	5	4	3
Ischnura sp.															3
Orthetrum chrysostigma			5	5	3					2			3	5	
Sympetrum fonscolombei			3	5									4	4	
Sympetrum nigrifemur	x			3								3			3
Zygonyx torrida		x		2		2									5
Trichoptera															
Agapetus adejensis	x	x	4			4			5	3					4
Hydropsyche maroccana			3	3		5		2	4	4					5
Hydroptila fortunata	x					3			3	2					
Mesophylax aspersus canariensis	x		3			6			6	6					
Orthotrichia angustella		x				2									
Oxyethira spinosella	x	x				4									
Stactobia storai	x	x				3			3						
Tinodes canariensis	x	x				4				3					3
Wormaldia taganananа		x				5			4	5					3
Ephemeroptera															
Baetis canariensis	x	x	5			5			3	4					4
Baetis nigrescens						3		4	3						3
Baetis pseudorhodani	x	x	3	3		4			4	3					5
Caenis luctuosa				3										3	
Cloeon dipterum			4	6	5		4	5			4	5	5	5	4

Taxonomic group/species	Endemic species or subspecies	Sensitive species	La Gomera								Tenerife				
			1	2	3	4	5	6	7	8	9	10	11	12	13
Coleoptera															
Agabus biguttatus						3			2						4
Agabus nebulosus			5	4											
Anacaena haemorrhoa	x	x							3	2		3			
Dryops gracilis			5	5		4	3	5	4	4			5		5
Enochrus politus			3							2				3	
Enochrus bicolor										2					
Gyrinus dejeani			5	5	5	4	5	4	4	4		4	5	4	4
Gyrinus urinator			3	3		3	3					4	3	4	3
Haliplus lineatocollis suffusus	x		3	4	4										
Hebrus pusillus canariensis													3		3
Herophydrus musicus				3		4			3				4	3	3
Hydraena serricollis	x	x				3			3						
Hydroporus errans	x		3			3		3	2	3					3
Hydroporus lucasi		x		3								3		5	4
Hygrotus confluens			3			2									
Laccobius canariensis	x		3	3		2									3
Laccophilus hyalinus			4	4		4			4				3	5	
Meladema coriacea			2	2		2						3	3	3	
Meladema imbricata	x	x	3			2									4
Heteroptera															
Gerris thoracicus				5	3	4	3	4	4	3			6		
Hebrus pusillus canariensis	x		3			2									
Hydrometra stagnorum			4	5		5	4	5	3	4			4		4
Microvelia gracillima						3			3						
Notonecta canariensis	x		4	4	3	3							4	4	5
Sigara lateralis	x		4	4	3	3			2						3
Velia lindbergi	x		4	5	3	4	3	5	4	4		4	3		4

Taxonomic group/species	Endemic species or subspecies	Sensitive species	La Gomera								Tenerife				
			1	2	3	4	5	6	7	8	9	10	11	12	13
Mollusca															
Ancylus fluviatilis striatus	x		4	5		5		4	5	4	4	4	3	3	4
Galba truncatula				4	5		4	3		4	4	4	5	5	4
Pisidium casertanum					3	4	3	3	5	4					3
Physella acuta			4	4		2		3			5	4	4	5	
Planorbis planorbis moquini				3	5							3			
Oligochaeta															
Eiseniella tetraedra			3	3	3	3	3		3	3	4	4	4		4
Tricladida															
Dugesia gonocephala			4	4		5			5	5		4	4		4
Crustacea															
Chaetogammarus chaetocerus	x	x				3		4	3						
Rhipidogammarus gomeranus	x					4			3	3					
Rhipidogammarus rheophilus															
Nematomorpha															
Gordius aquaticus						3									
Diptera															
Simulium sp.			3	4		4		5					4		
Simulium cf. *teneriferum*															5
Total species number	64		34	33	12	42	10	15	28	24	6	20	26	19	42
Number of endemic species	25		14	9	4	20	1	4	15	11	1	5	4	3	17
Number of sensitive species		15	4	3	0	12	0	1	8	6	0	1	0	2	11

Sampling sites on La Gomera:
1 – Stream reach upstream of the La Laja reservoir, 2 – Stream reach downstream of La Laja, 3 – Water body near Chejelipes, 4 – El Cedro stream, 5 – El Cedro stream downstream of the waterfall, 6 – Barranca del Aqua, 7 – Meriga, 8 – El Rejo

Sampling sites on Tenerife:
9 – Taganana, 10 – Igueste, 11 – Masca, 12 – Afour, 13 – Barranco de Infierno

(Malmqvist et al. 1993, Beyer 1993, Malmqvist et al. 1995). Concerning the number of endemic species, there is a ratio of 25 to 31 between the actually found and the formerly documented species. Individual sampling reaches contained 6 to 42 species, reflecting differences in hydromorphology, water quantity and water quality.

On the basis of the data, we developed a specific assessment system for the streams of the Canary Islands using five metrics:

- Water quality: assessed by calculating the saprobic index
- Diversity: total species number found in the sampling reach (length 100 m)
- Degree of naturalness: sum of abundances of sensitive species (species which occur only in streams with high water quality and nearly natural hydromorphology, Tab. 1)
- Refuge function: number of endemic species (Tab. 1)
- Hydromorphology

For each metric, a score of 1 to 5 was assigned (Tab. 3). The metrics were calibrated with reference to the rare undisturbed stream reaches (sampling sites 4, 13). The average of the five scores constituted the Ecological Integrity. Application of the system led to a well-differentiated assessment of the sampled bodies of water (Tab. 4).

It is clear that streams within and near the Garajonay National Park on La Gomera show a good or very good ecological status. On Tenerife, only one of the sampled streams (Infierno) corresponds to a reference status.

The rapid decrease in the overall water body quality at the other sampled and mapped sites is related to intensive use, canalization, and damming downstream of the natural forests. The number of endemic species and sensitive species is particularly affected. They are almost absent in the disturbed sites.

Some of the endemic and sensitive species occur only in a few streams. For example, the occurrence of the aquatic beetle *Meladema imbricata* is limited to one stream on La Gomera and two streams on Tenerife. The caddisflies *Oxyethira spinosella* and *Stactobia storai* were found only at one site and two sites respectively.

4 Discussion

Several studies on freshwater species of the Canary Islands have been carried out, but the most recent are between 11 and 15 years old and thus have no relation to the WFD.

The number of permanent, nearly natural streams on the Canary Islands is limited. The natural reaches of streams and brooks extend only a few kilometers or less. The significant decrease in stream numbers in the last century was caused by intensive agricultural use. Man-made canals now represent the majority of flowing-water bodies, and most former stream courses are dry, except for periods of flooding.

Before humans changed the vegetation on the islands, many streams must have been part of the *Laurisilva* ecosystem. Today only fragments of the laurel forest remain; on La Gomera, these are mostly in the Garajonay National Park. Small streams running through surroundings of this kind show a relatively poor but balanced composition of species (sites 7, 8). These small streams join with larger ones such as the El Cedro stream (site 4), which offer relatively high biodiversity and contain many endemic species. These streams and the upper part of the stream in Barranco de Infierno (site 13) can serve as reference sites although they may be disturbed, too, by changes downstream.

Overall, the number of species found in the reference streams is also low. In comparable streams in Central Europe, we found species numbers that were up to three times higher (e. g. Lüderitz et al. 2004). The reason is the absence of the typical lotic elements of continental streams, e. g. *Plecoptera* (not present) and limnephilid *Trichoptera* (only one species present).

Using the reference sites on La Gomera and Tenerife, we developed an assessment method for streams on the Atlantic islands. This method is a special adaptation of the multime-

Tab. 3: Metrics calibration for the assessment system for Canary Islands streams based on the requirements of the WFD.

Tab. 3: *Kalibrierung der Metriks des Bewertungssystems für Fließgewässer auf den Kanarischen Inseln nach Anforderungen der EU-Wasserrahmenrichtlinie.*

Metric	Very good / reference status	Good status	Moderate status	Poor status	Bad status
	5	4	3	2	1
Diversity	≥ 40	≥ 30	≥ 25	≥ 15	< 15
Naturalness*	≥ 20	≥ 15	≥10	≥ 5	< 5
Hydromorphology	1	2-3	4	5-6	7
Number of endemic species/ subspecies	≥ 15	≥ 10	≥ 6	≥ 4	< 4
Water quality (SI)	< 1.8	< 2.2	< 2.4	< 2.8	> 2.8
Ecological Integrity**	5	4	3	2	1

SI Saprobic index
*Sum of abundances of sensitive species
**The Ecological Integrity of each site was calculated as the average of the five metrics

Tab. 4: Results of stream assessment for La Gomera and Tenerife streams (5 = very good/reference status; 4 = good status; 3 = moderate status; 2 = poor status; 1 = bad status).

Tab. 4: *Ergebnisse der Bewertung von Fließgewässern auf La Gomera und Teneriffa (5 = sehr guter Zustand/Referenzzustand; 4 = guter Zustand; 3 = mäßiger Zustand; 2 = unbefriedigender Zustand; 1 = schlechter Zustand).*

Metric	Assessment value of sampling site												
	Number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Diversity	4	4	1	5	1	1	4	4	1	2	3	2	5
Naturalness	4	4	1	5	1	2	5	4	1	3	1	2	5
Hydromorphology	4	4	2	5	2	2	4	4	2	4	4	3	5
Endemic species/ subspecies	4	3	2	5	3	2	4	4	1	2	2	1	5
Water quality (SI)	4	4	3	4	3	3	4	5	3	4	4	3	4
	(2.1)	(2.1)	(2.3)	(2.0)	(2.3)	(2.4)	(1.9)	(1.7)	(2.3)	(2.15)	(2.15)	(2.3)	(2.1)
Ecological Integrity	4	4	2	5	2	2	4	4	2	3	3	2	5

SI Saprobic index

tric system developed for assessment of streams in Central Europe (Lüderitz et al. 2004). To assess the ecological integrity, this proposed method considers the hydromorphology, while emphasizing the biological factors biodiversity, endemism, and species sensitivity. In the case of relatively small islands with more or less small and isolated populations, such factors must receive much greater emphasis than they do at the continental scale. This method for assessing bodies of water based on the demands of the EU-WFD is also an instrument to assess conservation value and conservation needs. Our approach is able to distinguish water bodies according to the kind and degree of anthropogenic disturbances and to estimate even small differences. The method should be tested and applied to other bodies of water on other archipelagos as well.

With regard to species composition, Canarian streams showed high individuality. Thus, they are not interchangeable and none of the studied streams can be identified as being in greater need of protection than another. On the other hand, the similarity between the stream fauna of Tenerife and La Gomera is striking. The majority of species occur on both islands, but in the case of endemic species often only in small and isolated populations. Several species, especially among aquatic beetles and caddisflies, are endangered, and a number are already extinct (Nilsson et al. 1998).

As a prerequisite for conservation and restoration work, all kinds of man-made water bodies such as irrigation channels and any remaining pools in natural, intermittent streams must be included into strategies. There is no doubt that several endemic species are close to extinction and that only two factors can avoid that: more water and more natural streams.

Meanwhile as the water demand for agriculture decreases, the demand for water to support the tourism industry remains high or is even increasing. The solution is the enhanced use of desalinated seawater created with renewable energy.

There is an opportunity for stream restoration as agriculture retreats from parts of the islands. The possibility is high in the northern part of La Gomera (El Cedro) and in protected parts of Tenerife, especially in Barranco del Infierno and in the Anaga peninsula. For such selected water bodies, the authors will develop restoration concepts over the next few years. Stream restoration will also contribute to re-greening the valleys of the Canary Islands.

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Morphological development of the Ucayali River, Peru without human impacts

Morphologische Entwicklung des Ucayali in Peru ohne menschliche Einflüsse

Bernd Ettmer and Cesar Adolfo Alvarado-Ancieta

Abstract

The Ucayali River originates in the high Andean Mountains near the city of Cusco in Peru. After about 1,600 km, it joins with the Marañón River. Both the Ucayali River and the Marañón River are sources of the Amazon. From 2001 to 2005, the Ministry of Transport and Communication of Peru funded a study to determine the navigability of the Ucayali River. In the process, an extensive data set was acquired including hydrological and sedimentological data as well as a comprehensive topographical survey of the riverbed. Since the Ucayali River has experienced no stream channel modification in the past, the available data provide information about the flow pattern for a natural stream and insight into a reference ecosystem. This paper offers the first analysis of the available data and a sediment transport calculation for the Ucayali River.

Keywords: *Natural flow, sharp bends, scour, sediment transport*

Zusammenfassung

Der Ucayali entspringt in den Anden nahe der Stadt Cusco in Peru. Er fließt über eine Strecke von rd. 1.600 km durch Peru bis zum Zusammenfluss mit dem Marañón. Beide Flüsse bilden die Quellflüsse für den Amazonas. Im Rahmen einer Studie über die Schiffbarkeit des Ucayali wurden vom peruanischen Ministerium für Verkehr und Kommunikation von 2001 bis 2005 umfangreiche Datenerhebungen durchgeführt. Die Datenerhebungen umfassen u. a. hydrologische und sedimentologische Daten sowie umfangreiche Vermessungen des Flusslaufs. Da der Ucayali bislang keinerlei Regulierungs- oder Ausbaumaßnahmen unterlegen ist, geben die Daten einen Einblick in die natürlichen Fließverhältnisse eines großen Flusses und damit einen Einblick in ein Referenz-Ökosystem. Erste Ergebnisse der Datensichtung und Sedimenttransportberechnungen zum Ucayali werden vorgestellt.

Schlüsselwörter: Natürliches Fließgewässer, Mäander, Sedimenttransport

1 Introduction

The Ucayali River begins in the south of Peru near the city of Cusco in the Andes Mountains. The catchment area of the Ucayali River covers 337,519 km^2. The total length of the river stretches 1,600 km. The junction between the Marañón River and the Ucayali River constitutes the source of the Amazon. Figure 1 gives an overview of the Amazon system and the location of Ucayali River.

At the present time, the Ucayali River represents a natural river. No stream channel modifications such as straightening of the river, riverbed armoring, or bank protection have been undertaken. As presented in Figure 2 the Ucayali River has a meandering flow with numerous tributary streams and backwaters and shows natural sediment transport mechanisms (Alvarado-Ancieta & Ettmer 2008).

2 Basic results of topographical survey

The topographical survey of the river bed and floodplain was carried out between the city of Pucallpa and the confluence with the Amazon, a section of about 1,035 km. Pucallpa was defined as river station km 0 and the junction with the Marañón River as river station km 1,035. The riverbed was surveyed by boat with an echo-sounding system, and the banks were surveyed with a tachymetry system. In most cases that work was carried out by a team of nine persons as presented in Figure 3. They produced more than 2,000 detailed cross-sections of the Ucayali River.

As an example, Figure 4 shows cross-sections near river section km 235. The cross-sections were prepared with the Hydrologic Engineering Center River Analysis System (HEC RAS), from the U.S. Army Corps of Engineers. The average width, *w*, of the riverbed is approximately 600 m, and the water depth, *d*, is approximately 10 m during mean water conditions. Thus, the ratio of *w/d* is 60. Generally, the width of the riverbed ranged from 400 to 1,500 m, and the water depth from 8 to 15 m.

Figure 5 gives a plan view of the measured river section between Pucallpa and the junction with the Marañón River. The plan view illustrates the sinuous system of the Ucayali River. The sinuosity, *si*, defined as the ratio between the river length including curves and the direct distance without any curves, ranges from 1.2 to 1.5. That means the Ucayali River induces heavy bank erosion and shows a tendency toward bifurcation and tributary streams (Ahnert 1996).

The Ucayali River can be separated into three reaches. The first reach is located between the city of Pucallpa at km 0 and the entrance to a bifurcation at km 570. The average slope of that reach is 0.054 ‰. Then the Ucayali River divides into two arms called the Madre Channel and the Puinahua Channel. The Madre Channel is defined as the main stream with a longitudinal section of 270 km and an average slope of 0.055 ‰. At km 840, the Madre Channel and the Puinahua Channel unify again to a single flow section. Up to the junction with the Marañón River at km 1,035, the average slope is 0.028 ‰. The main values are presented in Table 1.

Figure 6 presents the thalweg (the lowest points along the entire length of the streambed) of the Ucayali River between the city of Pucallpa at km 0 and the confluence with the Marañón River at km 1,035. The average slope of the whole river section is approximately 0.05 ‰. Furthermore the variation in the riverbed elevation is remarkable, and deep bed elevations were frequently observed. This is due to the fact that the thalweg is defined as the deepest point in each cross-section, and at points where the river bends, the outer scour hole can be significantly deeper than the rest of the bed. In places, the scour holes can be more than 10 m deeper than the average bed depth.

In addition, more than 50 sinuous sections were identified between Pucallpa and the confluence of the Amazon. Some of these meanders were identified as sharp bends. Different experiments for sharp bend hydraulics have been done to identify the main characteristic parameters (i. e., Sutmuller & Glerum 1980, Odgaard 1982, Struiksma et al. 1985, Olesen

Fig. 1: Map of the Amazon system and Ucayali River stream course (Alvarado-Ancieta & Ettmer 2008).

Abb. 1: *Übersicht über das Amazonas Einzugsgebiet und den Verlauf des Ucayali (Alvarado-Ancieta & Ettmer 2008).*

Fig. 2: View of the Ucayali River a few kilometers above the city of Pucallpa, showing the meandering riverbed tributary streams and backwater (Consorcio H&O – ECSA 2005).

Abb. 2: *Blick aus dem Flugzeug auf den Ucayali mit Mäander, Nebenarm und Altarm, wenige Kilometer vor der Stadt Pucallpa (Consorcio H&O – ECSA 2005).*

Fig. 3: Survey team with speed boats and tachymetry equipment (Consorcio H&O – ECSA 2005).

Abb. 3: *Vermessungsteam mit Schnellboot und Ausrüstung (Consorcio H&O – ECSA 2005).*

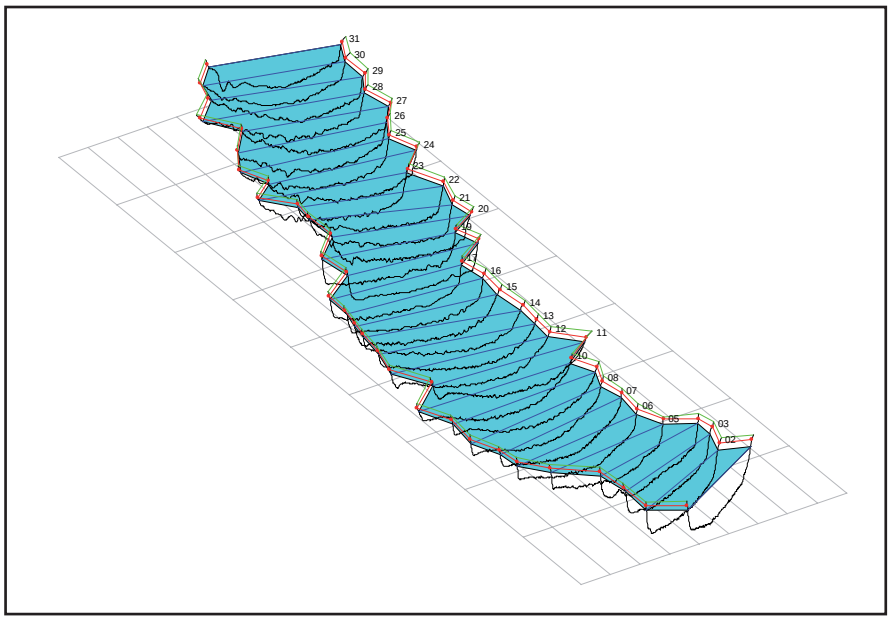

Fig. 4: Cross-sections near river station km 235, prepared with HEC RAS from the US Army Corps of Engineers (Alvarado-Ancieta & Ettmer 2008).

Abb. 4: *Querprofile in der Nähe des Flusskm 235, aufgearbeitet mit der Software HEC RAS vom US Army Corps of Engineers (Alvarado-Ancieta & Ettmer 2008).*

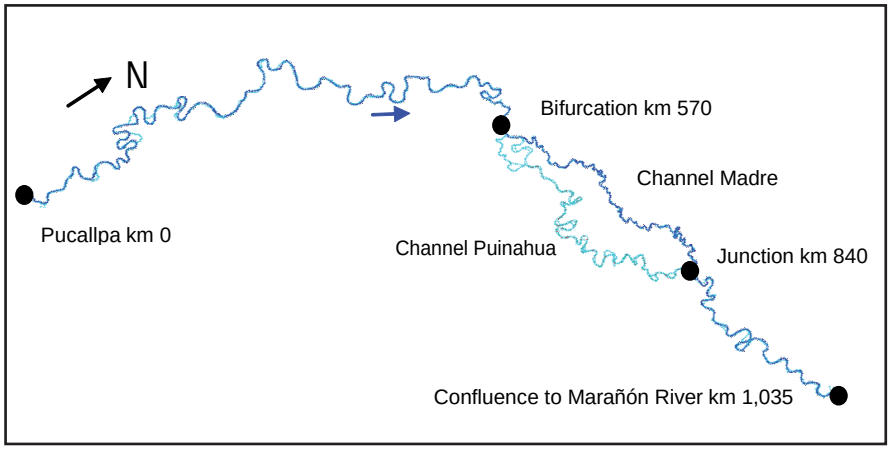

Fig. 5: Plan view of the Ucayali River with bifurcation into the Madre Channel and the Puinahua Channel.

Abb. 5: *Lageplan des Ucayali mit Verzweigung des Flusslaufes in den Kanal Madre und den Kanal Puinahua.*

Tab. 1: Three reaches of Ucayali River.

Tab. 1: *Die drei Fließabschnitte des Ucayali.*

Reach	Station (km)	Slope (‰)	Description
1	0–570	0.054	Pucallpa to the start of the bifurcation
2	570–840	0.055	Bifurcation
3	840–1,035	0.028	End of the bifurcation to the junction with the Marañón River

1987, Talmon 1992, Blanckaert & Graf 1999, Blanckaert 2002 and Alvarado-Ancieta 2004). Sharp bends have been defined according to the empirical equation (1):

$$R/B < 3 \quad (1)$$

where R = radius of bend and B = width of river. It should be noted that sharp bends often have an angle of aperture (angle measured from the beginning to the end of the bend) of more than 180°. That means a strong morphological development of the river bed and river banks of the Ucayali River could be expected.

3 Basics of hydrology and sediment transport

Hydrological data were collected over 20 years at the hydrometric station of Pucallpa as shown in Table 2. Low water discharge was measured on 19.08.1985 as 2,200 m³/s, whereas the maximum discharge was 20,440 m³/s measured on 05.03.1984. The mean water discharge is approximately 4,000 m³/s.

Between 2001 and 2004, more than 100 sediment samples were collected from the Ucayali River both as bed samples and as suspension samples (Fig. 7).

The sample probes corresponded to the gauging stations along the Ucayali River as shown in Table 3.

Figure 8 presents some representative sieve curves, used to assess the proportional contribution of sediment particles of different sizes, taken along the reach from Pucallpa km 0 to Libertad km 1,011. The sieve curves do not show any significant differences. Thus, the characteristic diameter of the sediment D_{50} (the sieve size at which 50 % of sediment weight pass through the sieve) only ranges from 0.15 to 0.40 mm with an average value of D_{50} = 0.25 mm.

The uniformity of the sediment can be calculated with equation (2) (Little & Mayer 1976).

Tab. 2: Discharges at the hydrometric station of Pucallpa.

Tab. 2: *Abflüsse an der Pegelstation Pucallpa.*

Description	Discharge (m³/s)
Low water	2,200 on 19.08.1985
Mean low water	2,830
Mean water	ca. 4,000
Mean high water	16,370
Maximum flood	20,440 on 05.03.1984

Tab. 3: Gauging stations at Ucayali River.

Tab. 3: *Pegelstationen entlang des Ucayali.*

Name of gauging station	Station (km)
Pucallpa	0
Tiruntán	133.52
Contamana	261.26
Orellana	355.95
Juancito	562.32
Requena	897.83
Libertad	1,011.33

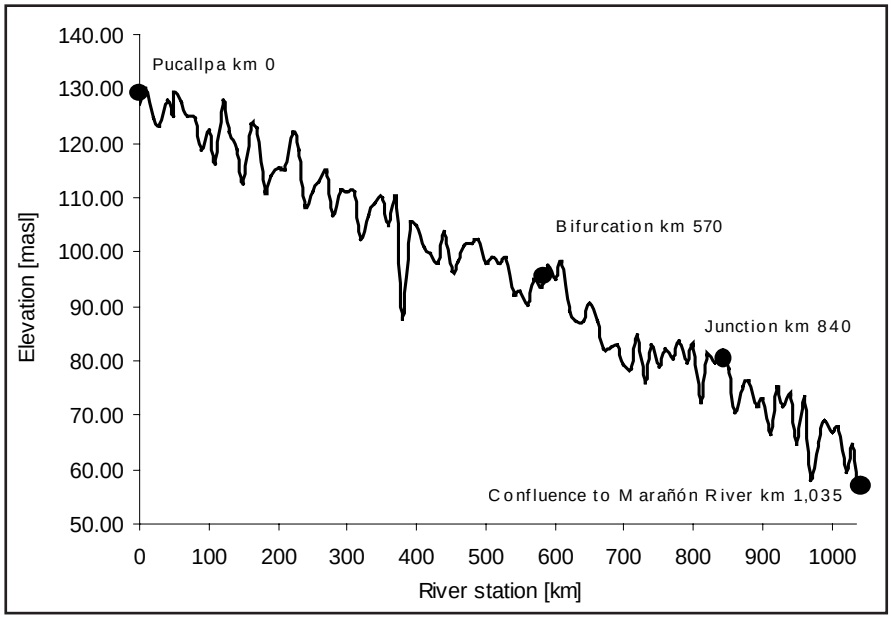

Fig. 6: Longitudinal section showing the thalweg of the Ucayali River between the city of Pucallpa and the junction with the Marañón River.

Abb. 6: *Längsschnitt des Talwegs zwischen der Stadt Pucallpa und dem Zusammenfluss mit dem Marañón.*

$$\sigma = (D_{84}/D_{16})^{0.5} \quad (2)$$

The grain diameter D_{84} was 0.30 mm and D_{16} was 0.15 mm. The calculated uniformity amounts to 1.41, indicating that the sediment of the Ucayali River could be described as nearly uniform.

Figure 9 shows the changes in D_{50} along a longitudinal section. The mean diameter D_{50} is 0.25 mm along the whole reach from Pucallpa to the confluence with the Amazon at km 1,035. Generally, only a small variation in D_{50}, with the lower bound at 0.15 mm and the upper bound at 0.40 mm, was observed. At km 250, however the D_{50} increased to 0.65 mm. The reason for that local coarsening of the sediment is the inflow of the Amacayacu River carrying coarser sediment into the Ucayali River. However, these effects were diminished after ca. 90 km at river station km 340, as shown in the diagram.

Hjulström (1935) gives a relation between the average velocity and the characteristic grain diameter, Figure 10. Thus, the begin of transportation of the grain size D_{50} = 0.25 mm. ranges between 0.15 and 0.30 m/s. It is in this range that the bed load transport of the Ucayali River begins and prevails up to an average velocity of approximately 0.94 m/s. Then, as the velocity increases, the sediment is suspended as described by the empirical approach of Kresser (1964),

Fig. 7: Sediment samples from river bed (a) and suspension samples (b) (Consorcio H&O – ECSA 2005).

Abb. 7: *Sedimententnahmen vom Flussbett (a) und Schwebstoffbeprobung (b) (Consorcio H&O – ECSA 2005).*

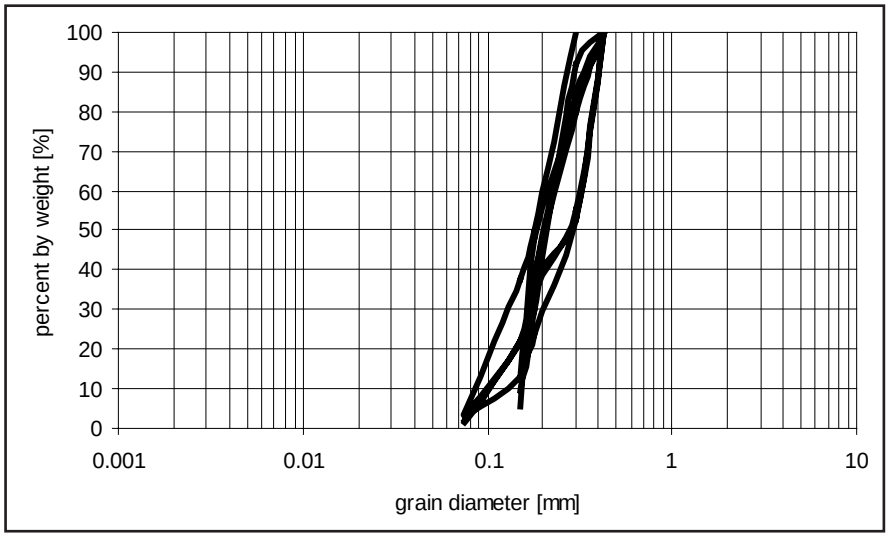

Fig. 8: Sieve curves from different probes between Pucallpa (km 0) and Libertad (km 1,011).

Abb. 8: *Sieblinien für verschiedene Probenahmestellen zwischen Pucallpa (km 0) und Libertad (km 1,011).*

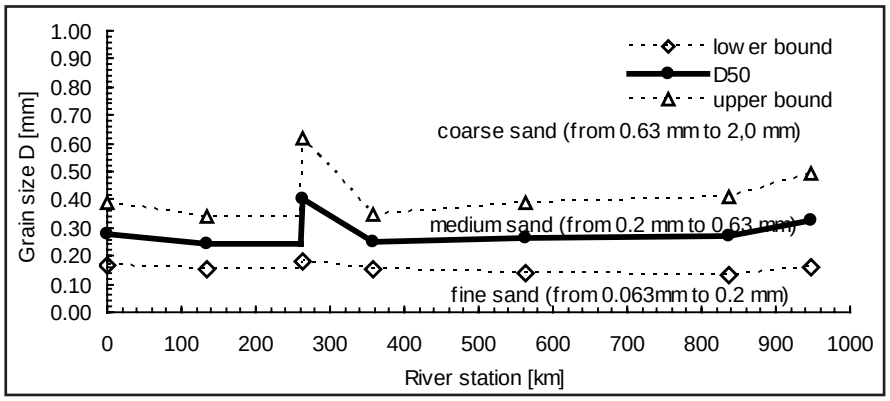

Fig. 9: Longitudinal profile of characteristic sediment diameter between Pucallpa (km 0) and Libertad (km 1,011).

Abb. 9: *Längsprofil der characteristischen Korndurchmesser zwischen Pucallpa (km 0) und Libertad (km 1,011).*

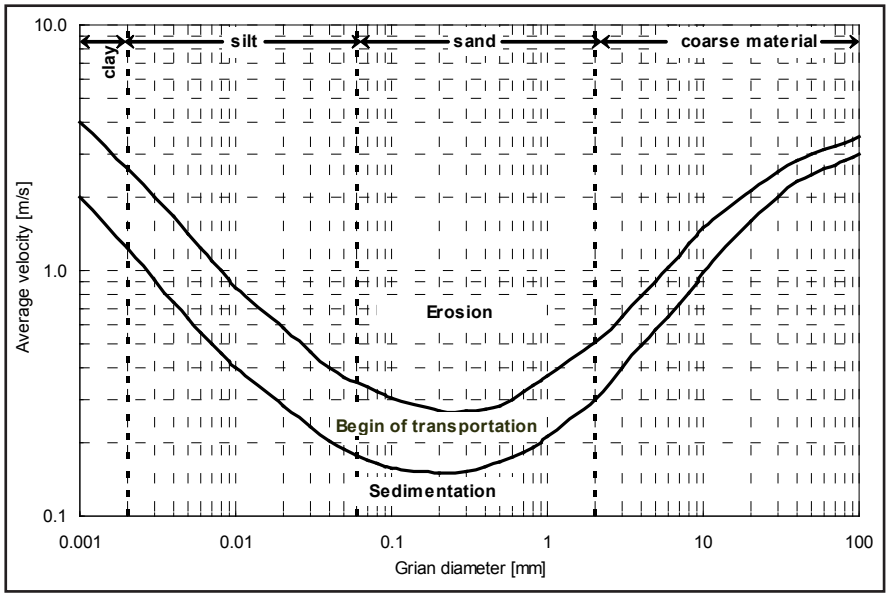

Fig. 10: Longitudinal profile of characteristic sediment diameter between Pucallpa (km 0) and Libertad (km 1,011).

Abb. 10: *Längsprofil der characteristischen Korndurchmesser zwischen Pucallpa (km 0) und Libertad (km 1,011).*

equation (3), with suspension load becoming the main type of sediment transport:

$$D = u_m^2 / 360g \quad (3)$$

where D = grain diameter for transition between bed load and suspension load; u_m = average velocity; g = acceleration of gravity.

Hydraulic conditions of the Ucayali River were calculated with the one-dimensional hydro-numerical model HEC-RAS from the U.S. Army Corps of Engineers (Consorcio H&O – ECSA 2005). The calculation showed that the average velocity of the Ucayali River exceeds 0.94 m/s for discharges of more than 2,200 m³/s, a level defined as low water conditions in Table 2. Thus, suspension load transport occurs as soon as the river discharge exceeds low water conditions. Accordingly, suspension load can be defined as the main mode of sediment transport in the Ucayali River.

The average sediment transport rate was calculated based on suspension measurements from 2004 and 2005[1] at the gauging stations shown in Table 3. As shown in Figure 11, a functional dependency between discharge and suspension load can be described roughly as a linear trend. It should be noted that the maximum discharge during the measurement period was approximately 10,000 m³/s. Equation (4) represents the linear regression:

$$S = 51.204Q - 27{,}797 \quad (4)$$

where S = sediment transport due to suspension load [t/day]; Q = discharge.

As an example, the suspension load was calculated as 187,000 t/day at a discharge of 4,200 m³/s. As calculated with values from Table 2, the sediment transport rate amounts to 177,000 t/day for the mean discharge (4,000 m³/s) and approximately 1 million t/day for the flood discharge (20,440 m³/s).

A further approximation of the annual sediment transport rate was calculated with equation (5) and mean water discharge of 4,000 m³/s. The result was an annual sediment transport rate of ca. 65 million t/year.

$$S_{annual} = (51.204Q - 27{,}797)\,\Delta t \quad (5)$$

where S_{annual} = suspension load per year; Δt = 365.25 days/year. A first evaluation of equation (5) delivers acceptable results by using values from Guyot et al. (1996 and 1999), Guyot & Filizola (2007).

4 Conclusions

Between 2001 and 2005 several basic investigations of the Ucayali River in Peru were carried out. Amongst others, a

1 Note: The sediment concentration was measured in [kg/m³] and was calculated as [t/day].

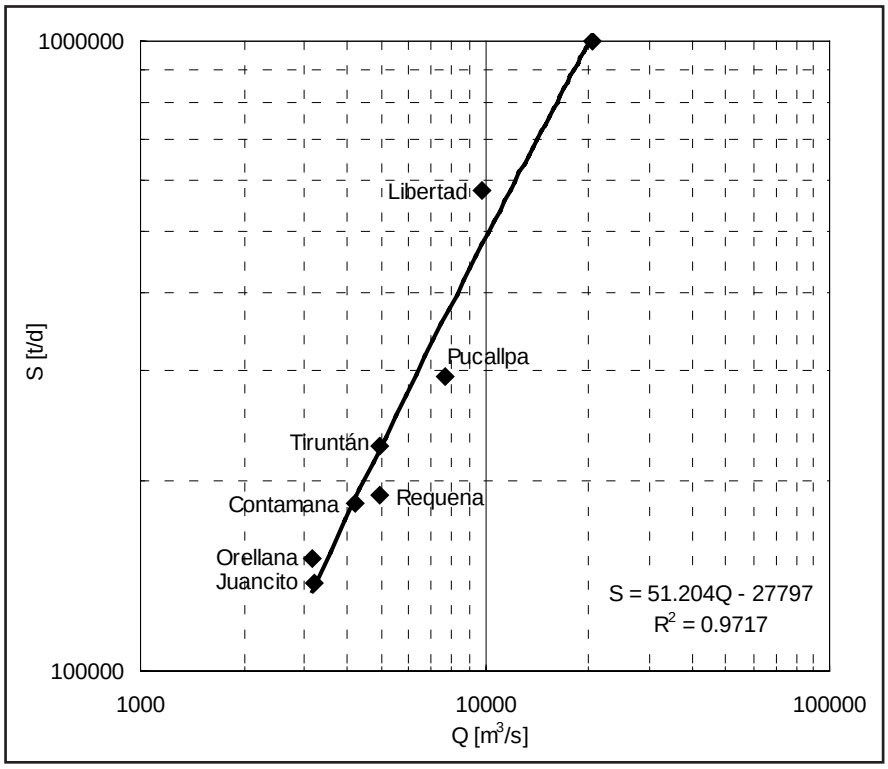

Fig. 11: Mean measured sediment concentration at gauging stations for different discharges.

Abb. 11: *Mittlere gemessene Sedimentkonzentration für verschiedene Abflüsse und Pegelstellen.*

longitudinal section of 1,035 km between the city of Pucallpa and the confluence of the Amazon was surveyed and more than 2,000 cross-sections were developed. A typical cross-section shows an average width of about 600 m and a water depth of 10 m during mean water conditions (4,000 m^3/s). The average slope on that reach is 0.05 ‰, and more than 50 sharp bends could be identified. Thus, the Ucayali River can be described as a sinuous system with a tendency toward bank erosion, bifurcation, and tributary streams. Further investigations showed that the bed material of the Ucayali River can be characterized as uniform sand with a characteristic diameter of D_{50} = 0.25 mm along the entire reach. The estimated sediment transport rate is approximately 65 million t/year, and the main type of sediment transport is suspension load.

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Vegetation, ecosystem dynamics, and restoration of floodplains in Central Asia – the Tarim River (Xinjiang, NW China) as an example

Vegetation, Ökosystemdynamik und Renaturierung von zentralasiatischen Flussauen am Beispiel des Tarim in Xinjiang, NW-China

Stefan Zerbe, Niels Thevs and Elfi Kühnel

Abstract

Naturally, the floodplains of Central Asian rivers harbour riparian, so-called 'Tugai' forests, reeds with Phragmites australis*, and shrub communities which form a mosaic depending on the variety of available ground water. In recent decades, these natural ecosystems have been strongly altered anthropogenically or even completely destroyed. In order to restore those ecosystems, knowledge on vegetation, ecosystem dynamics, and natural regeneration processes is essential. In our study, we present results of ecological investigations at the Tarim River. We gathered comprehensive data on soil, vegetation, forest stand age, tree vitality, river course dynamics, and land use and brought it to the landscape level. Thus, recommendations are derived for the maintenance of these floodplain ecosystems, in particular with regard to their biological diversity.*

Keywords: *Biodiversity, dendrochronology, natural resources,* Phragmites australis*,* Populus euphratica*, succession*

Zusammenfassung

Entlang der Flussauen Zentralasiens findet sich natürlicherweise ein Mosaik aus Auenwäldern (‚Tugai-Wäldern'), Schilfröhrichten mit *Phragmites australis* und Sträuchern, welches von der Verfügbarkeit des Grundwassers abhängt. In den vergangenen Jahrzehnten wurden diese natürlichen Ökosysteme durch den Menschen stark beeinträchtigt bis hin zu völlig zerstört. Um diese Ökosysteme wiederherzustellen, sind genaue Kenntnisse über die Vegetation, die Ökosystemdynamik und natürliche Regenerationsprozesse unabdingbar. In der vorliegenden Studie berichten wir über Ergebnisse unserer langjährigen ökologischen Untersuchungen am Tarim-Fluss. Diese umfassen Untersuchungen des Bodens, der Vegetation, der Altersstruktur und Vitalität der Tugai-Wälder, der Flusslaufdynamik und der Landnutzung, welche auf Landschaftsebene ausgewertet wurden. Auf dieser Grundlage leiten wir Empfehlungen zum dauerhaften Erhalt dieser Flussauenökosystem ab unter besonderer Berücksichtigung der biologischen Vielfalt.

Schlüsselwörter: Biodiversität, Dendrochronologie, natürliche Ressourcen, *Phragmites australis*, *Populus euphratica*, Sukzession

1 Introduction

Naturally, the floodplains of Central Asian rivers harbour so-called 'Tugai' forests, reeds, shrub communities, and halophyte vegetation which form a mosaic depending on the ground water level, distance from the main water courses, and groundwater salt content (Kuzmina & Treshkin 1997, Lavrenko 1956, Ogar 2003, Tian 1991, Thevs et al. 2008a, Treshkin 2001). Along the Tarim River in Xinjiang (NW China), the Tugai forests are mainly composed by the two tree species *Populus euphratica* and *P. pruinosa* (Liu et al. 1990, Wang et al. 1996, Zerbe & Thevs 2007). The reeds are built-up by *Phragmites australis* (Thevs et al. 2007). Within the shrub communities, *Tamarix* species are most abundant (Liu et al. 1990, Thevs et al. 2008a). This riparian vegetation performs the major habitat for plants and animals with the highest biodiversity in continental-arid desert regions. Additionally to the environmental benefits like wind protection, sand fixation and soil as well as riverbank stabilization, the floodplain ecosystems are the major resource of natural products for the local people, like timber from poplar and plant material as well as biomass from reed.

As a consequence of various land-use interests and increasing land-use changes, natural Tugai ecosystems have been more and more displaced by agricultural land in recent decades (Giese et al. 1998). Thus, the area of Tugai forests in the Aral Sea Delta shrunk from 500,000 ha in 1950 to only 70,000 in 1998 (Treshkin 2001). Along the Tarim river, the Tugai forest area decreased from 500,000 ha in the 1950ties to 200,000 ha in 1978 (Huang 1986). In the past decades, excessive use of water resources for cotton farming has lead to degradation or even a complete destruction of vast areas of floodplain forests with the consequence of desertification. However, at the Tarim river's middle reaches, we still can find one of the largest contiguous *Populus euphratica* floodplain forest areas worldwide (Thevs 2007).

Since ecological knowledge is essential for the restoration of these valuable and highly threatened ecosystems (cp. Zerbe & Wiegleb 2009), our research focuses on the differentiation of the floodplain vegetation according to the site conditions. Additionally, ecological ranges, the regeneration as well as the age structure of *Populus euphratica* forests were investigated. Furthermore, the comparison of the growth and the long-term development of natural and anthropogenically strongly influenced floodplain forests are objectives of our research.

2 Study site

Our study site is the 'Tarim Huyanglin Nature Reserve', located in the Tarim Basin, in Xinjiang, north-western China (Fig. 1). The extremely continental climate of the region is reflected by a mean annual precipitation below 50 mm

(Thevs 2007). Consequently, the water supply for the vegetation is exclusively provided by the groundwater (Thomas et al. 2006, Wang et al. 1996). The water sources of the Tarim river, which has a total length of about 1,300 km, are rivers and melting glaciers from the surrounding mountains (Song et al. 2000). While along the middle reaches of the river still near-natural forests and reeds with prevailing natural dynamics can be found, the forests along the lower reaches of the Tarim river are already strongly degraded or even completely destroyed (Westermann et al. 2008). Because of increasing water consumption for irrigation farming in the upper and middle reaches of the river, the Tarim lower reaches as well as the former end lakes Lopnor and Taitema fell dry already in 1972 (Song et al. 2000).

In order to reconstruct the natural vegetation and ecosystem dynamics at the lower reaches of the Tarim, a large-scaled irrigation project was carried out. Water from other river systems in the north of the area under consideration was conducted to the focus region and dykes to channel water towards disturbed areas were built. From 2000 to 2004, artificial flooding was released into the lower reaches of the Tarim River. These initiated flooding was implemented for 60 up to 131 days in duration. The water originated mainly from Lake Boston, which performs a huge water reservoir, and partly from the middle reaches of the Tarim and from the Daixihaizi water reservoir (Zhu et al. 2006).

3 Methods

In order to analyse the composition and differentiation of the vegetation as well as changes in the forest stand age and tree vitality along the middle and the lower reaches of the Tarim, comprehensive transect studies have been carried out applying phytosociological and landscape ecological (Thevs et al. 2008a) as well as dendrochronological methods (Westermann et al. 2008). River course changes in the past decades have been detected with the help of satellite images and excursion documents from the past century (Thevs et al. 2008b). Furthermore, soil texture, groundwater depth, and salt content of the soil water were analyzed (Thevs 2007). Thus, we gathered comprehensive data on soil, vegetation, forest stand age, tree vitality, river course dynamics, and land use and brought it to the landscape level.

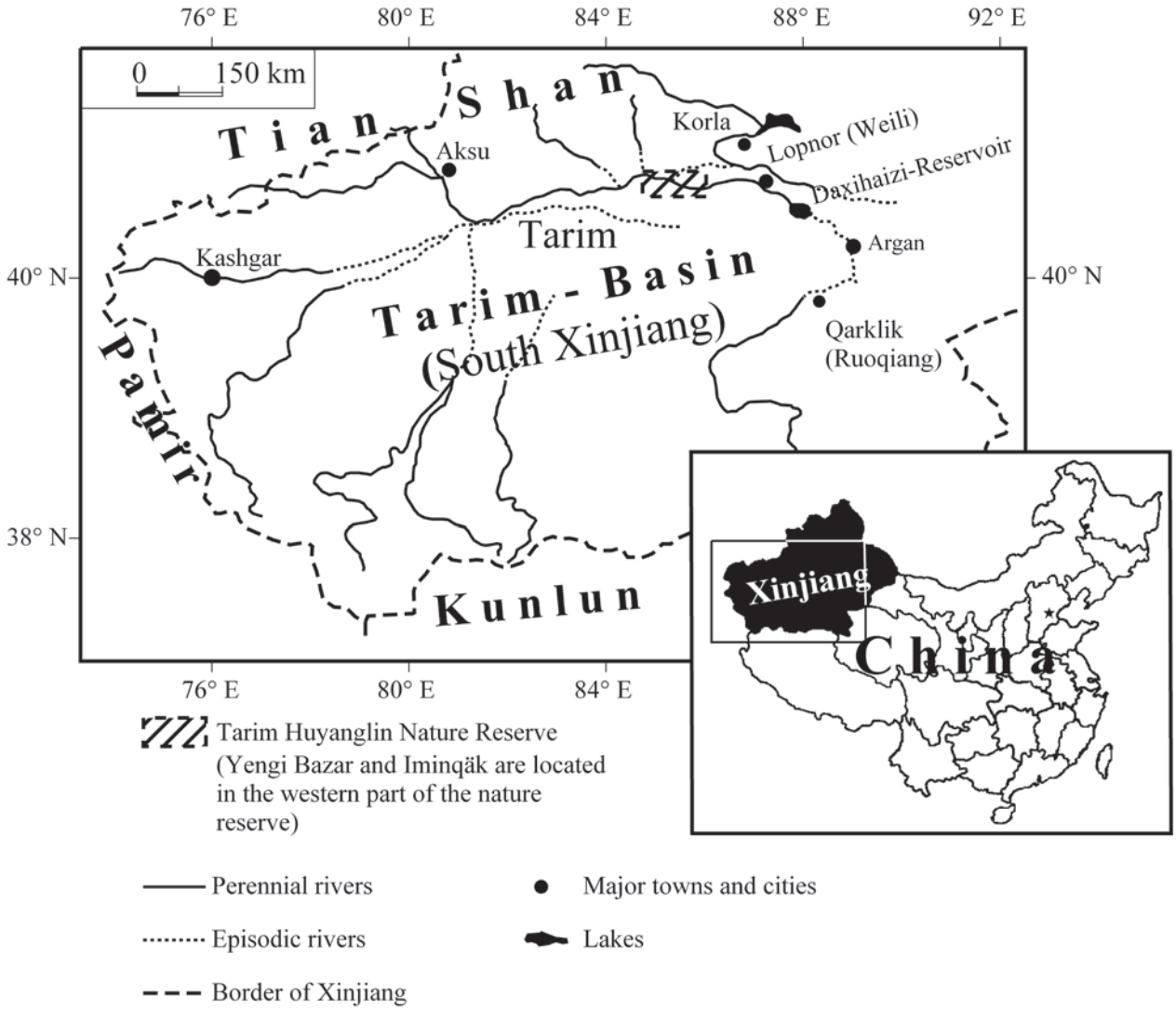

Fig. 1: Study site in NW China (from Thevs et al. 2008a).

Abb. 1: *Untersuchungsgebiet in NW-China (aus Thevs et al. 2008a).*

4 Results

As a result of the vegetation analysis at the middle reaches of the Tarim, where the floodplain can still be considered as near-natural, a typical zonation (transect shown in Fig. 2) could be detected. At the immediate river banks, we found reeds, followed by *Populus euphratica* shrubs and older Tugai forests (Thevs et al. 2008a, 2008b, Zerbe & Thevs 2007). Reeds with *Phragmites australis* are only found within a distance of up to 350 m from the river course, while *Tamarix* shrubs are growing along the whole transect, their occurrence stretching far into the Taklamakan desert. Generative rejuvenation of poplar was only recorded within a distance of 20–30 m from the river course and on sites which recently have been flooded. Along the transect, the forest stand age showed a considerable variety with mean ages of the trees ranging between ca. 10–60 years (Westermann et al. 2008).

While in near-natural stands, all age classes of the poplar trees occur, in strongly degraded stands, like it is shown for a transect at the lower reaches of the Tarim River (Fig. 3), the youngest age class from 1–20 years is completely missing. The analysis of the annual radial growth from 1954 to 2004 of some dendrochronologically studied trees at the lower reaches of the Tarim River shows a continuous growth decrease. However, strongly related to the artificial flooding of the lower reaches since 2000, an upward trend of the annual radial growth could be revealed (Westermann et al. 2008).

The river course changes in the past century show the extremely high dynamic of the river system (Fig. 4). While along the Tarim middle reaches three main river courses of the Tarim were recorded in 1903 (Hedin 1905), five ones prevailed in 1949 (Zhonghua Renmin Gongheguo Guojia Tuciju 1959). However today, only one main river course is left.

The natural development phases of *P. euphratica* forests can be separated into four stages, like it was shown by Westermann et al. (2008). The stand development begins with the colonization stage with a homogeneous age structure due to recently deposited land and subsequent tree colonization by generative propagation. The age span of the trees is narrow, most trees being younger than 20 years. Multi-aged stands can develop within the second stage because trees can perform clonal growth.

The third stage of stand persistence is characterised by decreasing groundwater levels, increasing soil salinisation and lacking regeneration. In the fourth stage, the process of dying-off begins and tree age span decreases. However, if the groundwater level rises due to the natural river course dynamics, vegetative reproduction can again be expected (Westermann et al. 2008).

5 Discussion and conclusion

Comparing the high river dynamics at the beginning of the 20th century to the current situation, where only one main

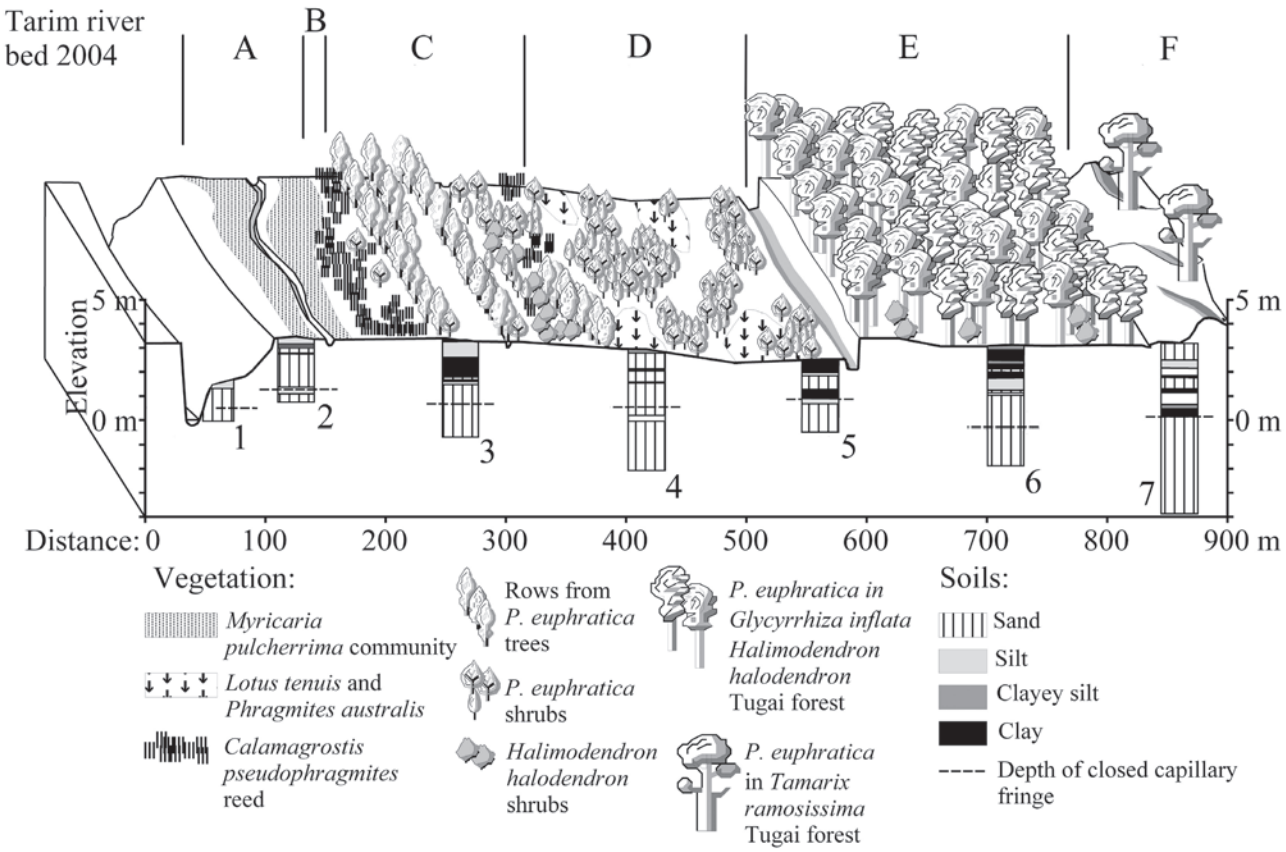

Fig. 2: Transect at the middle reaches of the Tarim river showing the typical zonation of sites and vegetation in a near-natural floodplain forest (from Thevs 2007).

Abb. 2: *Transekt am Mittellauf des Tarim-Flusses, welches die typische Zonierung der Standorte und deren Vegetation im naturnahen Flussauenwald darstellt (aus Thevs 2007).*

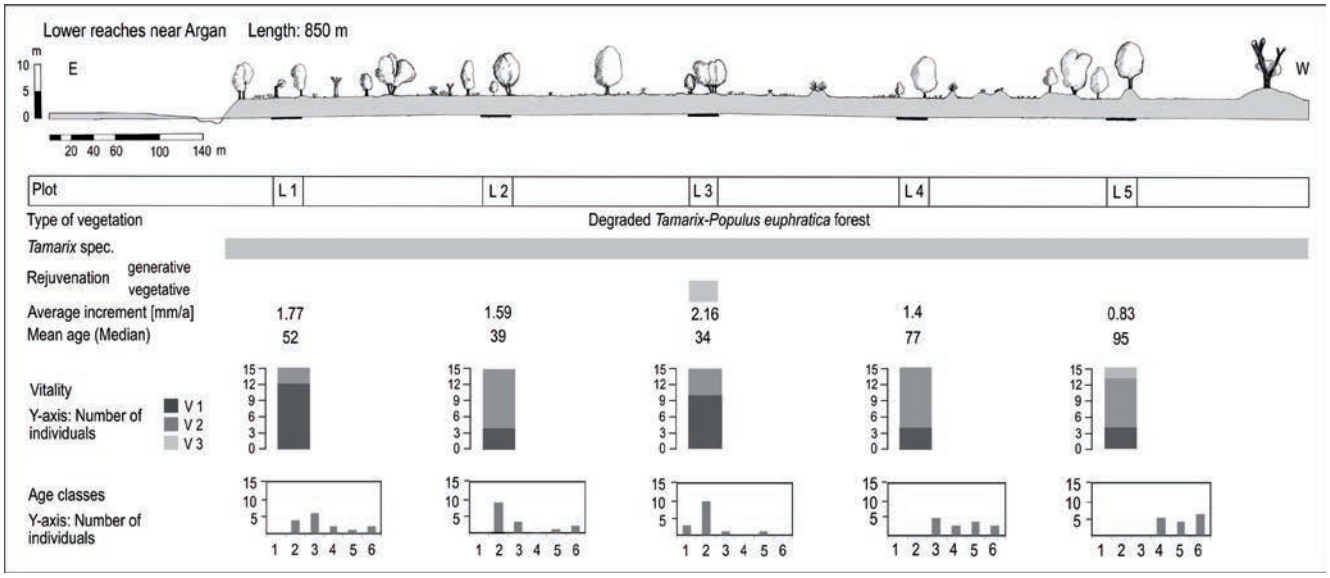

Fig. 3: Transect at the lower reaches of the Tarim river showing the age structure, growth, and vitality of a degraded floodplain forest (from Westermann et al. 2008).

Abb. 3: *Transekt am Unterlauf des Tarim-Flusses, welches die Altersstruktur, den mittleren Zuwachs und die Vitalität eines degradierten Flussauenwaldes darstellt (aus Westermann et al. 2008).*

stream remains, it is obvious, that the Tarim has lost its natural dynamic, which is important for the preservation of this valuable ecosystem. The fact, that reed patches are forming a mosaic together with groups of young poplar trees indicates the former occurrence of flooding and river channels, respectively. The old-growth poplar stands far away from the current river bed shows a shifting of the river course to the south since 1973, also reflecting the natural dynamics of the floodplain ecosystem.

The rejuvenation and establishment of Tugai forests as well as the maintenance of genetic diversity is, however, based on natural river dynamics. Summer floods, in particular from July to September provide safe sites for germination with moist river banks and a low salt content (< 0.2 %) in the upper soil. Furthermore, an early onset of the flood in the year after germination is important for a successful establishment.

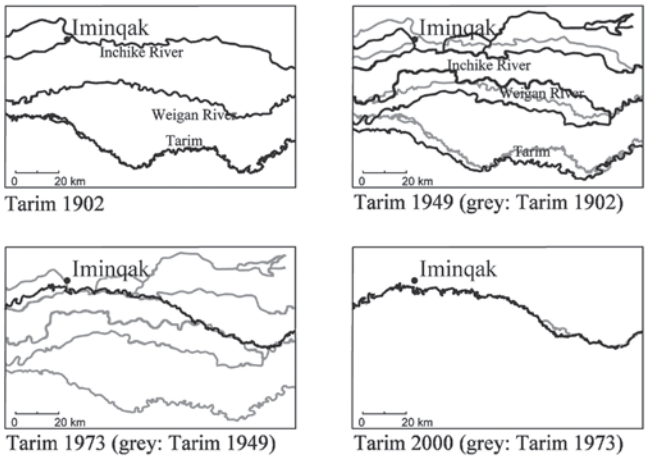

Fig. 4: River course changes of the Tarim River, Xinjiang, NW China in the past century (from Thevs 2007).

Abb. 4: *Veränderungen des Tarim-Flusslaufes in Xinjiang (NW-China) im vergangenen Jahrhundert (aus Thevs 2007).*

Additionally to poplar, also the majority of the other vegetation-forming plant species can only germinate and establish on flooded sites on the river banks. However, if the natural flood events do not occur any more also rejuvenation is interrupted as was shown for the degraded lower reaches of the Tarim River. Then, the natural succession is also strongly altered.

As a conclusion of our findings, we state that on the short term, controlled flooding may lead to the temporary recovery of the Tugai vegetation. However, on the long term, only the natural dynamics of the river system as well as a sustainable use of the water resources will succeed in the maintenance of the Tugai vegetation as the major biotic resource for the local society.

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