Concepts, Methods, an First Results of Ecological Investigations within the Austrian Mountain Grassland MAB-Projekt

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Introduction

The Austrian MAB-project on anthropogenous grasslands in the mountainous regions is taking into account a lot of ecosystem phenomena. Research being carried out on regional and national diversity of grassland types (Bassler et.al. 1998, Bohner et.al. 1999) and on the functioning of grassland types as ecosystems with a special focus on structural dynamics and content flows. But, of course, not all of these activities are conducted with totally satisfying intensity. Our primary aim is to get well working models linking with economic models for policy making.

In this contribution we want to show our efforts to make models working. The following aspects will be discussed:

- concepts and ideas on the ecosystem type "anthropogenous grasslands";
- availability of basic data for modelling such grasslands;
- considerations on possible links to economic models;
- first results:
  - evaluation of grassland types at the regional scale (pilot project)
  - generation and concentration of calibrated characteristics of Austrian grassland ecosystems by comparing the growth strategies of plants in two meadow types at the local scale differing in degree of management intensity (pilot project).
- Consequences and proposals for the ongoing project.

Course of work

The building of ecosystem models consists of several steps (Figure 1). Our aim was to look for a quantitative model and to elaborate quantitative links to economic models. In contrast to many economic models ecosystems never show linear relationships. Almost all functions (quantified rules) between the compartments of the system run nonlinearily.

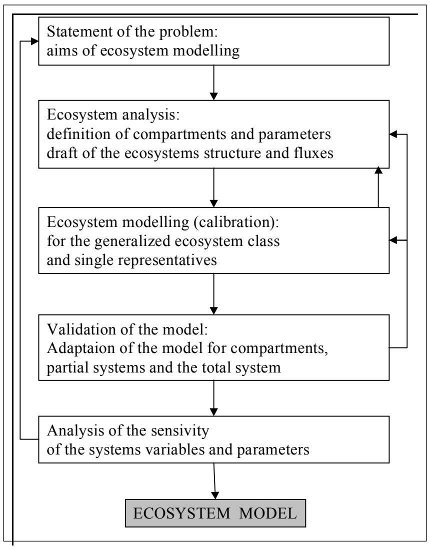

Figure 1: **Sequence of procedures in modelling ecosystems (adapted from Schubert 1991)**

We have to define biotic compartments that change nonregular from one ± stable stage to another. Such compartments may be, i.e., the single species at the population level and the associations of plants at the community level. Their changes are influenced by environmental input and output factors. We have to keep the number of variables as small as possible in describing the compartments' habit and the rules for their changes effectively.

As the first step in developing a relevant model of (anthropogenic) grassland a common ecosystem model was formulated (*Figure 2*). Using this primary model we elucidate the most important factors influencing the status and changes of structural compartments of the system (*Figure 3*). In order to measure and to look at reactions after changes the main biotic structural compartments are the plant species, their quantities, and at the secondary, agglomerative level plant functional types (PFT). Those compartments are controlled, besides others, by abiotic parameters, some of them with medium feedback effects (like soil type, humus type, soil pH, etc.), some of them ± without feedback (rainfall, elevation, etc.). Losses by gaseous emissions or soil water are only slightly influenced by biotic compartments. On the other hand, obviously there can be found intense feedback to biomass loss by cutting and

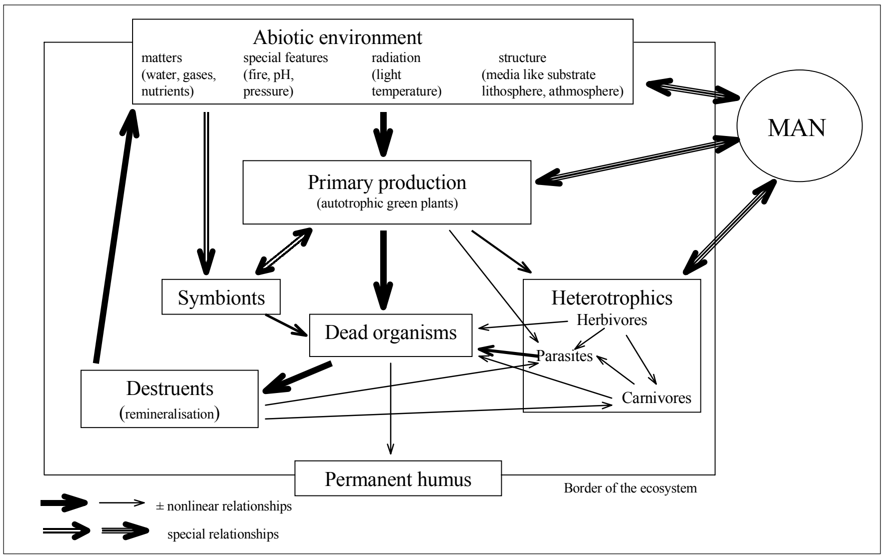

Figure 2: **Common ecosystem model, modified after Ellenberg (1996)**

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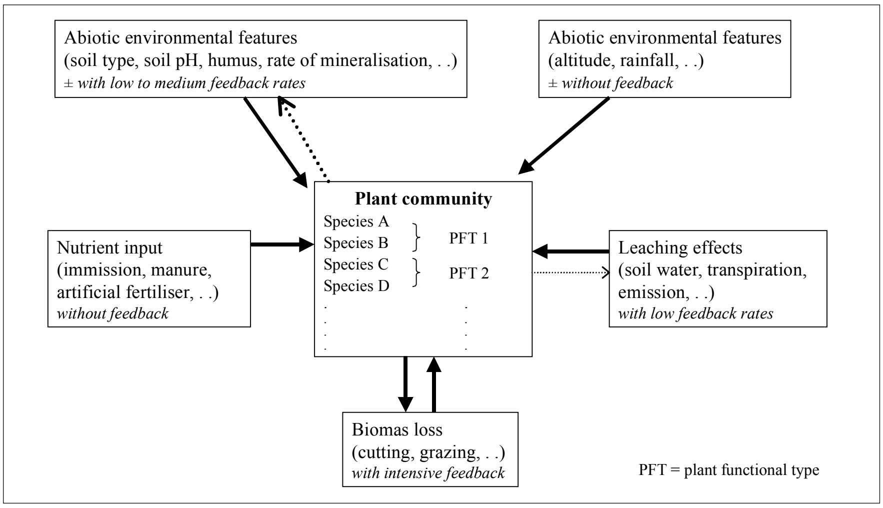

Figure 3: **Parameters controlling the system grassland**

grazing. No direct feedback effect can be maintained by the biotic ecosystem compartments with respect to nutrient inputs (immission, fertilisation, manuring).

Considering all these assumptions we analysed two representative land parcels that show big differences in the intensity of management. The lack of common knowledge about the ecological processes within these different sytems was surprising (Karrer et.al. 1998a). Besides the information found in the literature we concluded that it is neccessery to have a thorough knowlege about the processes operating in such systems in the mountainous region of Austria. We have got only little informations from the literature on the biology of all the 800 meadow plant species in the pilot project region. One may maintain that without knowing the most important details of the ecomorphological phenomena of plants it will not be possible to predict seriously the modification of grassland ecosystems under scenarios of changing management regimes.

The biotic compartments show absolute borders of existence in the region and a variety of stages (i.e., subtype variability of plant communities, phenological phases, vitality, etc.). Our meadows are composed of between 20 species to almost 100 species coexisting on plots of 5 m x 5 m. Thus, the competitive relationsships between all the species cannot be calculated with serious time effort.

The most important fluxes to measure are those of nitrogen and carbon (biomass). Carbon loss by cutting (or grazing) can be asserted to be the main disturbance factor. Nitrogen can be called the driving force and indicator for primary production at least in terrestrial ecosystems (Larcher1995). Thus carbon and nitrogen as the key elements of ecosystem fluxes should be measured at different scales in time and space. (Contents and state of C and N in the yield, in single plant species, in soil and soil water, in gaseous losses from the soil, in the atmosphere, in the fertilizer or compost.)

We decided to minimize the number of structural ecosystem characters by generating plant functional types (= PFT) in a wide and common sense (see Smith et al.1996 and compare strategy types like in Grime 1977, Kästner and Karrer 1995).

Property survey and collection

Table 1 gives a survey of data sets that are expected to be necessary for serious modelling. At least, we took into consideration most of the data types used by Oglethorpe and Sanderson (1998) and Sanderson et.al. (1995).

The diversity of community types may be stated at different geographical levels like national, regional or local. At the national scale in Austria there exists a compilation and nomenclatural evaluation of grassland communities by Mucina et.al. (1993). Indeed, this is a relatively rough compilation of most of the literature available in 1993. We found a good number of papers that were not identified by those authors or published later dealing with grassland ecology and management in Austria. Thus, we established a state of the art database comprising all the Austrian grassland literature available up to now (Karrer et.al. 1999c). We found some regional disparities in the density of communities and/or areas investigated in Austria. As an example of our results we found that only 30 per cent of the papers deal with intensively managed grassland (*Figure 4*), although these types account for about half the area of grassland in Austria (Buchgarber und Sobotik 1995).

Table 1: **Evaluable ecosystem characters to link the ecosystem model to economic ones and their availability at different scales.**

Character	Availabiltity local - regional	Availabiltity, national
Enumeration of community types	Yes	(yes)
Detailled floristic descriptions of the types	Yes	(yes)
Correlations of types to site characters	Yes	No
Number of species per type	Yes	No
Number of PFT (Plant functional types)	(yes)	No
Number of GFT (Growth form types)	(yes)	No
Number of Red Data Book species	Yes	(No)
Diversity measures (incl. eveness)	Yes	No
Rarity of the type	(Yes)	(no)
Productivity	(Yes)	(no)
Cutting regime	Yes	No
Manuring and fertilisation regime	(Yes)	No
Selective seed-input	(Yes)	No
"Age" (time for reestablishment)	(No)	No
Resiliency	(No)	No
Stability (successional trends)	(No)	(no)
Estetics	(No)	No

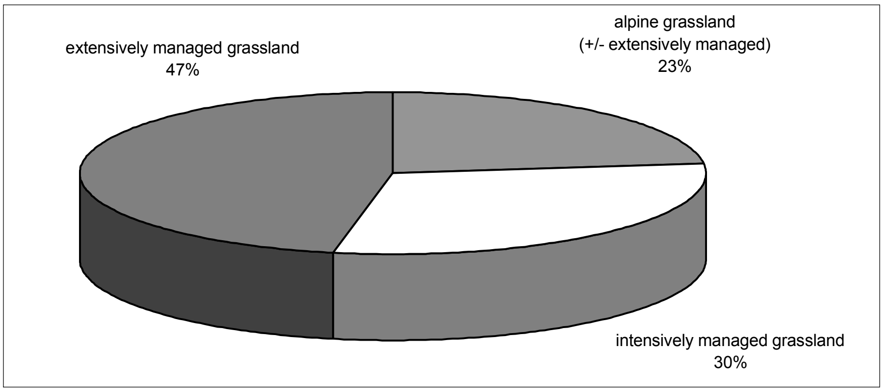

Figure 4: **Percentages of evaluated papers dealing with grasslands of different management intensity**

Figure 5 illustrates the diversity of Austrian anthropogenous grassland at different syntaxonomic levels. From all of Austria 54 different associations were documentet up to 1993. Most species-poor communities are the leas (resawed every 2 years or 3 years) consisting of 5 species up to 20 species of higher plants. The nutrient-poor meadows on dry calcareous soils cut once a year and sometimes grazed extensively turned out to be the plant associations with the highest number of species altogether. One may find one hundred and more plant species per relevée.

Doing a classification at the regional and local level we needed a review of the given classification. In *Table 2* we enumerated all the plant communities ("local associations") at the regional level of the Styrian Enns Valley near Gumpenstein. The differences between these associations one can find also in the evaluable system characterisitcs, like total species number, number of species in Red Data Books from the national (Niklfeld et.al. 1986) or the regional point of view (Zimmermann et.al. 1986).

General rules for the correlation between the presence of distinct plant communities and site characteristics or types of management are available only at the regional level, i.e., using the data from our case study in the Enns Valley (see Bohner et.al. 1999, Bassler et.al. 1998). Those data sets enable us to get hints on the driving forces (site characteristics, management types) for the grassland diversity and possible changes in the future. *Figure 6* shows an example of how to illustrate the correlation of site characteristics to the floristic diversity using the ordination space of a detrended correspondence analysis (see Jongman et.al. 1987); i.e., the positions of the relevees were placed between the first and the second axis where some enviromental factors are plotted as vectors to illustrate the part of the floristic space variance they account for.

Analysing two concrete ecosystems as examples we collected a lot of crucial ecomorphological features of the grassland species to get relevant data for generating PFTs (see *Table 1*). In many cases it made no sense to use biological databases (like that of Fitter and Peat 1994), but to get our own primary data set. (Karrer et.al. 1998a, Karrer et.al. 1998b, Karrer und Graf 1999a,b, Karrer und Graf 1999b). The behaviour of many meadow plants in Austria differs to a great extend from that in Great Britain or Northwest Europe.

Our collection of data on their growth form characteristics, growth strategy, reproductive strategy, diaspore behaviour (seed bank, place and time of germination), rhythmics of development, meristem activities and determinations, etc. are managed in a data base for generating plant functional types using standardized and operational techniques (see Westoby and Leishman in Smith et.a. 1996) in the future.

Those functional types should serve as the basic modules of the ecosystem compartments in our modelling concepts.

Some "environmental" variables are plotted as vectors from the mean of the data set (pH in the upper soil and gradients of moisture, nutrient supply and temperature that are characterized by the importance of the respective ecological indicator values.

Meadow plants develop in distinct populations (communities) following seasonal and ontogenetic rhythms. During

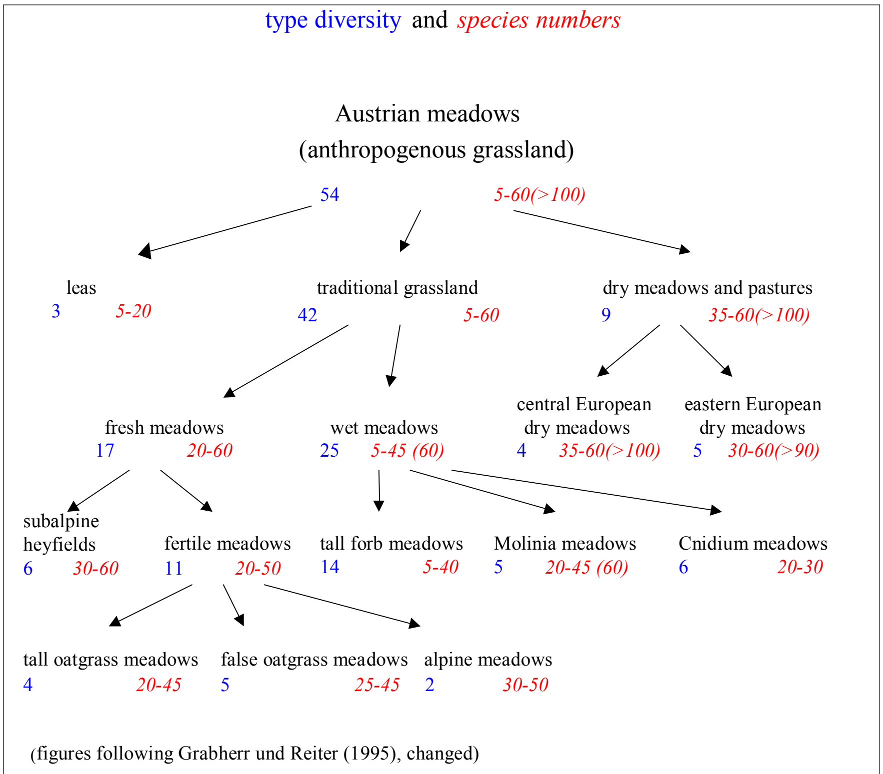

Figure 5: **Vegetation type diversity at the levels between classes and associations (left figures, standard) and species numbers (right figures, italic) of Austrian anthropogenous grassland.**

Table 2: **Grassland communities of the pilot project region in the Styrian Enns Valley between Oppenberg and Tauplitz (Styria): Evaluation parameters for nature protection: species number, number of threatened species at different geographical scales.**

community group (management characters)	**plant community**	average species number (incl. mosses)	nr of threatened plant species. (+ mosses) Austria	nr of threatened species Styria.
nutrient rich grassland (cut 2 to 4 times,- rarely once incl. soft grazing after cutting,	Frauenmantel-Glatthaferwiese	± 43	0	0
	Kriech-Schaumkresse-Goldhaferwiese	± 44	0	0
	Waldstorchschnabel-Goldhaferwiese	± 46	0	0
	Kohldistel-Schlagenknöterichwiese	± 44	0	0
	Nährstoffreiche Weidelgrasweide	± 36	0	0
	Weißklee-Rispengras-Mähweide	± 43	0	0
	Raygras-Luzernenbestände (Feldfutter)	± 33	0	0
	Rotschwingel-Straußgraswiese	± 51	0	0
± dry, nutrient poor grassland (cut once, some softly grazed)	Trespenwiesen-Brache	44-76	2	2
	Kreuzenzian-Trespenwiese	45-70	3	3
	Quirlsalbei-Trespenrasen	55-88	4 (5)	4
	Schillergras-Rotschwingelrasen	50-64	0	0
	Betonien-Narzissenwiese	73-89	1	1
	Kohldistel-Narzissenwiese	68-87	2	2
	Rotschwingel-Kammgrasweide	41-95	3 (5)	3
	Waldseggen-Bürstlingrasen	46	0	0
	Goldruten-Bürstlingrasen	39-59	0	0
nutrient poor pastures	Bergseggen-Schillergras-Kammgrasweide	61-88	2 (3)	2
	Goldhafer-Zittergras-Kammgrasweide	55-89	3 (4)	3
	Goldhafer-Weidelgras-Kammgrasweide	52-69	0	0
	Kammgrasweide mit dom. Rotschwingel	38-55	0 (1)	0
	Bürstlingreiche Kammgrasweide	49-92	1	1
wet meadows and bogs (often cut 1 or 2 times)	Kalk-Flachmoore	± 52	0-2 (0-2)	0-3
	Iriswiesen	± 50	0-3 (0-3)	0-3
	Großseggen-Flachmoore	± 22	1-4 (1-7)	0-1
	Hochmoore (bogs and fens)	± 31	2-9 (3-17)	0-8

their lifespan our meadow plants run different developmental stages that are mostly described by the gradual accumulation of biomass and/or by their regeneration phases. What we try to do can be called a **detailled morphological description of the structural development of plants in space and time**.

Of course, we also take into account other aspects like:

- resource uptake strategies;
- allocation processes within the plants (like storage compounds);
- fluxes within the ecosystem.

The relevant time scales to consider are:

- seasonal changes within a year,
- the ontogeny of a taxon (sometimes called individual lifespan),
- the taxons phylogeny.

The latter is not an object of this report and may be discussed somewhere else.

Semidry meadows:

1	Astragalus cicer- Bromus erectus-community
2	Gentiana cruciata-Bromus erectus- community
3.1	Salvia verticillata-Bromus erectus- community with Ononis spinosa
3.2	Salvia verticillata-Bromus erectus- community with Geranium sylvaticum
4	Festuca rubra agg.-Koeleria pyramidata- community
Narcissus meadows:	
5	Betonica officinalis-Narcissus radiiflorus- community
6	Cirsium oleraceum-Narcissus radiiflorus- community
Pastures on sites of low to medium nutrient supply:	
7	Carex montana-Koeleria pyramidata- community
8.1	Festuca rubra agg.-Cynosurus cristatus- community with Carex sylvatica
8.2	Festuca rubra agg.-Cynosurus cristatus- community with Lolium perenne
8.3	Festuca rubra agg.-Cynosurus cristatus- community with dominant Festuca rubra agg.
8.4	Festuca rubra agg.-Cynosurus cristatus- community with Nardus stricta
Nardus grasslands:	
9	Carex sylvatica-Nardus stricta- community
10	Solidago virgaurea-Nardus stricta- community

Nevertheless, speciation processes in man-made grasslands are of great importance.

The tools for the serious description of the development of plants with respect to their environment can be derived easily from the classical morphology approach, i.e., from functional morphology and from growth form analysis but also from classical ecosystem analysis (analysis of soil and climate).

First, we started with a more or less detailed verbal description of morphological features at the different developmental stages during lifespan following mainly an unpublished concept of Meusel et.al. (1973).

In *Table 3* there is a list of the main terms that stand for the groups of characteristics we are taking into account.

The starting point is always the phase of germination and establishment of a new plant; next is the development of the shoot system, the leaf system, and the root system. As meadows consist mostly of perennial species the "permanent shoot system" is described separa-

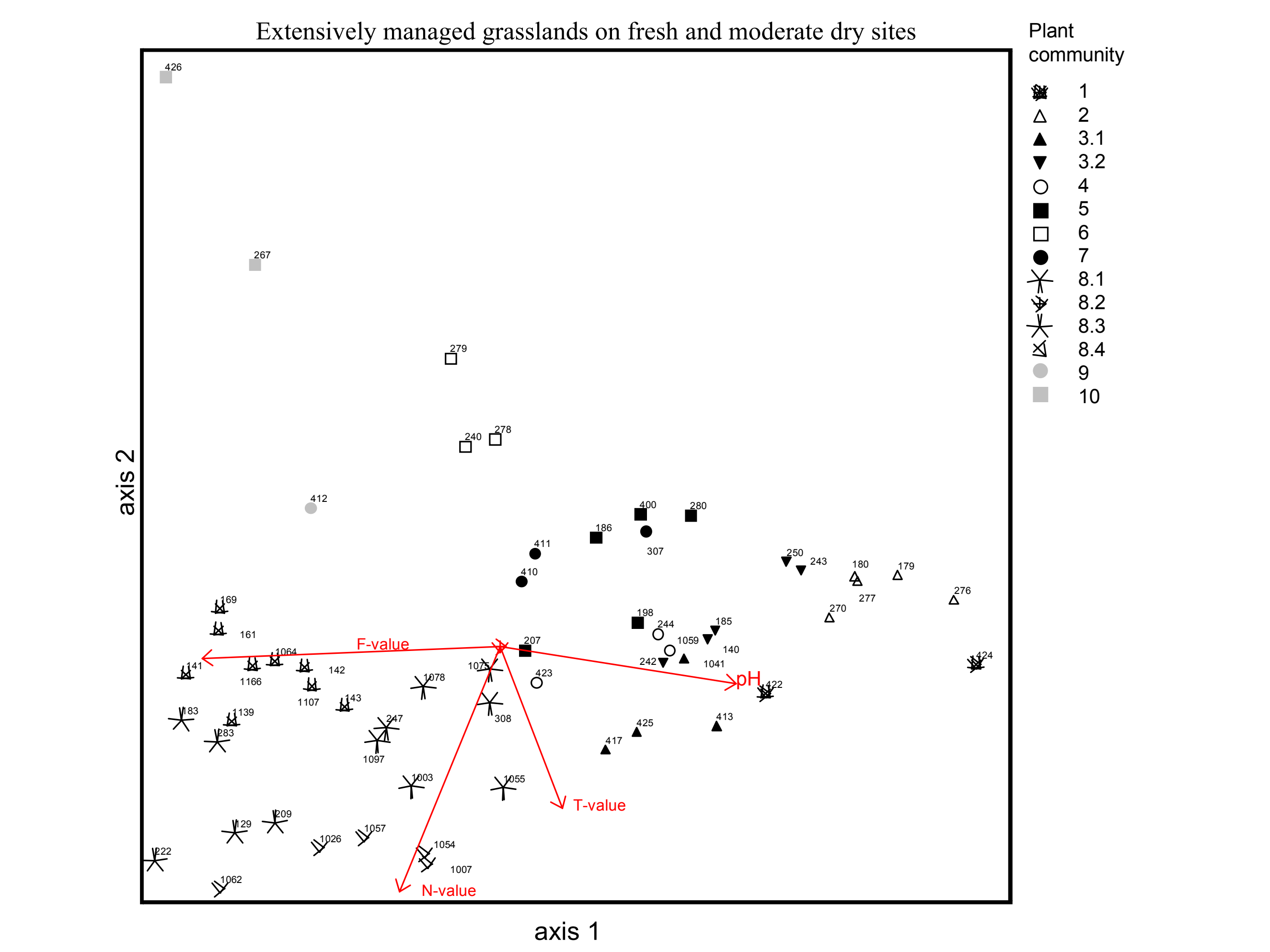

Figure 6: **Ordination of 59 releveès from extensively managed grasslands on fresh to semi dry sites using axis 1 and 2 of a detrended correspondence analysis**

tely. By this we understand the surviving part of the plant (except seeds) that bears the meristems for the continuation of growth in the next season. The first ten terms may be called the basal ecomorphological description, the latter terms serve as functional interpretations of the first group of characters.

To get primary results of this ecomorphological screening we compared a Bromus erectus meadow and a Trisetum flavescens meadow, differing especially in the intensity of management (for details of the charaters see the relevees in the appendix). The diversity of growth form types generated according to Kästner und Karrer (1995) is documented in *Table 4*. Brometum and Trisetetum community differ clearly in the total number of growth form types (32 to 22) but this result is positively correlated to the total species number too. More interesting results one can find in the details. For example, the number of species with inserting rosette leaves (at least during parts of the development) ist not higher in the poor Brometum than in the Trisetetum. This result was not expected, because nutrient rich meadows were told to consist of a lower number of rosette leaved plants than nutrient poor ones in the literature (see i.e., Ellenberg 1996). This somewhat surprising result will bechecked in the future case studies again.

Table 3: **Main character groups for ecomorphological analysis of grassland ecosystems**

germination, seedling phase, establishment growth
stem morphology and developmentS
leaf morphology and development
root system and development
permanent shoot system
flowering processes, inflorescences
diaspore and seed ecology
reproduction (vegetative, generative)
rhythmics (of growth and development)
age (lifespan, life cycles of organs or the whole organism)
population dynamics (demography)
circumscription of the ecological niche with respect to structural changes in space and time (stress factors, competitors)
allocation patterns within the plant (storage components, productive components like nitrogen)
strategy typology (r- and K-selektion, C-, S- and R-strategy, growth form typ)
adaptive particularities (hydrophytes, lianes, epiphytes, parasites, ...)

Table 4: **Comparison of the growth strategy patterns of two grassland types differing very distinct in their management intensity (shortcut descriptions see in the appendix)**

Growth form type	Brometum	Trisetetum
Großbaum	1	0
Halbstrauch	1	0
Halbstrauch-Pleiokormstaude	2	0
Ausläufer-Wurzelknollenstaude	1	0
Halbrosetten-Ausläuferstaude	2	0
Erosulat-Ausläuferstaude	2	3
Erosulat-Pleiokorm-Ausläuferstaude	1	0
Halbrosetten-Ausläuferstaude	0	2
Ausläufergrasstaude	4	6
Ausläufergras-Rhizomstaude	3	0
Kriechtriebgrasstaude	0	1
Ganzrosetten-Kriechtriebstaude	1	1
Halbrosetten-Kriechtriebstaude	2	2
Kriechtriebstaude	0	2
Erosulat-Kriechtriebstaude	0	1
Legtriebstaude	1	1
Halbrosetten-Pleiokormstaude	6	2
Halbrosetten-Pfahlwurzel-Pleiokormstaude	5	1
Halbrosetten-Pfahlwurzelstaude	1	0
Halbrosetten-Wurzelsproß-Pleiokormstaude	1	0
Halbrosetten-Rübenstaude	1	2
Halbrosetten-Monopodialrosettenstaude	3	1
Halbrosetten-Monopodialrosetten-Pfahlwurzelstaude	1	0
Ganzrosetten-Pleiokormstaude	2	2
Ganzrosetten-Pfahlwurzelstaude	2	1
Dilatations-Horststaude	1	2
Dilatations-Lockerhorststaude	1	0
Wenigtrieb-Horststaude	1	1
Locker-Horststaude	3	3
Kompakt-Horststaude	0	2
Erosulat-Wurzelkopf-Pleiokormstaude	1	1
Erosulat-Pfahlwurzel-Pleikormstaude	3	0
Erosulat-Achsenknollen-Staude	1	0
Achsenknollenstaude	1	0
Halbrosetten-Hapaxanthe	3	1
Halbrosetten-Rübenhapaxanthe	0	1
Orthotrop-Erosulat-Hapaxanthe	3	0
Parasiten	1	0
Total number of species	62	39
Total number of types	32	22
Nr. of species without rosettes	19 (30,6 %)	13 (33,3 %)
Nr. of semirosette species	38 (61,3 %)	22 (56,4 %)
Nr. of rosette species	5 (8,1 %)	4 (10,3 %)

Concluding remarks

Seeking some concepts and models to generalize all over the Austrian anthropogenous grassland we found no sufficient data base for a model of national validity. Thus we should work out models at some local or regional scale and validate this model in representative regions of Austria.

From the ecological point of view we must state that there is a need for a solid data base on the ecology of the single grassland plant species but also for the correlations between floristic phenomena (species, communities and deducted terms like diversity indices, grassland ecosystem stability, sustainability, etc.) and the characters if site and management intensity.

Thus we should concentrate our projects activities in the next years to very few stands but work there with enlarged intensity.

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Appendix

Gentiano-Brometum:

nr of vascular plants: 62	**nr of mosses:** 2
date: 16.06.1997	**place:** Extensivwiese
area: 5 x 10 m	**site:** Pz. Nr. 479 - KG Aigen/Ennstal
mesorelief: middle slope	**microrelief:** puffered
aspect: S	**inclination:** 30°
geology: Kulmmassiv, calcareous schist	**soil type:** typical Pararendsina
depth: 7 - 10 cm	**maximum height:** 80 cm
height (average): 25 cm	**coverage K:** 84 %
coverage M: 60 %	**coverage naked soil:** 5 %
overlapping coverage (K): 120 %	**cutting frequency:** 1

4a	Bromus erectus	2b	Trifolium montanum	1a	Medicago falcata
2b	Brachypodium pinnatum	2	Leucanthemum ircutianum	1a	Viola rupestris
2b	Carex caryophyllea	2	Thymus pulegioides	+	Arenaria sepyllifolia
2a	Arrhenatherum elatius	2a	Dianthus carthusianorum	+	Astragalus glycyphyllos
2a	Avenula pubescens	2a	Prunella grandiflora	+	Campanula patula
2a	Dactylis glomerata	2a	Silene nutans	+	Carlina acaulis
1b	Anthoxantum odoratum	1b	Achillea millefolium agg.	+	Centaurea scabiosa
1b	Carex ornithopoda	1b	Ajuga genevensis	+	Erigeron acris
1b	Luzula campestris	1b	Knautia arvensis	+	Gentiana verna
1	Koeleria pyramidata	1b	Linum carthaticum	+	Helianthemum ovatum
1	Trisetum flavescens	1b	Lotus corniculatus	+	Polygala amarella
+	Briza media	1b	Pimpinella saxifraga	+	Potentilla pusilla
+	Poa angustifolia	1b	Plantago lanceolata	+	Ranunculus acris
		1b	Ranunculus bulbosus	+	Silene vulgaris
		1b	Rhinanthus minor	+	Taraxacum officinale
		1b	Veronica chamaedrys	+	Vicia cracca
		1	Anthyllis vulneraria	r	Botrychium lunaria
		1	Hieracium pilosella	r	Campanula rapunculoides
		1	Lathyrus pratensis	r	Gentiana cruciata
		1	Polygala comosa	r	Orobanche caryophyllacea
		1	Trifolium pratense	r	Orobanche gracilis
		1a	Arabis ciliata	r	Prunus avium
		1a	Arabis hirsuta	r	Trifolium campestre
3b	Abietina abietinella	1a	Galium album	r	Verbascum austriacum
3a	Rhytidium rugosum	1a	Leontodon hispidus		

Geranio-Trisetetum:

nr of vascular plants: 39	**nr of mosses: 2**
date: 16.06.1997	**place:** Intensivwiese
area: 5 x 10 m	**site:** Pz. Nr. 479 - KG Aigen/Ennstal
mesorelief: plain	**microrelief:** puffered
aspect: S	**inclination:** 3°
geology: Kulmmassiv, calcareous schist	**soil type:** brown Pararendsina / brown soil
soil depth: 30 - 35 cm	**maximum height:** 120 cm
height (average): 38 cm	**coverage K:** 100 %
coverage M: 5 %	**coverage naked soil:** 0 %
overlapping coverage (K): 380 %	**cutting frequency:** 3

4b	Trisetum flavescens	3a	Trifolium repens	1	Veronica serpyllifolia
3	Poa angustifolia	2b	Pimpinella major	+	Rumex acetosa
3a	Dactylis glomerata	2b	Plantago lanceolata	+	Vicia sepium
2b	Festuca pratensis	2a	Crepis biennis	+	Lathyrus pratensis
2	Deschampsia cespitosa	2	Bellis perennis	+	Leucanthemum ircutianum
2a	Lolium perenne	2	Trifolium pratense	+	Stellaria graminea
2	Poa trivialis	2a	Glechoma hederacea	+	Anthriscus sylvestris
1a	Arrhenatherum elatius	2a	Veronica chamaedrys	r	Campanula patula
1a	Holcus lanatus	2b	Ranunculus acris	r	Carum carvi
1a	Agropyron repens	2b	Leontodon hispidus		
1a	Festuca rubra	2a	Taraxacum officinale		
+	Alopecurus pratensis	2a	Achillea millefolium		
r	Bromus erectus	2	Cerastium holosteoides		
r	Anthoxanthum odoratum	1b	Prunella vulgaris	2a	Brachythecium sp.
r	Bromus hordaceus ssp. hord.	1	Vicia cracca	+	Plagiomnium cf. affine