Inland Sand Ecosystems: Dynamics and restitution as a consequence of the use of different grazing systems

Angelika Schwabe[1], Dominique Remy[2], Thorsten Assmann[3], Anselm Kratochwil[2], Albrecht Mährlein[4], Michael Nobis[1], Christian Storm[1], Andreas Zehm[1], Harald Schlemmer[5], Robert Seuß[5], Sabine Bergmann[1], Carsten Eichberg[1], Uwe Menzel[2], Markus Persigehl[3], Kai Zimmermann[5], Mareike Weinert[2]

[1]Department of Biology, Geobotany/Vegetation Ecology, Darmstadt University of Technology, Germany
[2]Dep. of Biology/Chemistry, Division of Ecology, University of Osnabrück, Germany
[3]Institute for Ecology and Environmental Chemistry, University of Lüneburg, Germany
[4]Greven, Germany
[5]Institute of Geodesy, Darmstadt University of Technology, Germany

Abstract

In Germany, sand ecosystems are among the endangered habitats, particularly the open and the ecotone-rich forms including open oak and pine woodland. A practicable nature conservation concept has to take into account the often anthropo-zoogenically caused dynamics of sand ecosystems. The conservation of these ecosystems is problematic, as they form dynamic systems which lose relevance for species and habitat conservation if they are not used or if they are intensively used or fertilized.

Therefore, apart from existing sandy regions, restitution areas are studied, among them an inland dune complex the morphology of which was altered in the context of a trial and development project. The areas studied are located in the north-German lowland plain ("Hase valley", "Ems valley" in the Emsland region) and in the northern Upper Rhine valley (sandy regions near Darmstadt). Differentiated grazing systems with cattle, sheep, goats, horses, Mangalitza pigs and donkeys are employed.

The central aim of the project is to analyse the effects of different grazing systems on the vegetation, on nutrient dynamics, on selected animal groups and on socio-economics. The article presents conclusions for nature conservation and socio-economic aspects.

1 Background

Most open habitats developed as a result of human activities, especially as a consequence of the many and diverse forms of land use practised in historical times. Consequently, there was a wide variety of such habitats in Central Europe; many of them, however, have now disappeared.

Pasture Landscapes and Nature Conservation
B. Redecker, P. Finck, W. Härdtle, U. Riecken, E. Schröder (Eds.)

Tabelle 1. The concepts of redynamization and restitution in sand ecosystems (schematic)

	status quo	**management practices**		
		changes of abiotic conditions ("abiotic redynamization")	**transfer of diaspores (vascular plants, cryptogams)**	**grazing impact (hypothesis)**
redynamization	mono-dominance of species (e.g. *Poa angustifolia*, *Calamagrostis epigejos*, *Cynodon dactylon)*			- increase in species of early successional stages (indirect effects through the initiation of gaps) - selective grazing on nutrient-rich species, increase in some avoided endangered species (e.g. *Corynephorus canescens*, R: *Koeleria glauca*, *Helichrysum*) - specific effects: flower phenology (e.g. induction of second flowering after grazing)
restitution (including abiotic redynamization)	arable field, fallow land (e.g. former *Zea mays* fields)	manipulation of the upper soil layer (0-60 cm) which is rich in N and P: transfer of the upper layer or substitution by the lower layer poor in N and P, modelling of dune structures, hollows	the study sites are treated with diaspores of higher plant species and cryptogams by transfer of hay, litter or sods of sand-specific vegetation, seed bank and seed rain are studied	selective grazing on nutrient-rich, especially ruderal species, therefore increase in some avoided endangered species which are poor in nutrients, grazing of endangered species will be analysed

In Germany, sand ecosystems are among these endangered habitats, particularly the open types and those rich in ecotones including open oak and pine woodland. A practicable nature conservation concept has to take into account the often anthropo-zoogenically caused dynamics of sand ecosystems. The conservation of these ecosystems is problematic, as they form dynamic systems which are no longer of relevance for species and habitat conservation if they are not used or if they are intensively used or fertilized. Mosaic complexes need certain disturbance factors to also retain pioneer stages (BAKKER et al. 1983, OLFF et al. 1999, WHITE and JENTSCH 2001, KRATOCHWIL and SCHWABE 2001). Many poorly competitive plant species as well as xerophilous and thermophilous arthropods depend on such early successional stages.

Table 1 (cont.)

	target structures (abiotic)	**target species/communities which still occur in intact sand ecosystems (at the top) and target species/communities for the restitution areas (at the bottom) (examples)**	
		vegetation, plant species	**animal species**
redynamization	gaps, dune structures	Corynephoretalia and Armerion elongatae (e.g. *Corynephorus canescens, Teesdalia nudicaulis, Dianthus deltoides,* R: *Phleum arenarium, Silene conica, Veronica praecox, V. verna, Armeria*elongata*) R: Koelerion glaucae (e.g. *Jurinea cyanoides, Koeleria glauca, Alyssum*gmelinii, Medicago minima, Bassia laniflora, Poa badensis*)	R: *Oenanthe oenanthe* (Aves), *Oedipoda caerulescens* (Caelifera), *Harpalus neglectus* (Carabidae) R, H: *Myrmeleotettix maculatus* (Caelifera), *Cicindela hybrida* s.l. (Cicindelidae), *Poecilus lepidus, Masoreus wetterhallii* (Carabidae) R: *Eresus cinnaberinus* s.l. (Araneida), *Bembix rostrata* (Sphecidae), *Nomioides minutissimus, Andrena carbonaria* s.l., *Halictus sexcinctus* R, H: *Andrena barbilabris* (Apoidea)
restitution (including abiotic redynamization)	redynamization of dune structures H: fluviodynamic structures in the floodplain	dry habitats: Corynephoretalia /Armerion elongatae R: Koelerion glaucae, elements of Allio-Stipetum H (moist/wet habitats): e.g. *Elatine* species, different Nanocyperion species	dry habitats: *Poecilus lepidus, Masoreus wetterhallii* (Carabidae) (question of dispersal), translocation experiments with *Harpalus neglectus* (H) (wingless species), H = moist/wet habitats: *Agonum viridicupreum* (Carabidae)

R = Upper Rhine valley near Darmstadt; H = Ems/Hase region (NW Germany)
* = abbr. for species name

A management form aiming to maintain dynamic systems but also considering economic aspects has to be devised. It should be applicable to both **remnants of these habitats** and to **restitution areas**, i.e. areas where the re-establishment of such ecosystems is attempted. Especially the latter aspect is of great importance in regions where remnants of sand ecosystems are so small and fragmented that a gene exchange has become almost impossible. Therefore, apart from existing sandy regions, restitution areas are studied, among them an inland dune complex upmodelled in the framework of a trial and development project. "Projects that combine protection and utilization aspects are of special significance" (FEDERAL AGENCY FOR NATURE CONSERVATION 2000).

The areas studied are representative of their respective regions; they are located in the **north-German lowland plain** ("Hase valley", "Ems valley" in the Emsland region) and in the **northern Upper Rhine valley** (sandy areas near Darmstadt).

Differentiated grazing systems with cattle, sheep, goats, horses, Mangalitza pigs and donkeys are employed.

The Darmstadt University of Technology, the University of Osnabrück, the University of Lüneburg and the University of Göttingen take part in this research project.

2 Hypothesis, questions and the concept of restitution and redynamization

Our hypothesis is that grazing systems with extensive management (< 0.7 livestock units/ha) and hardy breeds are suitable to promote dynamic processes:

- to redynamize sand ecosystems which have become consolidated and contain mono-dominant species such as *Poa angustifolia, Calamagrostis epigejos, Cynodon dactylon* and
- to develop restitution areas e.g. by selective grazing of nutrient-rich, especially ruderal species; therefore populations of endangered plant species – often avoided by grazing stock – may increase. (Possible negative effects will be taken into consideration, see "Outlook".)

The following questions need to be addressed:

- Which dynamic effects are caused by grazing in existing and restituted sand ecosystems?
- Which effects can be identified concerning abiotic and biotic resource availability and preservation?
- How are the dispersal strategies in redynamised and restituted sand ecosystems for selected plant and animal species?
- Which effects are important for nature conservation management and for socio-economics?

To summarize: Which dynamic responses of abiotic and biotic structures can be identified, given the impact of the grazing regime employed, and what consequences for nature conservation and socio-economics can be deducted from this?

Table 1 summarizes the concepts of redynamization and restitution including the proposed hypothesis and relevant questions.

3 Some information about study sites and sampling design

The sandy sites in the Upper Rhine valley near Darmstadt (R) and in the Ems/Hase valley (H) still contain a number of endangered species and vegetation types (e.g. R: Bromo tectori-Phleetum arenarii, Jurineo-Koelerietum, Armerio-Festucetum trachyphyllae, H: Spergulo morisonii-Corynephoretum, Diantho deltoidis-Armerietum), as well as larger populations of endangered plant and animal species (e.g. R: *Jurinea cyanoides, Bassia laniflora, Nomioides minutissimus,* H: *Harpalus neglectus*); see Table 1. In the Ems/Hase region we have endangered mosaic complexes consisting of inland dunes and temporarily flooded hollows.

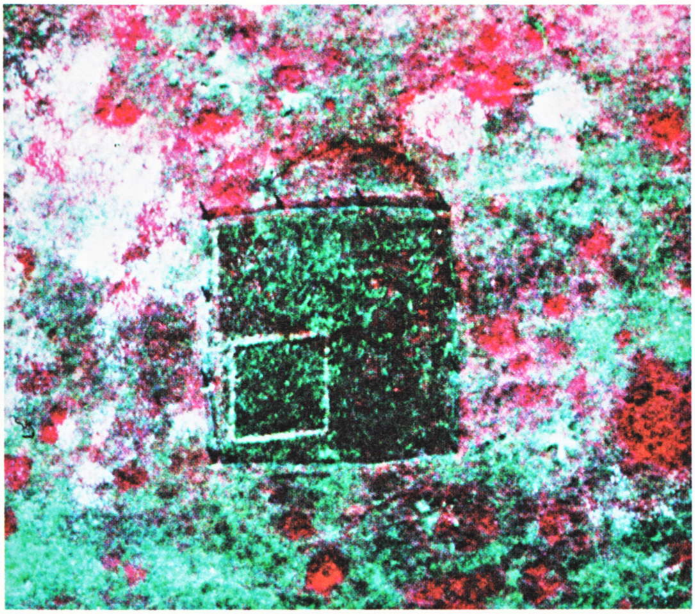

Fig. 1. Example of a fenced 14 x 14 m exclosure and the grazed plots outside the fence (colour infrared aerial photograph, May 2000, pixel size: 7 cm; "Ehemaliger August-Euler-Flugplatz von Darmstadt" in the Upper Rhine valley). The grazed area is dominated by flowering *Cerastium arvense* (white) and open structures which are very rich in therophytes, such as *Silene conica*; the fenced area (since March 1999) already has a different structure. The pathways for the study of flower phenology (exclosure: bottom left) are clearly discernible

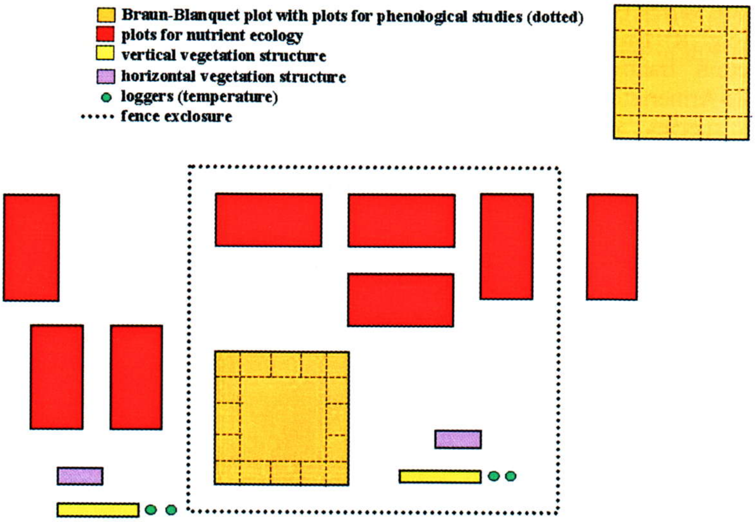

Fig. 2. Diagram of the experimental design shown in Fig. 1. In our project about 35 fenced exclosures will be studied

In open habitat sites, monodominant stands of *Poa angustifolia, Calamagrostis epigejos* and, in the recent past, an increase in the C_4 grass *Cynodon dactylon* have been observed (R), especially when the land was not utilized.

The study areas in the Emsland region are grazed extensively with cattle and/or horses. In the Darmstadt region mainly sheep grazing regimes with different sheep breeds can be compared (hardy indigenous sheep breeds such as Rhoen sheep, Skudde, Moorschnucke); ZEHM et al. (2002). No supplementary feeding is provided during the pasture period (for Rhoen sheep: May – December).

In addition to classic approaches (e.g. vegetation mapping) we have been able to study replicated fenced and grazed plots in different vegetation complexes (e.g. typical and ruderalised Koelerion glaucae complex, Armerio-Festucetum trachyphyllae complex, Spergulo-Corynephoretum complex, Diantho-Armerietum complex and others) (see Figs. 1 and 2). In both regions two replicated exclosures were established in each vegetation complex. In a further step the data will be scaled up in order to obtain results for the landscape level (see below).

4 Structure of the project

The investigations focus on the impact of the different grazing animals on vegetation structure, nutrient dynamics and selected arthropod groups, as well as on agricultural yield, applied economics and socio-economics. Moreover the colonization dynamics of arthropod species in "habitat islands" (original situation of restitution sites) is studied as an important aspect in nature conservation management. The data are processed, analysed in a four-dimensional Geographic Information System (GIS) and scaled up for larger areas.

4.1 Module: Vegetation – structure and dynamics

The effects of grazing (mainly with cattle, sheep, goats, horses and Mangalitza pigs) on the vegetation and structure of the stratified sampling plots are studied and compared to reference plots. Existing sand ecosystems and restitution areas are studied with respect to their horizontal and vertical vegetation structure, their flower and fruit phenology and the diaspore dynamics. Relationships between vegetation structure and animals like grasshoppers (Ensifera/Caelifera) and bees (Hymenoptera Apoidea) are also studied. Two examples of grazing preferences are given in Fig. 3.

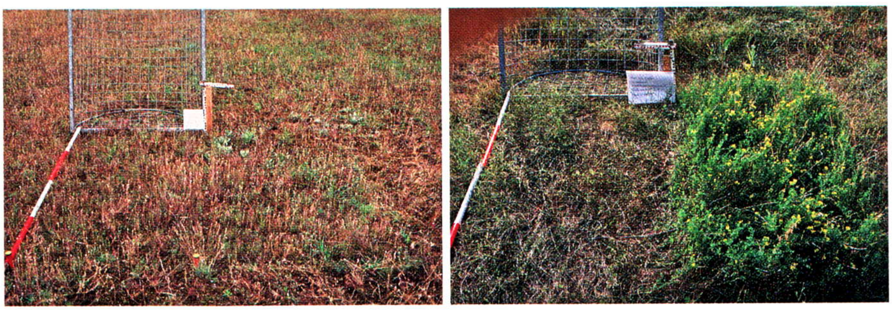

Fig. 3. Grazing preferences demonstrated using wicker baskets (examples from the nature reserve "Ehemaliger August-Euler-Flugplatz von Darmstadt"). Vegetation underneath a wicker basket of 1 x 2 m (right) and after two weeks of Rhoen sheep grazing (left).
Example 1 (left): Bromo-Phleetum-/Koelerion glaucae-complex with 6 endangered species (e.g. *Koeleria glauca, Medicago minima, Silene conica, Veronica verna, Veronica praecox*); standing crop (above stubbles): 87 g/m^2 dry weight, grazed percentage of dry weight 26%, nearly no endangered species grazed.
Example 2 (right): Armerio elongatae-Festucetum rich in the leguminous plant species *Medicago falcata* with one endangered species (*Medicago minima*); standing crop (above stubbles): 585 g/m^2 dry weight, grazed percentage of dry weight 61%

4.2 Module: Nutrient dynamics

Nutrient dynamics of intact or ruderalised sand ecosystems: investigation of the influences of grazing, particularly on the nitrogen and phosphorus regime of sand ecosystems. Statements on the sustainability of use and a possible compensation of eutrophying influences can be made.

Nutrient dynamics of restituted sand ecosystems: whether and to what extent the restitution of oligo-mesotraphent vegetation complexes is possible after former intensive agricultural use or other interventions. Turnover and reduction of the nutrients accumulated in soil during the intensive agricultural use as well as their translocation to the groundwater are studied.

4.3 Module: Dynamics of selected arthropod populations

The stenotopic arthropod fauna of sand ecosystems contains many endangered species. For the restitution of habitats, the following aspects are important from the point of view of animal ecology:

- to analyse the dispersal types of arthropod species with regard to the potential for colonizing new habitat, and to assess the importance of the ability to fly for the dispersal of a species,
- to ascertain the individual numbers required for the establishment of a population,
- to determine the source populations and their distance,
- to analyse the establishment of new populations in the habitats, the migration patterns, and the utilization of available space by individuals.

4.4 Module: Agricultural yield, applied economics, socio-economics

This interdisciplinary module aims at recording and analysing the agricultural aspects of the project, i.e. agricultural production and keeping of livestock, in their micro-economic and socio-economic dimensions. With the help of wicker baskets (Fig. 3) the production of the pastures can be calculated, including essential nutrients. Aspects of nature conservation agricultural and economic aspects have to be brought together.

4.5 Module: Geographic Information Systems (GIS): Generation of a four-dimensional GIS

Using a GIS, geocoded data from other modules are gathered, depicted, analysed and summarized. This requires in part the spatial extrapolation of the data of representative sites to areas with a size of many hectares. The results are partly shown in the form of scenarios, i.e. the development in non-grazed areas is compared to that in grazed parts.

5 Investigating different scales

We use the following approaches to study different scales:

Population level: Quantitative data of the flower and fruit phenology are sampled in some fenced/unfenced plots following the method established by KRATOCHWIL (1984). Especially the seed production of threatened species, such as *Veronica verna, Silene conica, Silene otites* and others, will be studied.

Level of population micro-patterns: The horizontal structure of vegetation and the dynamic processes in the time axis are studied using a very fine grid (5 x 5, 10 x 10 cm) and the positiometer method after NOBIS (1999). The vertical structure is recorded by taking digital images (after ZEHM 1997 and in prep.) of fenced ungrazed and grazed plots and is analysed with specially elaborated software.

Level of plant communities and vegetation complexes: Plant communities and vegetation complexes are sampled and mapped using the 'classic' methods.

Broad scale investigations: These are based on special aerial photographs (colour infrared film material, pixel size 7 cm) and taken annually prior to the start of the grazing season (May). The vegetation pattern will be quantified. For this purpose different methods of digital image processing as well as different analytical tools of Geographic Information Systems (GIS) are used. In combination with the results of the detailed examination it will be possible to describe some dynamic processes.

6 The main restitution project: Extensively grazed pasture landscape in the Emsland region (north-western Germany)

This part of the project aims at the restitution and redynamization of a typical semi-open pasture landscape in north-western Germany. On the sandy soils of the Hase river floodplain, complexes of inland dunes and temporarily flooded hollows will be restored. In a first step the dikes of two oxbows ("Hammer Schleife" and "Wester Schleife"), which are at present used as maize fields and fertilized pastures, will be completely removed. In an area of about 37 ha, the morphology of structures such as small inland dunes and temporarily flooded hollows will be modelled (example Fig. 4) and these will then be extensively grazed by cattle and horse.

In the base-poor sandy regions of the north-western German lowlands complexes of inland dunes, temporarily flooded hollows or abandoned channels in river meadows are typical elements of pasture-woodlands. In the study area, this landscape type is characterized by a mosaic of nutrient-rich and nutrient-poor grasslands of variable humidity, containing, amongst other vegetation types, seasonally flooded grassland with *Dianthus deltoides* and sandy dry meadows interspersed e.g. with blackthorn (*Prunus spinosa*) and juniper (*Juniperus* *communis*). River engineering like the building of dikes hydrodynamically separated the riparian grassland from the river. The frequency and duration of floods was thus reduced and the ground-water level lowered. The region was then intensively used agriculturally, leading to a quantitative and qualitative reduction of the semi-open pasture landscapes and their biocoenoses.

We assume that it is possible to restore a levelled, heavily fertilized agricultural area to an extensively used complex of inland dunes and temporarily flooded hollows and to develop this complex as a dynamic system in the long term. Under an extensive grazing regime site-typical plant and animal species with their communities should develop from residual populations, from persistent seed banks, from transferred diaspores (hay, sods; see Table 1) or immigrate from the vicinity.

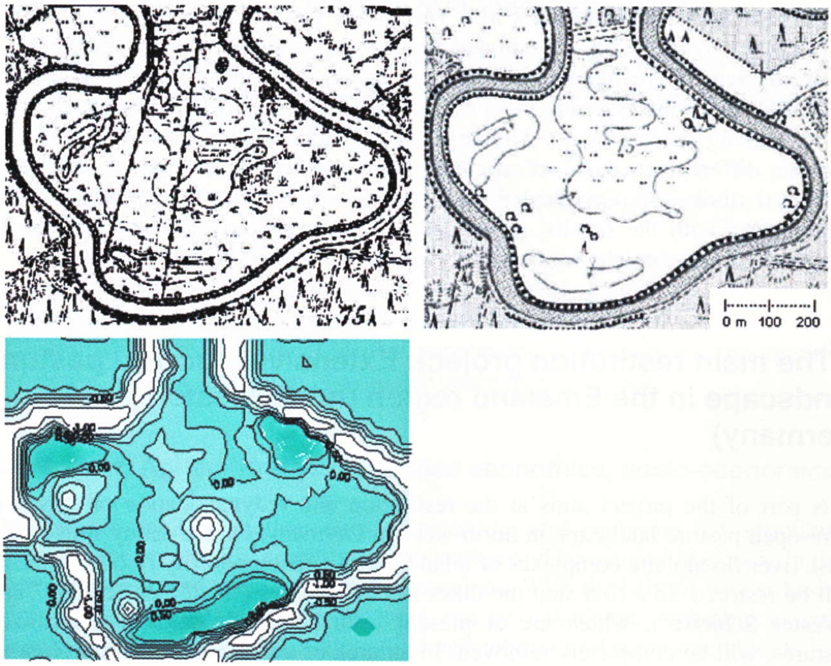

Fig. 4. Concept for the restitution (including abiotic redynamization) within the "Hammer Schleife" (Ems region, north-western Germany)

4a Situation around 1900 (survey: Königlich Preußische Landesaufnahme)

4b Present situation (from topographic map 1 : 25,000)

4c Future relief of the restitution area adapted from the historic situation and considering the local deposits of sandy material (relief modelling using the Surfer Software). (Height given in m)

The biotic targets for the ecological restoration (BAKKER et al. 2000) have been defined according to typical vegetation types (BAKKER and BERENDSE 1999) and animal communities of nutrient-poor sand ecosystems (target species/communities, see Table 1). For this reason the impact of grazing on intact vegetation complexes of the Ems and Hase valley has also been studied. Grazed and ungrazed (fenced) plots were set up in different vegetation units in these study areas (different types of Spergulo-Corynephoretum, Diantho deltoidis-Armerietum) with the experimental design shown in Fig. 2.

The restitution project has been divided into three phases: 1. Planning and preliminary investigations; 2. Restoration and initial phase; 3. Phase of dynamic development.

In the first phase, completed at the end of the year 2000, models of the landscape including the abiotic target structures (Table 1) were developed. A plan for altering the dune morphology were drawn up (Fig. 2) on the basis of historical data (maps, aerial photographs) and the models as well as the available soil masses were assessed with regard to quantity and quality (soil type, nutrient content).

Ground modelling was completed in a short second phase in the winter of 2001: an artificial relief is to be created and simultaneously natural hydrodynamics are to be restored. The upper soil layer (0-60 cm) which is rich in N and P was transferred to the deeper part of the dune structures and was substituted by layers poor in nutrients. Immediately after having moved the soil, site typical grassland species are to be sown in the main area to prevent ruderalization. The reshaped dune areas (Fig. 4) are to be "inoculated" through the transfer of hay or sods from sand-specific vegetation. Sporadically, site-typical shrubs will be planted (e.g. *Prunus spinosa*). Eight permanent plots will be established, four of which will be ungrazed fenced areas. Measurement devices for hydrogeological / geochemical investigations (WEINERT et al. 2000) was placed in the soil (soil moisture samplers with nylon cups, water-level indicators, lysimeters).

In the third phase of the development of natural morphological structures and biocoenoses under the influence of abiotic processes and extensive grazing, these systems will be studied carefully (monitoring). "Monitoring is a *conditio sine qua non* for the evaluation of the effects of ecological restoration" (BAKKER et al. 2000).

Other restoration projects in smaller areas (1-2 ha) were initiated in the Darmstadt-Dieburg region. One project has already been running since 1998 and demonstrates the effects of grazing by sheep preferring nutrient-rich plant species and neglecting e.g. *Corynephorus canescens, Koeleria glauca* and other endangered species.

7 Outlook

Having completely analysed and summarized the data, recommendations for nature conservation measures can be formulated, which should be applicable to other sand ecosystems and restoration projects. The measures are to be judged as to their efficiency, also considering economic aspects.

Following the first year of study there are some initial results:

- an increase in plant species biodiversity in mono-dominant stands of competitively aggressive grasses, such as *Calamagrostis epigejos*, after grazing (ZEHM et al., 2002)
- an increasing number of gaps and therefore of therophytes in the grazed plots (e.g. *Silene conica*)
- strong structural changes in both grazed and ungrazed plots. Results concerning connections e.g. between structural changes, plant and animal populations will be outlined.

Possible negative effects of local overgrazing and grazing of endangered species as reported by ROSÉN and VAN DER MAAREL (2000) for the Alvar vegetation (Öland) will be taken into consideration. In our extensive grazing systems local overgrazing probably does not play a role. Grazing of endangered species will be analysed, such as *Armeria*elongata* and *Dianthus deltoides*. In the case of *Armeria* a second flowering induction phase after grazing can be observed.

We are confident that our project can contribute empirical and synoptic data to answer questions on the importance of dynamic processes in landscapes grazed by hardy breeds (FINCK et al. 1998).

8 German summary

In der Landschaft sowohl der nördlichen Oberrheinebene als auch des Emslandes sollten Sandstandorte Beispiele von Ökosystemen darstellen, die z.T. noch großflächigeren dynamischen Prozessen unterliegen. Die Sandstandorte des nördlichen Teils der Oberrheinebene weisen eine Reihe extrem gefährdeter Vegetationstypen, Pflanzen- und Tierarten auf (s. Tab. 1). Im Zuge von Ruderalisierungen nehmen in den letzten Jahrzehnten unduldsame Gräser wie z.B. Schmalblättriges Rispengras (*Poa angustifolia*) und Sandrohr (*Calamagrostis epigejos*) überhand. Die flußnahen Sand-Vegetationskomplexe im Ems-/Hase-Gebiet bergen mit Sand-Pionierfluren und -Rasen in ihrer Verzahnung mit Flutmulden ebenfalls eine Fülle gefährdeter Vegetationstypen, Pflanzen- und Tierarten (Tab. 1).

Das typische Vegetationsmosaik der gefährdeten Pflanzengesellschaften von Sand-Ökosystemen bildet sich in der Regel nur bei vorhandenen Störungen aus, die die Sukzessionsprozesse immer wieder initiieren; so kommen konkurrenzschwache Pionier-Pflanzenarten zur Entwicklung und xero-/thermobionte Arthropoden finden entsprechende offene Lebensräume.

Neben einer möglichen Redynamisierung gewachsener Ökosysteme spielt für den Naturschutz die Frage der Restitution eine bedeutende Rolle. Unsere Hypothese ist, daß Beweidung ein tragfähiges Konzept darstellt, um konsolidierte Sandstandorte zu redynamisieren und um Restitutionsflächen im Sinne des Naturschutzes zu entwickeln.

In einem BMBF-Projekt werden in der nördlichen Oberrheinebene und im Emsland neben bestehenden Sandgebieten auch Restitutionsflächen untersucht, darunter eine in dem E+E-Vorhaben „Hasetal" aufmodellierte Binnendünenfläche. Differenzierte Weidesysteme

(u.a. mit Rindern, Schafen, Ziegen) werden eingesetzt. Wesentliches Ziel des Projektes ist die Untersuchung der Auswirkungen unterschiedlicher Weidesysteme auf die Vegetationsentwicklung, die Nährstoffdynamik und ausgewählte Tiergruppen. Ertrags- und betriebswirtschaftliche sowie sozioökonomische Untersuchungen ermöglichen eine Bewertung der ökonomischen Gesichtspunkte der verschiedenen Beweidungsvarianten. Unter Berücksichtigung der naturschutzfachlichen und sozioökonomischen Aspekte wird eine Szenarienbildung mit Hilfe eines vierdimensionalen GIS (Raum und Zeit) erarbeitet.

In allen Gebieten wurden neben größerflächigen Untersuchungsansätzen (Luftbilder, Vegetationskartierungen) nicht beweidete Vergleichsflächen eingerichtet.

Nach vollständiger Analyse der Daten sollen Empfehlungen für den Naturschutz gegeben werden, die auch auf andere Sandökosysteme und Restitutionsprojekte übertragbar sind. Hierbei wird auch die Effizienz der möglichen Maßnahmen betrachtet.

Acknowledgements and corresponding authors

We are grateful to the German Federal Ministry for Education and Research (Bundesministerium für Bildung und Forschung, BMBF; funded 2000-2003, No. 01LN0003) and the Federal Agency for Nature Conservation (Bundesamt für Naturschutz, BfN) for supporting our projects. The studies have been made possible by the cooperation of the competent authorities; in some instances cooperation contracts exist with these authorities. We would especially like to thank the Weser-Ems regional administration, the Darmstadt regional administration and the Darmstadt-Dieburg district authority. We are also grateful to the livestock owners in both study areas for their cooperation.

More information about the project can be found at:
http://www.tu-darmstadt.de/fb/bio/bot/geobot/BMBFSTAR.htm.

References

Bakker, J P, Berendse, F (1999) Constraints in the restoration of ecological diversity in grassland and heathland communities. Trends Ecol Evol 14 (2): 63-68

Bakker, J P, de Leeuw, J, van Wieren, S E (1983) Micro-patterns in grassland vegetation created and sustained by sheep-grazing. Vegetatio 55: 153-161

Bakker, J P, Grootjaans, A P, Hermy, M, Poschlod, P (2000) How to define targets for ecological restoration? Applied Vegetation Science 3: 3-6

Federal Agency for Nature Conservation (2000) Nature Data 1999. Landwirtschaftsverlag, Münster

Finck P, Klein M, Riecken U, Schröder E (eds) (1998) Schutz und Förderung dynamischer Prozesse in der Landschaft. Schr. -R. f. Landschaftspfl. u. Natursch. 56: 1-424

Kratochwil A (1984) Pflanzengesellschaften und Blütenbesuchergemeinschaften: biozönologische Untersuchungen in einem nicht mehr bewirtschafteten Halbtrockenrasen (Mesobrometum) im Kaiserstuhl (Südwestdeutschland). Phytocoenologia 11(4): 455-669

Kratochwil A, Schwabe A (2001) Ökologie der Lebensgemeinschaften. Biozönologie. Ulmer, Stuttgart. 756 pp

NOBIS M (1999) Sukzessionslinien in der Pioniervegetation auf Lockersedimentböden – Eine auf multivariater Ordination basierende Analyse von Beispielen aus der Oberrheinebene. Diss., Univ. Freiburg i. Br.

OLFF H, VERA F W M, BOKDAM J, BAKKER E S, GLEICHMAN J M, MAEYER K, DE SMIT R (1999) Shifting mosaics in grazed woodlands driven by the alternation of plant facilitation and competition. Plant Biol. 1: 127-137

ROSÉN E, VAN DER MAAREL E (2000) Restoration of the alvar vegetation on Öland, Sweden. Applied Vegetation Science 3: 65-72

WEINERT M, REMY D, LÖHNERT EP (2000) Hydrogeologische Systemanalyse des Naturschutzgebietes „Heiliges Meer" (Kreis Steinfurt, Nordrhein-Westfalen). Abh Westf Mus Naturk 62 (Beiheft): 41-172

WHITE P S, JENTSCH A (2001) The search for generality in studies of disturbance and ecosystem dynamics. Progress in Botany 62: 399-450

ZEHM A (1997) Zur Koinzidenz von Sandvegetation, ihrer Struktur und Heuschrecken-Zönosen (Orthoptera) in der hessischen Oberrheinebene. Tuexenia 17: 193-222

ZEHM A, STORM C, NOBIS M, GEBHARDT S, SCHWABE, A (2002) Beweidung in Sand-Ökosystemen – Konzekt eines Forschungsprojektes und erste Ergebnisse aus der nördlichen Oberrheinebene. Naturschutz und Landschaftsplanung 34: 67-73