Development of biodiversity during 20 years of succession as a basis for management

Summary

Universität Bremen

Zentrum für Umweltforschung und Umwelttechnologie

UFT

bioDIVEMAN

FKZ 01 LC 0005

Forschungsvorhaben im Rahmen von

BIOLOG

Entwicklung der Biodiversität während einer 20 jährigen Sukzession als Grundlage für Managementmaßnahmen

Auftraggeber

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1 Objectives

The report contributes to the understanding of ecological succession and the concomitant dynamics of biodiversity as well as to ecological restoration and to concepts for bio-monitoring. The conclusions are based on comprehensive analyses of a vast number of samples and extensive data-sets (e.g., more than 16.000 predatory mites were determined to species), that have been regularly collected since 1980. Of particular interest is the synchronous coverage of soil ecological and phytocenological data by the two authors. This allows for an integrative ecosystem-based contemplation, which might be unparalleled for such a long period of time in this intensity.

In ecological succession, staggered sequences of communities may be observed (biodiversity-dynamics). The results confirm that ecological succession is a slow ecosystem process and requires time scales which measure in decades. For a management in the sense of guided succession (restoration, recultivation), an appreciation of succession as an ecosystem process is mandatory to achieve an optimal use of the natural potential. Also, in the context of bio-monitoring, knowledge on slow successional processes is essential; these may be initiated, e.g., by in-situ soil remediation or may be modified by change of environmental conditions (e.g., climate change; permanent soil observation plots).

The results are a basis for applications in the context of an innovative restoration technology (ReviTec®). Various methodological details for a standard framework for an assessment of biodiversity and its spatio-temporal dynamics have been derived

2 Framework of the project

In most parts, the project was dedicated to the evaluation of an investigation over 20 years. Although quite a set of samples had to be analyzed from pedology, soil fauna and vegetation, it could resort on a considerable set of data, which to some extent have been taken unsalaried in the previous years in expectation of future funding. The continued availability of the site over the whole period of time and beyond has been an essential and fortunate premise. The authors could resort to the infrastructure of the *Center of Environmental Research and Environmental Technology* (UFT, http://www.uft.uni-bremen.de) of the University of Bremen; the integration of the project into the *Main Research Topic II Remediation, self purification and restoration* was very helpful and indispensable for the success of the project. Presentations on status seminars of the BIOLOG project of the BMBF and on several conferences and meetings produced inspiring and helpful discussions.

3 Planning and Development of the Project

Largely, the project complied with the time-frame given; due to the inclusion of supplementary data and due to the vast amount of data, delivery of the final report was delayed (Fig.1).

Preliminary and partial results have been presented on four conferences and meetings of the German Ecological Society (Gesellschaft für Ökologie, GfÖ), two have been published as extended abstracts

(Basel 2001, Hohenheim 2002, Cottbus 2002, Halle 2003). Publication in international journals is under way.

The final **chapter 13 Outlook** (*Ausblick*) focuses on applications of the results by discussing the long-term experiences and results in the context of monitoring and control of success and by giving future perspectives particularly in the framework of BIOLOG.

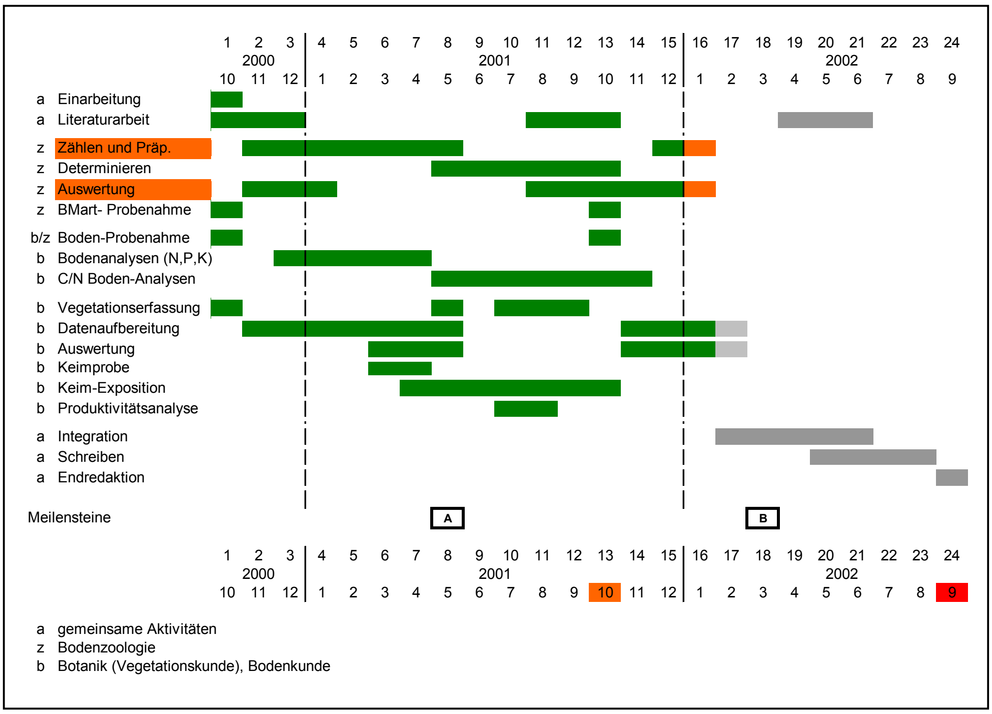

Fig. 1: Development of the project

4 Reference to objectives

Firstly, the report summarizes the state of the art of succession research and the current problems associated with assessing hazards to biodiversity. The research approach is embedded in a theoretical framework.

The experiments and the long-term investigations were conducted on a rubble and debris dump in the vicinity of Bremen, Northern Germany, which was covered with soil in 1970-1976. In 1980, the plateau of the dump was graded and two experimental sites were established, one left undisturbed for natural secondary succession (SUK), the other was recultivated with rotary-tilling and sowing of grass (REK). Ever since, the succession on the twin-plots SUK-REK was followed in regular sampling campaigns for pedology, vegetation and soil zoology.

In the introduction, specific objectives were deduced which could be answered with the data available:

- How and from where does the initial colonization by plants and animals occur? What is the role of diaspores, survivors and immigration? Are there any factors identifiable, that control colonization?

The colonization of the plateau occurs in part actively from the immediate environs (macrofauna, vegetation; hill slopes, adjacent biotopes), in majority passively by transport (wind [anemochory], animals [phoresy, zoochory]). The seed bank is of major importance for the development of the vegetation; also for soil fauna, survivors of the grading and tilling play an important role (cocoons of Enchytraeids, small microarthropods). Soil compaction, soil water (water logging) and microclimate are selecting filters, both for plants and the invertebrates investigated. Feed-back processes of facilitation point up the self organizing character of succession.

- Description and analysis of germination of plants (underground floristics).

Starting with the very beginning of secondary succession, natural selection by abiotic factors takes place. From the prevailing life history traits those are selected, the ecological constitution of which guarantees under given environmental conditions an adequate answer to the external selection pressures – in this early phase without any influence of competition! The best pre-requisite under changing und highly unpredictable initial conditions (climate, pre-treatments of site [history], small scale heterogeneity) is a multifaceted set of life history traits, i.e., a species rich seed bank.

- Influence of vegetation: is vegetation a pre-requisite for the colonization of soil mesofauna?

In secondary succession, this can be denied even for the higher soil animals investigated. However, the vegetation influences the colonization of soil fauna by the configuration of the habitat (rhizosphere in a wide sense, microclimate). Still, internal control of population dynamics seem to be very strong (cycles, asynchronies to seasons and to the establishment of vegetation).

- Is the pioneer-maximum observed, which has been described by DUNGER?

Distinct pioneer-maxima were found on the level of group-abundances of soil mesofauna, but only to a limited extent on species level. Their appearance in time is not restricted to a specific age of succession, but varies between the groups investigated and is influenced by recultivation.

- What is the relevance of experimental settlement of soil fauna for the course of succession? Are site factors or the dispersal potential limiting?

Transplantation experiments of litter and breeding of soil in the laboratory (zoological potential) substantiate for many species the constrictive role of slow dispersal. On the other hand, the conditions on the site are selective. Supporting colonization by bringing-in individuals is only promising when they are not only adapted to the site, but also belong to the specific successional stage. To what extent succession can be accelerated by supported colonization remains an open question due to the rather small scale experiments. However, the acceleration of pedozootic successional phases by recultivation might hint to conducive effects of biotope management including transplantation of elements of the biocenosis.

- Are the physical soil properties changed by biota?

Soil compaction and water infiltration are influenced by the vegetation and by burrowing animals. By a biogenic amelioration due to intensively and deep rooting pioneer plants on SUK, the soil is loosened to a greater extent as was achieved by the rotary tilling on REK. The experiments do not discriminate between plant species. Within 20 years, differentiated soil horizons have not yet developed to a larger extent and seem to be more distinct on REK than on SUK.

- Which management can be proposed for early successional phases and what does it mean for the course of succession?

Disturbances in the early phase of succession (year 1-5) result in a reset to the initial conditions. Repeated clearing experiments and encroachment in the early phase on the one hand support the assumption of the reproducibility of succession (flora and fauna) by reproducing the seed bank (reduction of historically conditioned stochasticity), on the other hand they allow for a renewal particularly of species with a transient seed bank.

Due to the intense abiotic filters in the early phase produce, gentle disturbances and changes of the initial constitution produce relatively weak responses in the species composition of the biocenosis, as is documented in the high similarities of the Gamasina taxocenosis in the first phase of succession. In the following years a conspicuous differentiation can be observed. This also is true for the vegetation. The recultivation measures encourage the development of quantitative aspects, such as cover and abundance of soil animals.

Many rare plant species of agro- and ruderal communities survive only short-lived in the seed bank of the soil. Their development is facilitated in particular by frequent disturbances, which at the same time impede expansive vegetative propagation of potential dominants by the destruction of the plants (not the seeds!). Consequently, the most species rich ruderal plant communities are found in young ruderal sites, which are characterized by many annuals, biennials or shortlived species that lack in late successional stages.

5 Most important results

The prevalent assumption, that the development of the animal communities follows that of the plants has to be differentiated considerably in the light of the results of the project. They support those authors, who highlight the importance of consumer connections and multi-level food webs for biodiversity and ecosystem function, as well as a promotion of succession and plant diversity by invertebrates.

The phytocenosis as autotrophic energy base is fundamental to the persistence of the ecosystem. The early development of soil fauna with its pioneer maxima point to their involvement in successional processes from the very beginning – at least in secondary succession. In the beginning, soil fauna is species poor, but at the same time highly abundant In the course of succession, diversity of the soil fauna groups investigated is increasing; for the Gamasina, this trend prevailed for 20 years. In contrast, the diversity of the vegetation is strongly declining in time. Consequently, biodiversity results from different, either self amplifying or opposing processes. For their understanding it is necessary to consider the structuring of biodiversity, which is accomplished by the potential of life history traits available on site and which are selected in the course of succession by biotic and abiotic interactions. Different effects of site specific environmental factors on phyto- and zoocenosis are asserted in the literature for the diversity of herbivorous insects, which is influenced as well directly as indirectly by below-ground factors.

Of high interest not only from a methodological perspective is the concomitant decrease of small scaled structural diversity in favor of larger structures and the increase of biodiversity of soil fauna (small scaled spatial reference) while plant diversity is decreasing. Asynchronicity and un-representative assessment of biodiversity, e.g. by focusing either on vascular plants or soil fauna, as well as complex and unknown or misconceived interactions do not make plausible a direct link between diversity of one system compartment (e.g., plants) and ecosystem functions.

Generalized trends are: for the development of the vegetation the increase of the spatio-temporal dimension of the phytocenotic patterns, for the development of soil mesofauna abundances a pioneer-maximum followed by fluctuations, which are only to some extent seasonal (juvenile Gamasina; Fig. 2, top).

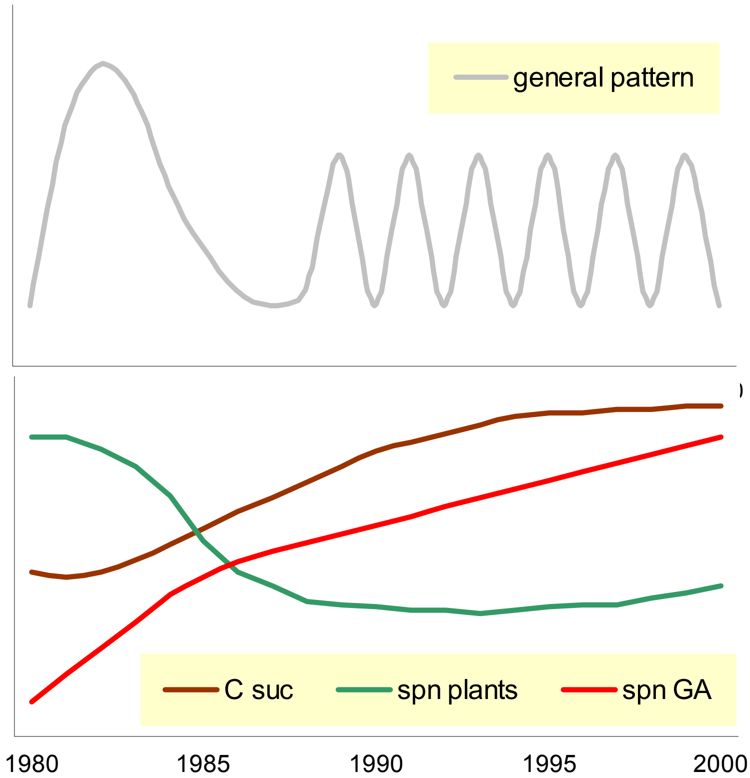

Fig. 2: Generalized trends for soil mesofauna abundances (top) and C-content of soil, as well as for species numbers of plants (spn plants) and Gamasina (spn GA)

The differences of trends of abiotic parameters (soil C and N) and of species numbers of plants and Gamasina are shown in Fig. 2 (bottom). While the development of soil mesofauna (with the exception of the Enchytraeids) starts from almost nil, the soil is not totally impoverished, in the contrary, in the investigation at hand it is well nourished and has a diverse and rich seed bank from the previous pioneer vegetation or from the soil used for covering the dump.

In Fig. 3, impact factors for the succession of plants and soil fauna are outlined. Plants and soil conditions are considered as indirect factors in respect to the soil fauna, but also indirectly feeding back on the plants themselves by facilitation. It becomes obvious that succession is an ecosystem process with a closely tight network from direct and indirect interactions, including historicity and complex spatio-temporal dynamics.

In view of the historicity of succession, including those of the starting conditions, the problems of space for time approaches become obvious (cf. Chapter 11.1.3) and highlight the importance of long-term ecological research. Considering the result, that successional phases become evident in temporal intervals in the range of 5 years, an investigation period of 20 years still covers only 4 such periods and is rather short. The increasing extent of phytocenotic patterns leads to relevant methodological problems and has to be accounted for in the research design. High-resolution near earth remote sensing may help at least for the analysis of vegetation dynamics: compared to permanent plots, it covers an expanded area. Soil zoology has to deal with increasing complexity of extended vegetation patterns with an almost insurmountable expenditure of labor, since each of the patches has to be sampled for its own. The spatially limited representativity of soil biological investigations is illustrated by the magnifying glass in Fig. 3.

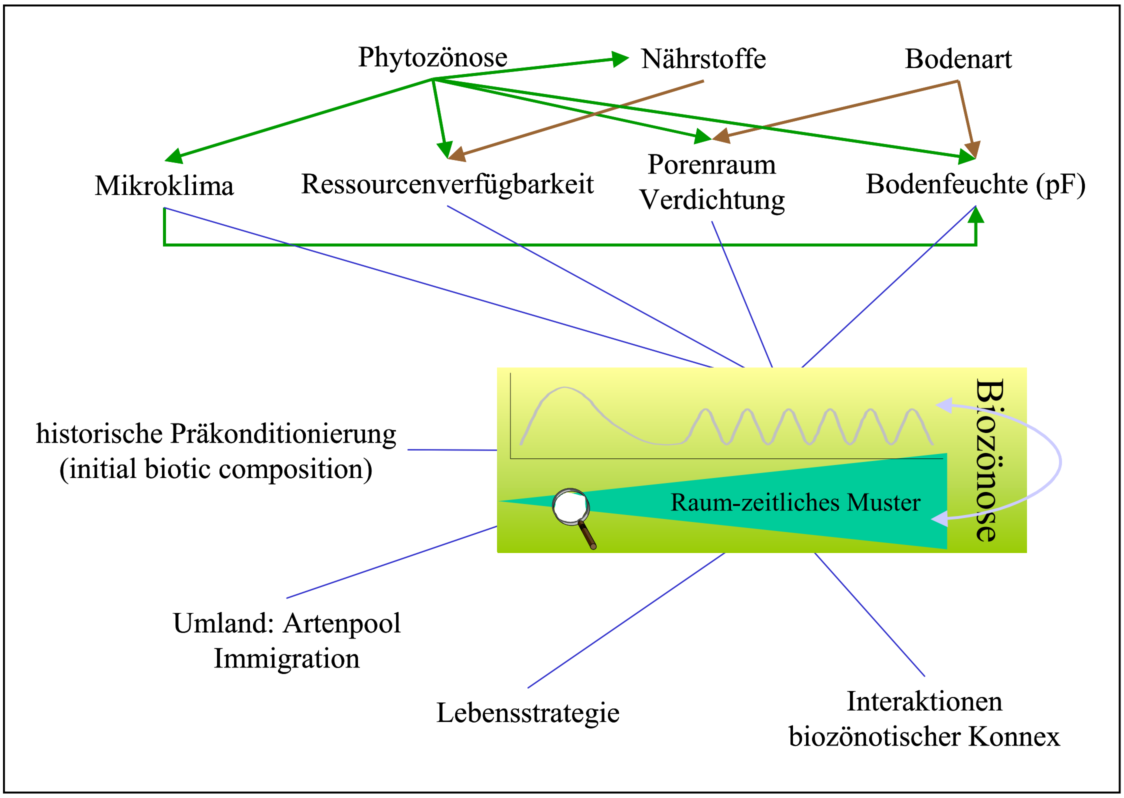

Fig. 3: Influences and regulators on the succession of soil mesofauna (yellow) and vascular plants (green) in the ecosystem context: explanations in text

The multivariate analyses explain the variability of vegetation as well as of Gamasina to a much higher extent by soil compaction and time (historicity) than by C and N content of the soil. From the comparison of the analyses of Gamasina from SUK and REK, respectively, it can be concluded that the importance of environmental factors (including biotic factors) for an investigated (partial-)cenosis is relativized by the biocenotic context: the factor *grass* is only relevant on SUK but not on REK.

These analyses confirm the relevance of the structure of the vegetation for soil fauna, while later tall forbs differ in their effects clearly from those of the initial phase (*Melilotus* spp., *Tanaceto-Artemisietum*). Also when looked at the Gamasina separately, pedologic factors as C, N and water content play an subordinate if not unimportant role. All this is superimposed by the temporal dynamics; for the vegetation as well as for the Gamasina it is more pronounced on the successional site SUK than on the recultivated site REK. This can be judged in the sense of the head start of vegetation and soil fauna on REK.

6 Conclusion and outlook

- On the basis of state-of-the-art systems theory, the theoretical foundations of succession have to be developed and consolidated. Central are aspects of self-organization and concomitantly hierarchical structure, historicity, irreversibility and a certain amount of constitutive unpredictability.
- Rehabilitation sites are islands which offer specific chances for the creation, respectively for the conservation of regional biodiversity. The report highlights the importance of the *initial biotic composition* and discusses possibilities to create by means of a mosaic sites for retreat and development for asynchronously developing elements of the ecosystem. The mosaic consists of plots of disturbances of varied size, intensity and frequency.
- As well for the assessment of biodiversity as for monitoring and control of success methodological standards have to be developed further (e.g., spatial and temporal frequency of sampling campaigns, grid pattern, assurance of representativity in extended spatio-temporal scales, pattern analysis). This includes a return to the importance of classical taxonomy, for which the preservation of specimen collections is of vital importance (cf. DIVERSITAS, GBIF).

From the project the following starting points for future research and applications are derived:

- Collembola and Oribatei only have been evaluated for the first years of succession on species level; the material waits for processing to compare the long-term dynamics of different groups of soil fauna and elaborate implications for ecosystem functions.
- Inclusion of the up to know fragmentary data-bank of *Gamasina-predatory mites* in an computer supported determination key; it should be developed in co-operation with ETI, Amsterdam.
- Verification of the possibilities deduced for supporting succession (e.g., by *facilitation, initial biotic composition*) and of the hypotheses concerning retreat and disturbances by (a) advancement and testing of the ReviTec®-approach, among others, in the context of combating degradation in arid zones and by (b) implementation of the mosaic of disturbances in a long-term experiment.