Comparative ecological and functional analysis of grazing systems

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Chapter 1

General introduction

Development of anthropogenic grasslands in Central Europe

Semi-natural grasslands are among the most species-rich and endangered ecosystems in Central Europe (Poschlod & Schumacher 1998; Poschlod & WallisDeVries 2002; WallisDeVries *et al.* 2002). There are only few naturally treeless landscapes such as lakes, swamps, dunes or rocky and alpine areas. The development of grasslands in Europe started without any impact of humans. It can be assumed that ancient forests were at least locally not closed or open islands within already existing forests. First human settlements possibly have been established at these open sites (Poschlod 2015). This hypothesis is supported by the “Steppenheidetheorie” (Gradmann 1901; 1933) and the “Megaherbivore Theory” (e.g. Vera 2000, see also below). According to recent findings of Pokorny *et al.* (2015) the landscape was a patchy mosaic consisting of open pine-birch forests and steppe grasslands which confirms the above mentioned hypotheses.

Human settlement started during the Neolithic period and included the domestication or introduction of cattle, sheep, goats and pigs in the fertile crescent (Poschlod 2015). Since then, anthropogenic habitats like arable land and pastures (heathland) have developed. Pastures resulted from clear-cutting, application of fire and forest grazing (Roberts 1998; Behre 2008; Poschlod 2015). During the Bronze Age wetlands have been increasingly used due to the domestication of horses (Küster 1995). Hodgson *et al.* (1999) assumed that mowing of grasslands happened soonest at the Iron Age. During the Roman Period mowing was taking place on larger scale and the first meadows occurred (Knörzer 1979; Körber-Grohne 1983; 1990; Hodgson *et al.* 1999). The next expansion of grassland happened in the Medieval Age when the cultivated area in Central Europe achieved their biggest extent (Bork *et al.* 1998). For example, even moorlands were used as meadows or pastures (Poschlod 2015). However, there was no strict separation between meadows and pastures. The meadows often were grazed in spring before mowing occurred and after mowing in autumn (Kapfer 2010).

In 19th century the principle of segregation was established and forest grazing was forbidden (Beck 1996). Also, collectively used areas (e.g. “Allmende”, “Hutweiden”) were given up and livestock were increasingly housed indoors (Poschlod 2015). Since then, grasslands often have been mown twice a year and the cultivation of grasslands became very important. There was even the profession of meadow “architects” which had existed until the middle of the 20th century (Poschlod 2015). Due to animals in stables more dung was available and therewith nutrient supply improved. Still, the biological diversity had remained very high until the 1960s. The use of mineral fertilizer increased since mineral oil became cheaper after the Second World War. Therefore, foraging value and cutting frequencies increased (Poschlod 2015). The raising industrial progress since the 1950ies mainly has been replaced the traditional forms of land use (e.g. sheep herding) (Poschlod & WallisDeVries 2002; Poschlod 2015).

Due to the diverse low-intensity land use semi-natural grasslands accumulated a huge amount of biodiversity (Habel *et al.* 2013). The long continuity of management contributed to their high species richness (Austrheim *et al.* 1999; Pärtel *et al.* 1999; Cousins & Eriksson 2002; Poschlod 2015). Since the middle of the last century semi-natural grasslands have been becoming threatened when intensification of agricultural practice increased. They have been fertilized, afforested or abandoned (Poschlod & Schumacher 1998; WallisDeVries *et al.* 2002). The maintenance of remaining semi-natural grasslands by management is one main task in European nature conservation efforts (Kahmen & Poschlod 2008b).

“Megaherbivore Theory”

The “high-forest” hypothesis was proposed by vegetation historians over 50 years ago (Firbas 1949; 1952) and has been widely accepted by forest ecologists and conservationists. This hypothesis states that temperate Europe was dominated by high, closed-canopy, mixed-deciduous primeval forests before settlement of humans. In contrast, since the beginning of 1990ies the “Megaherbivore Theory” has been discussed (e.g. Geiser 1992;

Bunzel-Drüke *et al.* 1994; Beutler 1996; Bunzel-Drüke M. 1997; Vera 2000; Bunzel-Drüke *et al.* 2008). This theory formed an alternative basis for understanding the current biodiversity and landscape development in recent years (Bunzel-Drüke *et al.* 2008).

The "Megaherbivore Theory" states that in Central Europe a diverse natural landscape once existed and that it has been shaped in major parts by large herbivores (e.g. mammoth, elephant, rhinoceros, aurochs, wisent and wild horses). Probably, the landscape was a spatially and temporally highly heterogeneous and dynamic mosaic of all possible intermediate stages between forest and steppe (e.g. Bunzel-Drüke M. 1997; Bunzel-Drüke *et al.* 1999). Large herbivores had a key part within ecosystems and created the livelihoods for several other animal and plant species. Closed forests could only develop on islands, slopes or swamps where large herbivores rarely or never passed by (Schüle & Schuster 1997). At the end of Pleistocene a lot of megaherbivore species disappeared. This extinction was often explained by hunting through humans (e.g. Martin & Wright 1967; Bunzel-Drüke *et al.* 1994; Beutler 1996; Bunzel-Drüke M 1997). Some species like aurochs, wisent and wild horse only distinct in Holocene and formed vegetation and landscape even after the glacial period (Vera 2000). Due to extinction or displacement of large herbivores their domesticated descendants (domestic cattle and horses, pigs, sheep, goats etc.) were responsible for the creation of landscape (Bunzel-Drüke *et al.* 2008). For instance, highly structured and species rich "Hudelandschaften" were built (Pott & Hüppe 1991). Apart from "overkill-hypothesis" (Martin & Wright 1967) pollen analysis represents the basis for "Megaherbivore Theory". Pollen analyses showed co-occurrence of light demanding (oak, hazel) and shade tolerant trees (beech, ash, elm, hornbeam, maple, lime - only *Tilia platyphyllos*). The strong presence of hazel in the forests of Central Europe until about 3000 years ago is a strong evidence for semi-open landscapes because the hazel does usually not flower in closed forests. Furthermore, it was hard for the oak to rejuvenate in closed forests (Vera 2000).

However, there are also arguments against the "Megaherbivore theory". Firstly, the palynological records can be interpreted in a different way supporting the hypothesis of closed forest landscape (Svenning 2002). The landscape must have consisted of closed forest mainly, because in pollen analysis only small proportions of non-forest species were found (Litt 2000; Birks 2005). Secondly, von Königswald (2000) argues that the density of human population was not high enough to extinguish all mega herbivores by hunting. Recent findings of Pokorny *et al.* (2015) that landscape was a patchy mosaic consisting of open pine-birch forests and steppe grasslands which confirms the “Megaherbivore theory”. Also Hajkova *et al.* (2011) showed that semi-dry grasslands have existed since the last glacial period. The “Megaherbivore theory” is the basis for the concepts “Semi-open Pasture Landscape” and “New Wilderness” (see below).

The concepts of “Semi-open Pasture Landscape” and “New Wilderness”

“Semi-open Pasture Landscape”

The concept of “Semi-open Pasture Landscape” (Figure 1-1) is based on certain traditional forms of land use (e.g. forest grazing) (e.g. Harding & Rose 1986; Schwabe & Kratochwil 1987; Assmann & Falke 1997; Hüppe 1997). Currently discussed theories about the influence of natural herbivore communities (e.g. aurochs, wisent, wild horse, elk, red deer) on the structure of primeval forests are also of importance (see also above). Livestock is kept all year round in a “semi-wild” manner in fenced areas. Robust breeds of domestic livestock (cattle, horses, sheep, goats) are used. Little livestock care is needed and therefore costs (e.g. personal costs, care costs) remain comparatively low. Only at the beginning of the grazing experiment high costs are required for fence building and purchasing the animals (Riecken *et al.* 1997). An area of adequate size is required to guarantee sufficient fodder for the livestock. It is also important to combine different habitats (e.g. areas with low and high productivity) to ensure enough food supply all year round. A landscape with open and locally intensively used areas and various stages of succession is expected (Finck *et al.* 2002). This management concept is easy combinable with other forms of utilization (e.g. temporarily more intense grazing, complementary grazing with different grazers) or specific management methods (e.g. mowing, shrub clearance) (Härdtle *et al.* 2003). It is accepted that the development is not precisely controllable and results are not predictable (Riecken *et al.* 2004).

Figure 1-1 Schematic overview of the concept "Semi-open Pasture Landscape" (Riecken 2004, modified).

"New Wilderness"

The concept of Wilderness was gaining importance in Europe during recent years and is an intensively discussed issue. The Wild Europe Initiative elaborated the following "working definition" of Wilderness: "A wilderness is an area governed by natural processes. It is composed of native habitats and species, and large enough for the effective ecological functioning of natural processes. It is unmodified or only slightly modified and without intrusive or extractive human activity, settlements, infrastructure or visual disturbance." (www.wildeurope.org). However, it is undisputed that in large parts of Central Europe and especially in Germany, there are almost no areas corresponding to true wilderness. This relates to the protection and re-establishment of natural dynamic processes and therefore creation of "New Wilderness" (Figure 1-2) areas (Riecken *et al.* 2004). The "New Wilderness" concept is based on the structure of primeval forests under the influence of large herbivores (see also above). This concept tries to preserve open landscape habitats and to re-establish wood pasture (Finck *et al.* 2002). For shaping the landscape wild animals (e.g. Przewalski horses, red deer, roe deer, elk etc.) or robust breeds (e.g. Heck cattle, Konik horses serving as substitutes for their extinct ancestors) are often utilized (Bunzel-Drüke *et al.* 2008). The use of animals as tools for Nature Conservation and the use as uncontrolled parts of the ecosystem are merging (Bunzel-Drüke *et al.* 1999). The enclosures for "New Wilderness" projects have to have an adequate size to guarantee an appropriate food supply. Almost no effort for animal care is needed because a development without or with only little human disturbances in these areas is desirable. A landscape with various stages of succession and of smaller open, locally intensively used areas is expected. In the beginning high costs are required for fence building and for founding herds. These are followed by very low subsequent costs (Finck *et al.* 2002). As well as for the “Semi-open Pasture Landscape” approach results and development of landscapes are not predictable.

Figure 1-2 Schematic overview of the concept “New Wilderness” (Riecken 2004, modified).

Grazing as a management tool for Nature Conservation

Since the middle of the last century the intensification of agricultural practice has been increasing and semi-natural grasslands have been fertilised, afforested or abandoned (Nitsche & Nitsche 1994; Poschlod *et al.* 1998; WallisDeVries *et al.* 2002, see also above). The maintenance of remaining semi-natural grasslands by management is one main task in European nature conservation (Kahmen & Poschlod 2008b). Traditional management methods (e.g. mowing, mulching) encounter their logistical and financial limits and grazing represents possible economically and ecologically viable alternatives for the conservation of open areas (Riecken *et al.* 1997; Kämmer 2001; Lühr 2007). Grazing as a management tool for nature conservation has been progressively discussed since the 1980ies. Particularly in the last years grazing aroused increasing interest in public and for experts (e.g. Redecker *et al.* 2002; Finck *et al.* 2004; Schley & Leytem 2004; Bunzel-Drüke *et al.* 2008; Rosenthal *et al.* 2012). Grazing with domestic animals practically constitutes an ecological process in ecosystems that have been developed with the presence of large herbivores (Papanastasis 2009). The adaption of extensive grazing systems to historical systems and large-scale, mostly uncontrolled grazing systems with large herbivores are tested. Both strategies are oriented towards the ideal of a semi-open landscape with fluent transitions between open land and closed forest. This concept of semi-open landscape is based on traditional land use forms (Assmann & Falke 1997) and on the so-called “Megaherbivore Theory” (e.g. Vera 2000, see also above).

Grazing systems were already analysed in different habitat types and mainly positive effects on biodiversity, vegetation structure, species richness and initiation of natural processes could be detected (Olff & Ritchie 1998; Bokdam & Gleichman 2000; Pykälä 2000; Adler *et al.* 2001; Zahn *et al.* 2002; Bokdam 2003; Pykälä 2003; Stammel *et al.* 2003; Schley & Leytem 2004; Jewell *et al.* 2005; Süss 2005). Loucougaray *et al.* (2004) noted that generally large herbivores grazed in a patchy way and produce a mosaic of vegetation. Intensively grazed areas alternated on small-scale with less intensively grazed areas (Bromisch 2005; Rüther & Venne 2005). Therefore, promotion of high structure diversity and in consequence species richness takes place (Zahn *et al.* 2001; Loucougaray *et al.* 2004). Herbivores alter the spatial structure of the affected ecosystem including changes in habitat diversity. Grazing creates germination niches in the bare soil (Grubb 1977) and reduces the dominance of competitive species by trampling. Thus, grazing has a direct effect on the structure and organisation of plant communities (Noy-Meir *et al.* 1989; Sternberg *et al.* 2000) and additionally, on a huge number of ecosystem functions (Adler *et al.* 2001) (Table 1-1). Grazing causes higher plant species diversity due to the selective phytomass extraction by herbivores (Hadar *et al.* 1999) in contrast to mowing where every part of an area is treated in the same way. Thereby some plant species or certain plant functional types are promoted and others are disadvantaged depending on the preferences of used livestock (Sternberg *et al.* 2000; Hülber *et al.* 2005). Furthermore, nutrient fluxes can be influenced directly or indirectly (Frank & Evans 1997; Bakker *et al.* 2004). Grazing can also create microsites due to trampling, scratching or rolling (Lamoot *et al.* 2004). This is very important for low-competitive plant species which need patches of bare ground (Bullock *et al.* 1994; Bakker 2003). Altogether, the creation of a mosaic of patches is one of the most important mechanisms by which herbivores affect ecosystems (Bakker 2003).

Table 1-1 Impacts of large domestic herbivores on biotic and abiotic key processes for biodiversity on different spatial scales (Rosenthal *et al.* 2012, modified).

Spatial scales	**patch**	**community**	**landscape**
Herbivore impacts	trampling (hoof prints, plant damage) selective feeding of plant species/plant parts faces deposition	trampling (soil compaction, hummock- hollow complexes, soil erosion) selective feeding of plant communities	trampling (livestock trails) gradients of grazing intensity selection of preferential sites (e.g. watering points) (directed) diaspore dispersal
Biotic and abiotic processes	germination establishment vegetative regeneration of plant tissue	competition dominance coexistence succession nutrient relocation	colonization landscape structuring nutrient relocation

Nowadays, projects using large herbivores to maintain semi-natural landscapes take place all over Europe. The Netherlands plays a leading role by the implementation of extensive large-scale year-round grazing projects. The best known example is an around 5000 hectare large area called “Oostvaardersplassen” which has been grazed with large herbivores (cattle, horses, red deer) since 1983 (Kampf 2000). Also, in Germany there have been numerous small-scale or large-scale year-round grazing projects until yet. For example: all-year-round grazing project in the Lippe floodplain (Bunzel-Drüke *et al.* 1999), Müritz National Park (Martin 1997), Hiddensee (Jeschke 1997), the Eidertal pasture landscape (Schrautzer *et al.* 2004), grazing of nature reserve “Gundelfinger Moos” (Demartin 2005), grazing of nature reserve “Hühnerfeld” (Preuschhof 2005), semi-open pasture landscape Höltigbaum (von Oheimb *et al.* 2006) and wood pasture in Solling-Vogler (Gerken *et al.* 2008).

Thesis outline

Grazing as a management tool for nature conservation gained importance in recent years. But, there are very insufficient scientific studies about the comparison of different grazers and studies about grazing occur mostly over a relatively short time period (often three years) (e.g. Redecker *et al.* 2002; Gilhaus *et al.* 2014). Therefore, the subject of this thesis is a comparative evaluation of different long-term grazing systems. A detailed examination of the grazing project “Stadtwald Augsburg” is intended in order to determine the effects of different grazing animals on vegetation. The changes in the vegetation of old sites, which are still grazed but haven’t been monitored scientifically for longer periods, will be analysed. Therefore a resumption of monitoring activities will take place by using the same monitoring methods as the previous investigations. Depending on geographical location and habitat the species pools differ from site to site. For this reason a comparative evaluation only based on floristic data is not possible. In this case a functional trait analysis is the method of choice. This analysing method considers both floristic and functional data as well as habitat specific parameters of long-term experiments (Römermann *et al.* 2009).

Following questions were on focus:

- What impacts do different grazing animals have on the same habitat type? (Chapter 2)
- How did the vegetation develop on areas of still existing, but no longer scientifically monitored grazing experiments? Are there changes compared to results of former investigations? (Chapter 3)
- Are there any similar patterns in functional traits considering different habitat types and grazing systems? (Chapter 4)

The manuscripts are supposed to be published separately in appropriate scientific journals, and therefore they each feature an abstract, an introduction, a section explaining the methods, a presentation of the respective results, as well as a thoroughly discussion.

In chapter 2 the grazing effect of large herbivores on a pre-alpine Pine forest was analysed. These very open and slow growing Pine forests are characterised by extremely high biodiversity. Nowadays, formerly spacious open Pine forests along the Bavarian Lech occur only in small remnants. In the Nature Reserve “Stadtwald Augsburg” year-round grazing with Przewalski horses and red deer should maintain these Pine forests. The vegetation development of both types of grazing and the difference between the grazers were on focus.

Chapter 3 deals with the vegetation development in the “Semi-open Pasture Landscape Höltigbaum” after twelve years of grazing management. A series of studies on “semi-open pasture landscapes” took place in recent years as an alternative management approach for extensively used landscape. In this study the project “Semi-open Pasture Landscape Höltigbaum” was on focus. Vegetation development after five years of grazing and after twelve years of grazing will be compared. Analyses were conducted with particular attention to the influence of grazing on different habitat parameters and structural diversity. If grazing can maintain and promote open and species rich grasslands, dry grasslands and heathland would also be of interest.

In chapter 4 a comparative analysis of six long-term grazing experiments in Germany was performed. By comparing long-term grazing experiments with a trait-based approach general patterns of grassland development due to grazing should be worked out. The change of plant functional traits in relative importance over time was taken into account as well. The functional approach was chosen because study areas differ in their abiotic conditions and occurring plant species. Thus, a comparison of changes in floristic composition in relation to grazing was not possible.

Finally, the results of the previous chapters were reviewed and concluding remarks were given.

Chapter 2

The effect of grazing with large herbivores on a pre-alpine Pine forest

Abstract

Spring Heath-Pine woods are the typical vegetation on more or less lime-rich dry slopes and gravel beds as well as at foothill to montane levels. These very open and slow growing Pine forests are characterised by extremely high biodiversity. Nowadays, formerly spacious open Pine forests along the Bavarian Lech occur only in small remnants. In the Nature Reserve "Stadtwald Augsburg" year-round grazing with Przewalski horses and red deer should remain these Pine forests. In this study the vegetation development of both types of grazing were on focus.

To analyse vegetation changes over time, an indirect ordination method was used. In order to document the effects of grazing on grass and shrub layer, mean values of grass and shrub species abundances were calculated. Additionally, the development of selected plant species was analysed. Vegetation composition of some sites in the Przewalski enclosure developed towards vegetation composition of open land. In the red deer enclosure the decline of shrub layer was greater than in the Przewalski enclosure. These results can also be seen in the development of selected plant species.

To sum up, grazing of pre-alpine Pine forests with large herbivores had a positive influence on vegetation and vegetation structure. A reduction of old grass stock and shrub layer took place and species diversity increased depending on the grazing animals. Vegetation structure after eight years in the Przewalski enclosure was closer to the desired target than in the red deer enclosure.

Introduction

Spring Heath-Pine woods (*Erico-Pinetum*) are the typical vegetation on more or less lime-rich dry slopes and gravel beds as well as at foothill to montane levels (Hölzel 1996; Kelly & Connolly 2000). On the gravels or terraces of calcareous alpine rivers, at levels no longer subject to inundation, Spring Heath-Pine woods are the final stage of floodplain succession (Müller 1991b; Mucina *et al.* 1993). They are primarily located along rivers, which are filled due to their geology in their valley areas with high percentage of coarse gravel, such as the Rhine, Isar and Lech valleys (Müller 1991b). Pine forests often are interleaved with calcareous grasslands and form a mosaic of open land and wood (Riegel 2002). In former times the gravel bars were grazed and the Pine forests became more open and succession to thick forest was prevented or diverse semi-dry grasslands developed (Müller 1991b; Riegel & Hiemeyer 2001; Liebig 2002). These very open and slow growing Pine forests are characterised by extremely high biodiversity (Liebig 2006). The open Spring Heath Pine forests are in steep decline because they are strongly bound to the dynamics of an intact pre alpine wild river ecosystem as well as to grazing (Müller 1991a; Liebig 2006). Based on the loss of river dynamics gravel bars emerge no more and therefore the Spring Heath-Pine forests cannot rejuvenate (Müller 1991a). Scots Pine needs raw soil for germination (Müller 1991a; Walentowski *et al.* 2007).

At the river Lech considerable river-engineering measures took place in the early 20th century (Müller 1991b; Riegel 2002; Liebig 2006). The consequence was a progressing decline and loss of habitats and species communities typical for the Lech (Bresinsky 1963; Müller 1991a; b). As de-alpine, continental and sub-mediterranean floral elements converge on the “Lechheiden”, they are outstanding. The Lech serves as a “plant-bridge” between the Alps and Jurassic (Jura mountains) (Müller *et al.* 1998). For a long time the Natural Science Association of Swabia pointed out the importance of “dry pine forests” for species and habitat protection at the Lech (Bresinsky 1963; Pfeuffer 1993; Müller & Waldert 1996).

In addition to river-engineering structural changes in agriculture influenced the changes in biodiversity. Until the middle of the 20th century the “Lechheiden” were traditional summer pastures for nomadic shepherds from Southern Germany (Mayer 1999; Poschlod 2015). To improve the conditions on pastures, pine forests further away from the river were thinned

(Liebig 2002). It is known that the pine forests in the valleys of Isar and Inn were used as forest pasture for cattle (Hölzel 1996). Due to the changing economic conditions, the associated decline in transhumance and the more intensive land use only around 1% of the “Lechheiden” are left (Müller 1991a; Liebig 2002; Riegel 2002).

Nowadays, formerly spacious open Pine forests along the Bavarian Lech occur only in small remnants. In the Nature Reserve “Stadtwald Augsburg” remnant forests comprises round 225 ha. The Landcare Association of the City of Augsburg wants to maintain this ecologically vulnerable habitat to receive its unique biodiversity. During the years 2000 to 2005 an about one hectare large part of the Pine forest has been grazed by sheep. However, the required grazing intensity could not be established (Liebig 2006; Liebig & Pantel 2009). Therefore, alternative management methods had to be taken into consideration. As a result, in 2007 the Landcare Association of the City of Augsburg initiated the project “Landscape management with large herbivores in the Nature Reserve “Stadtwald Augsburg” (Liebig 2006). The role of large herbivores in the development of Central European landscapes was discussed in the nature conservation circle of experts since the beginning of the 1990ies (e.g. Geiser 1992; Bunzel-Drüke *et al.* 1994; Bunzel-Drüke M. 1997; Vera 2000). Since then, numerous grazing projects with large grazing animals were developed (e.g. Krüger 1999; Riecken *et al.* 2001; Redecker *et al.* 2002; Anders *et al.* 2004; von Oheimb *et al.* 2006; Gerken *et al.* 2008). Driesch (2001) showed that in prehistoric times the pre-alpine Pine forests on gravel bars were grazed by free-living large herbivores. More recently wood pasture took place (Hölzel 1996). In 2007 two enclosures for year-round grazing of Przewalski horses (about 15 ha) and red deer (about 13 ha) were fenced. The main aim of the project was to promote and maintain the semi-open structures of the Pine forest. Through grazing, the litter layer and the raw humus layer should be reduced and bare ground should be created (Liebig 2006; Liebig & Pantel 2009).

In this study the following questions should be addressed: (1) What influence did grazing have on vegetation, species number and vegetation structure? (2) What influence did grazing have on the development of selected species? (3) Are there any differences between the grazing with Przewalski horses and Red deer?

Material & Methods

Study site

The study site is located in the southwest of the Nature Reserve “Stadtwald Augsburg” (509 m NN, annual precipitation 831 mm, mean temperature 8.1 °C), which is south of Augsburg in Southwest Bavaria in the administrative region Swabia. The “Stadtwald Augsburg” is an about 30 hectare large pine forest. It forms a mosaic of ancient and afforested forest and open land and is currently more or less closed. The site is characterised by medium to shallow alluvial soils. Soil substrates consist of gravel as well as of sandy and loamy gravel. In the south of the study area two semi-natural calcareous grasslands on gravel banks exist: The “Königsbrunner Heide” (about 5 ha) that is managed by mowing in strips and the “Hasenheide” (about 8 ha) that is grazed by sheep.

Field methods

In 2007, 96 permanent plots (2 m x 2 m) along 12 transects were installed (Table 2-1). All different vegetation structures and units (areas with thick shrub layer, semi-open pine forest areas, lime-dry grassland) that occur in this area were adequately included. In each enclosure there are two transects in forest area, one transect in open land and one transect representing the transition between forest and open land (Table 2-1). Also, reference sites were installed to exclude climatic or environmental influences. Vegetation on the permanent plots had primarily been recorded before grazing with horses and red deer started. This reference was used as a direct comparison for the vegetation development in the following years. Vegetation relevés have been conducted every year in June and July. The percentage cover values have been estimated according to Braun-Blanquet (1964). The nomenclature followed Rothmaler (2011).

Table 2-1 Overview of transects, each with 8 permanent plots and used abbreviations for transects.

Name	Habitat	Habitat structure	Type of grazing	Abbreviation
Hasenheide	dry calcareous grassland	open	Reference	HH
Przewalski open	dry pine-wood	open	Przewalski horses	PO
Przewalski transition	dry pine-wood	transition grassland to forest	Przewalski horses	PT
Przewalski Forest I	dry pine-wood	closed forest	Przewalski horses	PFI
Przewalski Forest II	dry pine-wood	closed forest	Przewalski horses	PFII
Control Forest II	dry pine-wood	closed forest	Reference	CFII
Königsbrunner Heide	dry calcareous grassland	open	Reference	KH
Red deer open	dry pine-wood	open	Red deer	RO
Red deer transition	dry pine-wood	transition grassland to forest	Red deer	RC
Red deer Forest I	dry pine-wood	closed forest	Red deer	RFI
Red deer Forest II	dry pine-wood	closed forest	Red deer	RFII
Control Forest I	dry pine-wood	closed forest	Reference	CFI

Data analysis

To analyse vegetation changes over time, Detrended Correspondence Analysis (DCA) as an indirect ordination method was used (Hill & Gauch 1980). The DCA was carried out with default settings in PcOrd 5.17 (McCune & Mefford 2006). Averaged species abundances per transect and year formed the basis of the main matrix. Furthermore, as direct measurements of environmental variables are missing, weighted Ellenberg indicator values as substitutes are used (Ellenberg *et al.* 2001). Evidence for the accuracy of these indicator values is provided by several studies that report a close correlation between indicator values and corresponding measurements of environmental variables on large gradients (Schaffers & Sykora 2000; Diekmann 2003). Mean weighted Ellenberg indicator values per vegetation relevé were estimated for nutrient (N), light (L), moisture (F), and reaction (R) (Ellenberg *et al.* 2001). Besides, the species abundances of main matrix the weighted Ellenberg indicator values were included as habitat parameters to the second matrix. The diagram was presented as a biplot. Selected species were showed as vectors, which pointed in the direction of increasing abundance (Leyer & Wesche 2007). Also, appropriate to their correlation with axes, the habitat parameters were displayed as vectors (Ter Braak 1995). To illustrate the vegetation changes over time, vegetation relevés of different years were connected with arrows.

Additionally, species numbers per transect and Eveness were calculated. Eveness is the uniformity of the frequency by which the species occur in a plot. This means, if all species occur with the same percentage the value of Eveness is 1. Are there a lot of dominant species in a plot the value of Eveness tends to zero.

In order to document the effects of grazing on grass and shrub layer, mean values of grass and shrub species abundances were calculated. For this purpose the abundances of all grass and shrub species were summed and the annually mean value was estimated. Only for transects where shrubs occurred mean cover was determined.

Significant differences between the years 2007 and 2014 were tested using the pair wise Wilcoxon Signed-Rank test. To test significant differences between all years Repeated Measures ANOVA (RM-ANOVA) (Field 2009) was used. The assumptions for this analysis are normal distribution and sphericity. If data violated the sphericity assumption, the Greenhouse & Geisser (1959) estimate was used to adjust the degrees of freedom. Consequently, the new degrees of freedom are used to ascertain the critical value of F (Field 1998). To find differences between particular years a Bonferroni post hoc test was executed. If the RM-ANOVA was significant and no differences were detected by the post hoc Bonferroni test, the post hoc LSD test was applied. The RM-ANOVA and the post hoc test were carried out with IBM SPSS Statistics 22 for Windows (Bühl 2014).

Furthermore, differences between sites were evaluated using one way ANOVAs being robust against a deviation from a normal distribution (Field *et al.* 2012). The robust ANOVA and following post hoc tests (for the omnibus test function t1wayv2() and for post hoc test function mcppb20() with 5000 bootstrap (Wilcox 2012)) were performed with R Software Version 3.0.3 (R Core Team 2014) using the web page of Rand Wilcox (URL: (http://dornsife.usc.edu/labs/rwilcox/software/). The groups were significantly different when the confidence intervals did not overlap.

The development of selected species was analysed, too. The selected species are presented in Table 2-2. Selection criteria were: endangered species, sensitive to grazing, dominant *Poaceae*, typical for open areas, dominant in shrub layer. Endangered species and species typical for open areas, which were present on all or almost all transects, were chosen for the subsets. The choice included one species which was considered to be sensitive to grazing and one which was considered to be insensitive to grazing. Finally dominant sweet grass species and shrub species were chosen to see if grazing was able to reduce their dominance.

Mean cover per transect and year for each species was estimated and compared. If the mean cover declined by at least 0.5%, a decrease was defined. If the mean cover rose by at least 0.5%, an increase was defined. Additionally, the steadiness has been estimated. If a species disappeared in at least one plot, a decrease was defined. If a species appeared in at least one plot, an increase was defined. To test significant differences between species abundances in 2007 and 2014, the pair wise Wilcoxon Signed-Rank test was used. The calculation was performed with IBM SPSS Statistics 22 for Windows (Bühl 2014).

Table 2-2 List of selected species. *= due to trampling intolerance and according to Rosquist & Prentice (2000) *Anthericum ramosum* was characterised as sensitive to grazing contrary to Briemle *et al.* (2002) which classified the species as well grazing tolerant.

Criteria	Species
endangered species	*Allium carinatum*
	Asperula tinctoria
	Danthonia decumbens
	Scabiosa canescens
sensitive to grazing and trampling	*Anthericum ramosum**
dominant Poaceae	*Brachypodium rupestre*
	Calamagrostis epigejos
	Calamagrostis varia
	Molinia arundinacea
	Molinia caerulea
insensitive to grazing	*Polygala chamaebuxus*
typical for open areas	*Bromus erectus*
	Carex caryophyllea
	Carex humilis
	Euphorbia cyparissias
	Plantago media
	Potentilla neumanniana
	Prunella grandiflora
dominant in shrub layer	*Berberis vulgaris*
	Frangula alnus
	Fraxinus excelsior
	Rhamnus cathartica

Results

Development of vegetation, species number and vegetation structure

The ordination diagram of the Detrended Correspondence Analysis (DCA) of vegetation progress on the 12 transects is presented in Figure 2-1. Axis 1 represents 60.9% of the variance in the data set and Axis 2 represents 8.1%. Transects of open land are on the right-hand side and transects of wood on the left-hand side of the diagram. The two reference sites “Hasenheide” and “Königsbrunner Heide” and the two transects “Przewalski open” and “Red deer open” showed no clear trend. The species composition of transects “Przewalski transition”, “Red deer transition” and “Przewalski Forest I” shifted mainly along Axis 1. The species composition of the two references in Forest (“Control Forest I”, “Control Forest II”) shifted mainly along Axis 2. Transects “Przewalski Forest II”, “Red deer Forest I” and “Red deer Forest II” exhibited a backward oriented trend in the last years. The plots at the right-hand side were mainly characterised by the species *Bromus erectus* (r= 0.75), Carex *humilis* (r= 0.91) and *Helianthemum nummularium* (r= 0.84). On these plots also high proportions of thermophilous and photophilous plant species occurred. On the left-hand side the plots were mainly characterised by *Carex alba* (r= -0.80) and high proportions of nitrophilous and hygrophilous plant species.

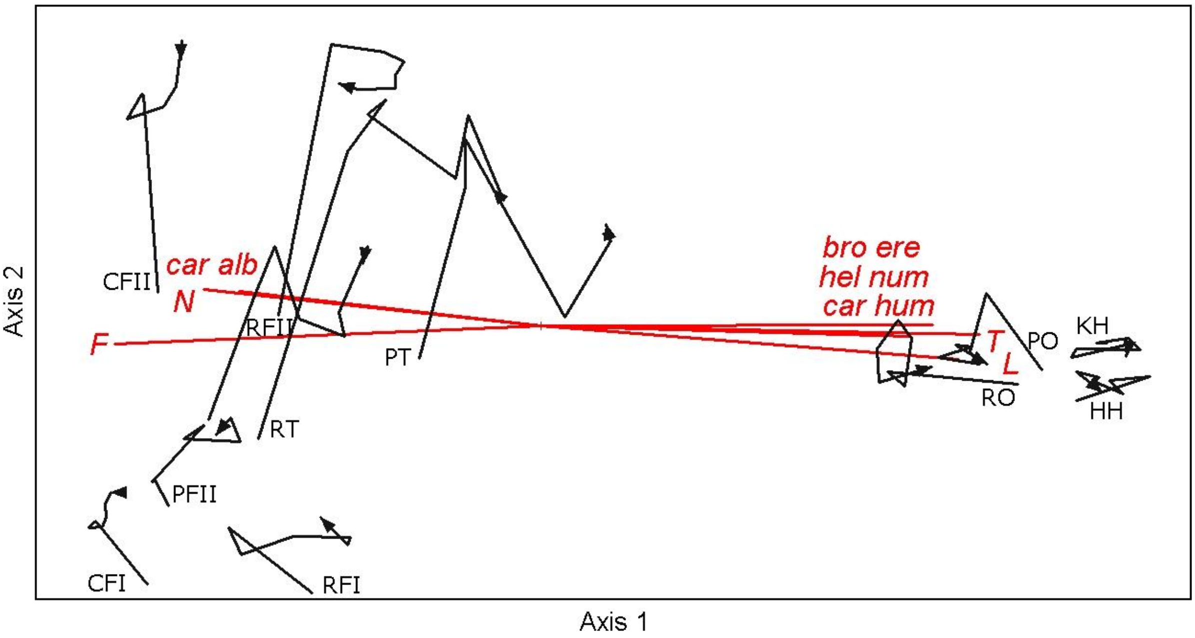

Figure 2-1 Detrended correspondence analysis (DCA) of vegetation progress on the 12 transects in the years 2007 to 2014. Weighted Ellenberg indicator values and species were correlated with the axes. Axis 1 explains 60.9% of variance; Axis 2 explains 8.1% of variance. The length of gradient (Axis 1) is 3.69 SD. Cut-off-value for correlations of species abundances with axes: $r^2 > 0.5$. Changes over time are marked through arrows, beginning with the initial state in the year 2007. The arrow head shows the year 2014. car alb= *Carex alba* (r= -0.80), hel num= *Helianthemum nummularium* (r= 0.84), bro ere= *Bromus erectus* (r= 0.75), car hum= *Carex humilis* (r= 0.91), N= weighted Ellenberg indicator Nitrogen (r= -0.75) , F= weighted Ellenberg indicator Moisture (r= -0.90), L= weighted Ellenberg indicator Light (r= 0.86), T= weighted Ellenberg indicator Temperature (r= 0.89). HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Figure 2-2 shows the mean species numbers per year for each transect in both enclosures. The species number was between 10 on transects in forest areas and 35 on the reference transect “Hasenheide”. The species number increased on transects “Hasenheide”, “Przewalski open”, “Przewalski transition”, “Königsbrunner Heide” and “Red deer open”. A decrease of species number was found in the following transects: “Red deer transition”, “Red deer Forest I”, “Red deer Forest II”, “Control Forest I” and “Control Forest II”. There were no significant differences for three transects in the Przewalski enclosure (Table 2-3). Except “Red deer open” on all sites in the red deer enclosure significant differences between 2007 and 2014 were found (Table 2-3).

For statistical results of the Repeated Measures ANOVA and post-hoc Bonferroni-test see Appendix 2-1. Also, the results of the robust ANOVA and the following post-hoc-test were summarised in Appendix 2-2. There were significant differences between the sites in 2007 (test statistic= 81.06, p<0.001) and 2014 (test statistic= 100.60, p<0.001). Between following sites differences in 2007, but no differences in 2014 were found: “Hasenheide” and “Przewalski open”; “Hasenheide” and “Königsbrunner Heide”; “Przewalski transition” and “Red deer open”. In contrast between following sites: “Przewalski transition” and “Red deer Forest I”; “Przewalski transition” and “Red deer Forest II”; “Königsbrunner Heide” and “Red deer open”.

The Eveness values for all sites are presented in Appendix 2-3. The results of Wilcoxon Signed-Rank test and the results of the Repeated Measures ANOVA and post-hoc Bonferroni-test are summarised in Appendix 2-4 and 2-5. In 2007 “Przewalski open” had the slightest Eveness (0.67) and the highest Eveness (0.78) could be seen on “Przewalski Forest I”. In the red deer enclosure the values of Eveness were very similar to each other in 2007. There was a greater variation between the values in the year 2014. A decrease of Eveness was found on following sites: “Przewalski Forest I”, “Przewalski Forest II”, all transects in the red deer enclosure and “Control Forest I”. At “Hasenheide”, “Königsbrunner Heide” and “Przewalski open” the Eveness increased. There were significant differences on “Przewalski Forest I”, “Red deer transition”, “Red deer Forest II” and on “Control Forest I” (Appendix 2-6).

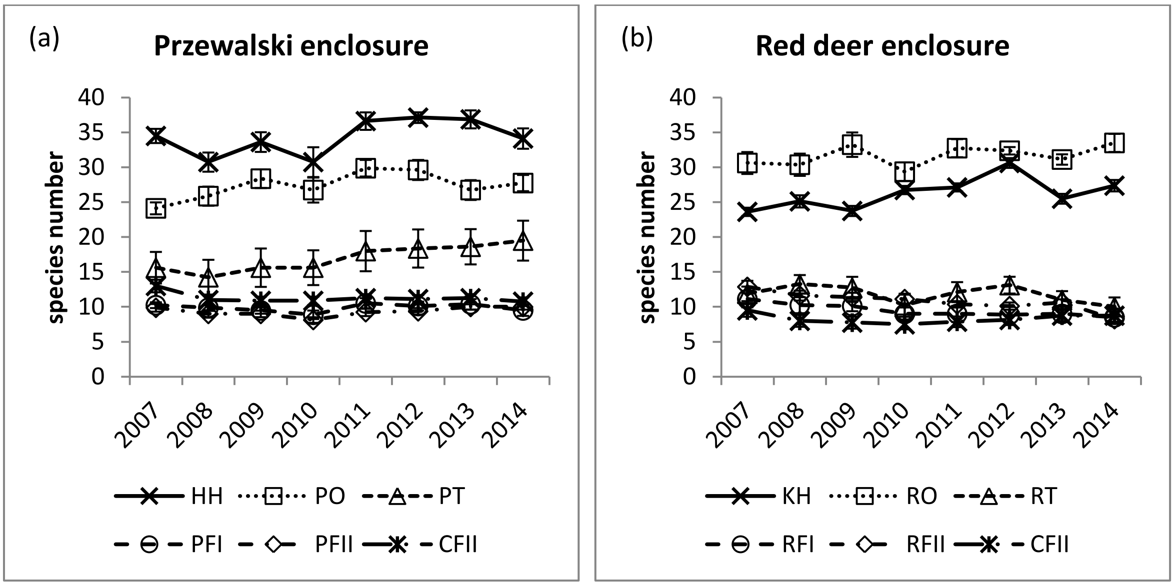

Figure 2-2 Mean species number and standard error per transect in (a) Przewalski enclosure and (b) Red deer enclosure in the years 2007 to 2014. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Table 2-3 Differences in mean species number per transect between 2007 and 2014. Results of the Wilcoxon Signed-Rank test. Significant results printed in bold type (p<0.05). Z= test statistic, N= 8. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	Z	p-value	Site	Z	p-value
HH	-0.28	0.778	**KH**	-2.54	**0.011**
PO	-1.96	0.050	**RO**	-1.61	0.108
PT	-2.12	**0.034**	**RT**	-1.98	**0.048**
PFI	-1.06	0.288	**RFI**	-2.21	**0.027**
PFII	-0.11	0.914	**RFII**	-2.53	**0.012**
CFII	-2.06	**0.040**	**CFI**	-1.51	0.131

The mean cover of grass is estimated and illustrated in Figure 2-3. The general trend was that the cover of grass decreased on transects in the Przewalski enclosure and increased on the sites in the red deer enclosure. On the reference sites in open areas and “Control Forest II” the mean cover decreased and on reference site “Control Forest I” the mean cover remained constant. There was a significant difference in mean cover of grass between 2007 and 2014 on four transects (“Przewalski transition”, “Przewalski Forest I”, “Red deer transition”, “Red deer Forest II”). On all other sites no significant differences could be detected (Table 2-4).

For statistical results of the Repeated Measures ANOVA and post-hoc Bonferroni-test see Appendix 2-7. Also, the results of the robust ANOVA and the following post-hoc-test were summarised in Appendix 2-8. There were significant differences between the sites in 2007 (test statistic= 15.07, p<0.001) and 2014 (test statistic= 8.87, p<0.001). Sixteen differences were determined in 2007 that no longer existed in 2014. Between following sites no differences were seen in 2007, but in 2014: “Przewalski transition” and “Red deer Forest II”; “Przewalski Forest I” and “Red deer transition”; “Przewalski Forest I” and “Red deer Forest II”; “Przewalski Forest II” and “Red deer Forest II”.

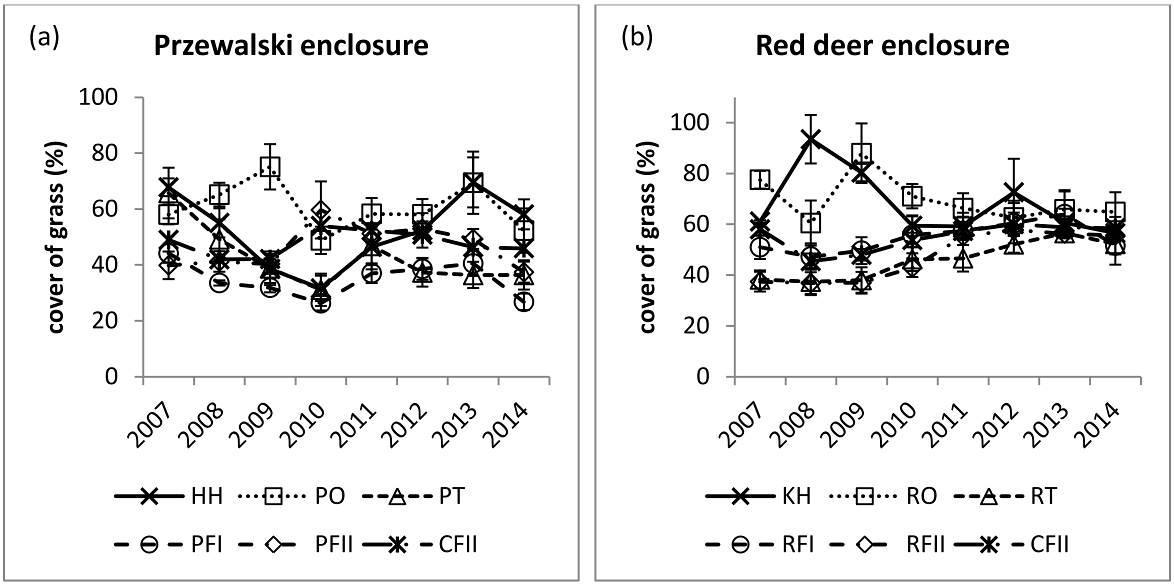

Figure 2-3 Mean cover of grass (%) and standard error per transect in (a) Przewalski enclosure and (b) Red deer enclosure in the years 2007 to 2014. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Table 2-4 Differences in mean cover of grass (%) per transect between 2007 and 2014. Results of the Wilcoxon Signed-Rank test. Significant results printed in bold type (p<0.05). Z= test statistic, N= 8. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	Z	p-value	Site	Z	p-value
HH	-0.98	0.326	**KH**	-1.52	0.128
PO	-0.70	0.484	**RO**	-1.68	0.093
PT	-2.52	**0.012**	**RT**	-1.97	**0.049**
PFI	-2.52	**0.012**	**RFI**	0.00	1.000
PFII	-0.21	0.833	**RFII**	-2.52	**0.012**
CFII	-0.84	0.400	**CFI**	-0.07	0.944

Figure 2-4 shows the changes in mean cover of shrubs. On almost all sites a decrease took place. The highest values were detected on transects in the red deer enclosure. A slight increase could be located on “Przewalski Forest II”. This rise showed no significance (Table 2-5). Also, the decrease of cover of shrubs on both reference sites was not significant. For all other changes significant differences could be detected (Table 2-5). Since two years a slight increase in cover of shrubs took place on “Red deer Forest I”.

For statistical results of the Repeated Measures ANOVA and post-hoc LSD-test see Appendix 2-9. Also, in the years 2007 and 2014 differences between the sites were tested (Appendix 2-10). There were no significant differences between the sites in 2007. Between the following sites significant differences could be detected in 2014 (test statistic= 8.87, p<0.001): “Przewalski Forest I” and “Control Forest II”; “Control Forest II” and “Red deer transition”; “Control Forest II” and “Red deer Forest I”; “Red deer transition” and “Control Forest I”.

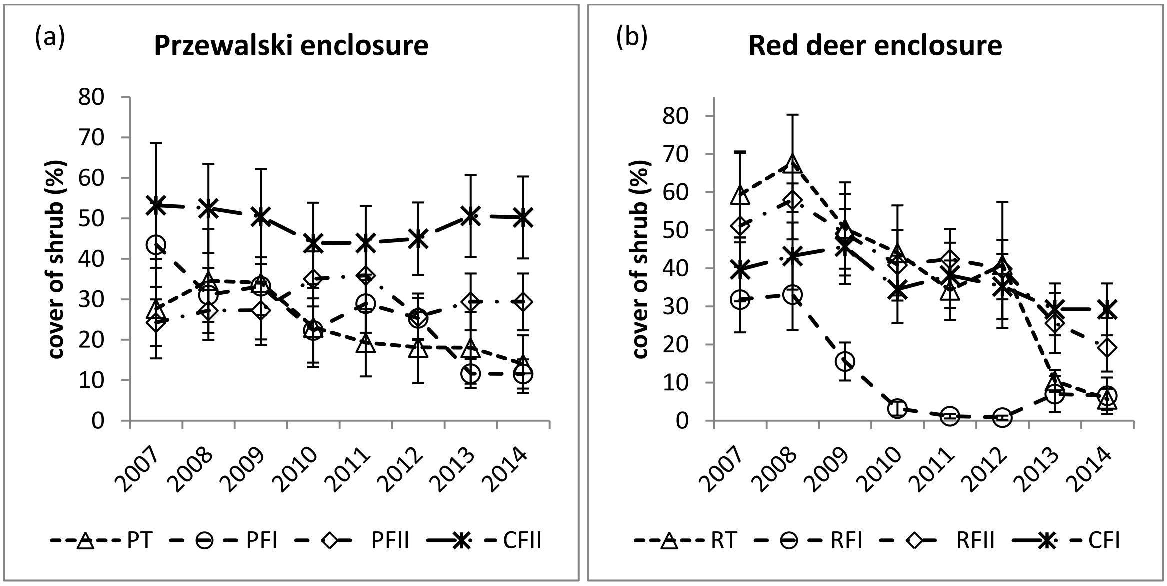

Figure 2-4 Mean cover of shrubs (%) and standard error per transect in (a) Przewalski enclosure and (b) Red deer enclosure in the years 2007 to 2014. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Table 2-5 Differences in mean cover of shrubs (%) per transect between 2007 and 2014. Results of the Wilcoxon Signed-Rank test. Significant results printed in bold type ($p<0.05$). Z= test statistic, N= 8. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	Z	p-value	Site	Z	p-value
PT	-2.31	**0.021**	**RT**	-2.52	**0.012**
PFI	-2.52	**0.012**	**RFI**	-2.37	**0.018**
PFII	-1.01	0.310	**RFII**	-2.52	**0.012**
CFII	-0.56	0.575	**CFI**	-1.10	0.273

Development of selected species

Endangered species

The changes in coverage and steadiness of selected species are presented in Table 2-6. The coverage of *Asperula tinctoria* (vulnerable) decreased on three transects (“Przewalski open”, “Przewalski transition”, “Red deer open”). Also, on the reference sites “Hasenheide” and “Königsbrunner Heide” a decline was found. The coverage of *Danthonia decumbens* (nearly threatened) increased on five transects (Table 2-6). The endangered species *Scabiosa canescens* declined on “Red deer open” and “Königsbrunner Heide”. At “Przewalski open” and “Przewalski transition” the coverage of *Scabiosa canescens* rose (Figure 2-5). The coverage of *Allium carinatum* (vulnerable) remained constant, but steadiness increased on “Przewalski open” and “Königsbrunner Heide”.

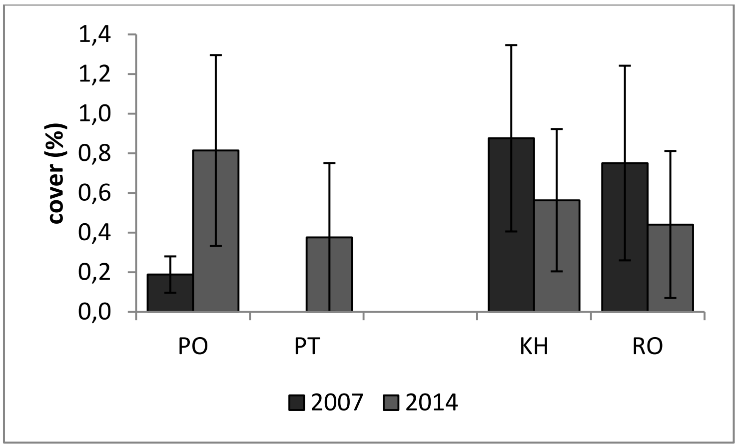

Figure 2-5 Changes of coverage of *Scabiosa canescens* for transects on which it occurred in both enclosures between 2007 and 2014. PO= Przewalski open, PT= Przewalski transition, KH= Königsbrunner Heide, RO= Red deer open.

Sensitive to grazing and trampling

The coverage of *Anthericum ramosum* which is considered to be sensitive to grazing, decreased on all transects in the red deer enclosure and on two transects in the Przewalski enclosure ("Przewalski transition", "Przewalski Forest I") (Figure 2-6). An increase could be found at two reference sites ("Königsbrunner Heide", "Control Forest II") and two transects in the Przewalski enclosure ("Przewalski open", "Przewalski Forest II") (Table 2-6).

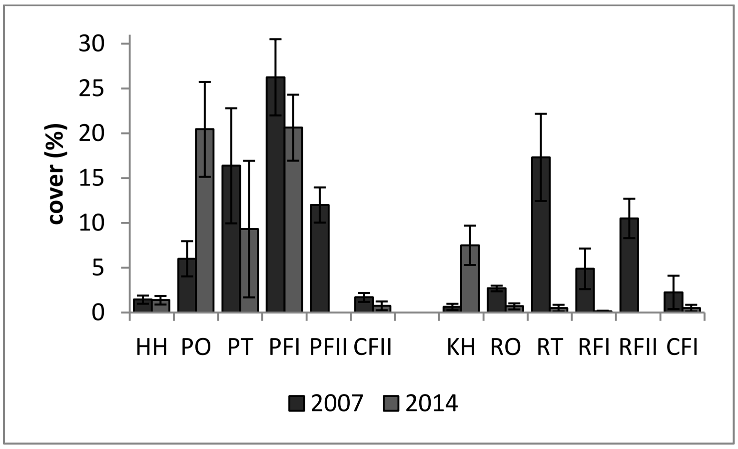

Figure 2-6 Changes of coverage of *Anthericum ramosum* for transects on which it occurred in both enclosures between 2007 and 2014. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Dominant Poaceae

The coverage of dominant sweet grass species declined on all transects in the Przewalski enclosure and to some extent on reference "Control Forest II" (Table 2-6). *Brachypodium rupestre* rose on transects in the red deer enclosure and declined in the Przewalski enclosure (Figure 2-7). *Calamagrostis epigejos* increased significantly on "Red deer Forest I" and *Calamagrostis varia* on "Red deer transition". Only the species *Molinia caerulea* decreased on sites in the red deer enclosure ("Red deer open", "Red deer transition"). The general trend was that dominant sweet grass species declined in the Przewalski enclosure and remained constant or increased in the red deer enclosure (Table 2-6).

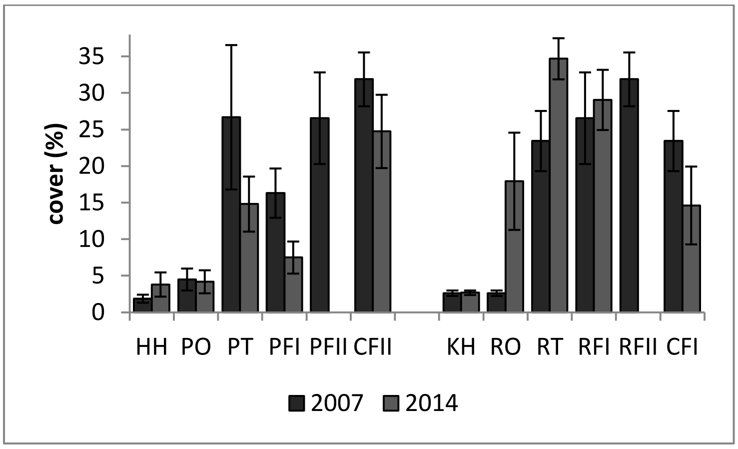

Figure 2-7 Changes of coverage of *Brachypodium rupestre* for transects on which it occurred in both enclosures between 2007 and 2014. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Insensitive to grazing

The coverage of *Polygala chamaebuxus* which is considered to be insensitive to grazing, decreased on "Red deer Wood I" and rose on "Przewalski transition" (Figure 2-8, Table 2-6). Also, on reference "Hasenheide" an increase was observed.

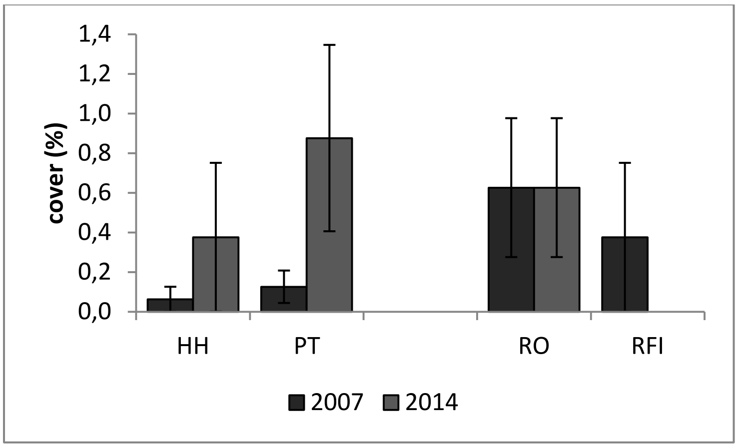

Figure 2-8 Changes of coverage of *Polygala chamaebuxus* for transects on which it occurred in both enclosures between 2007 and 2014. HH= Hasenheide, PT= Przewalski transition, KH= Königsbrunner Heide, RO= Red deer open, RFI= Red deer Forest I.

Typical for open areas

On transects in the Przewalski enclosure more species typical for open areas increased in coverage than in the red deer enclosure (Table 2-6). Figure 2-9 presented the species *Carex humilis* as an example. Five species typical for calcareous grasslands (*Carex caryophyllea,* *Carex humilis, Euphorbia cyparissias, Plantago media, Prunella grandiflora*) increased on “Przewalski transition”. At “Przewalski open” the coverage of three species (*Euphorbia cyparissias, Potentilla neumanniana, Prunella grandiflora*) enhanced. Three species (*Bromus erectus, Carex humilis, Euphorbia cyparissias*) rose at “Red deer transition”. The coverage of three species (*Carex caryophyllea, Potentilla neumanniana, Prunella grandiflora*) increased on “Red deer open” and the coverage of four species (*Bromus erectus, Carex humilis, Euphorbia cyparissias, Plantago media*) declined.

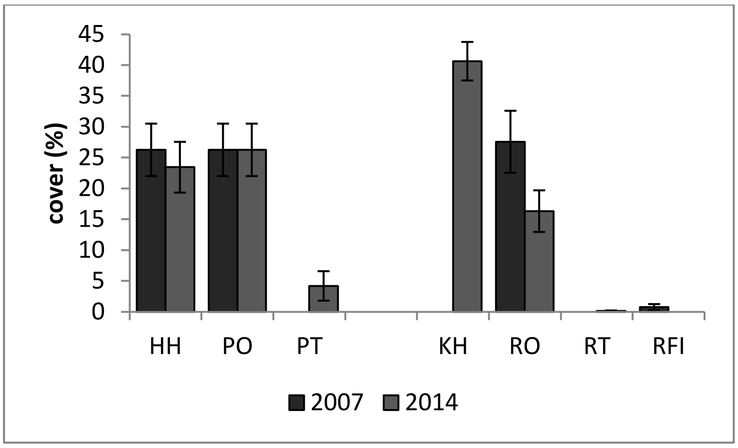

Figure 2-9 Changes of coverage of *Carex humilis* for transects on which it occurred in both enclosures between 2007 and 2014. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I.

Dominant in shrub layer

The general trend was that species dominant in shrub layer decreased in greater extent on transects in the red deer enclosure (Table 2-6). The coverage of *Rhamnus catharticus* increased on “Przewalski Forest I” as well as the coverage of *Frangula alnus* on “Przewalski Forest II” (Figure 2-10). On all other sites in the Przewalski enclosure the shrub species declined in coverage. In the red deer enclosure *Berberis vulgaris* increased on “Red deer Forest II”. On the remaining transects a decrease for all shrub species was found.

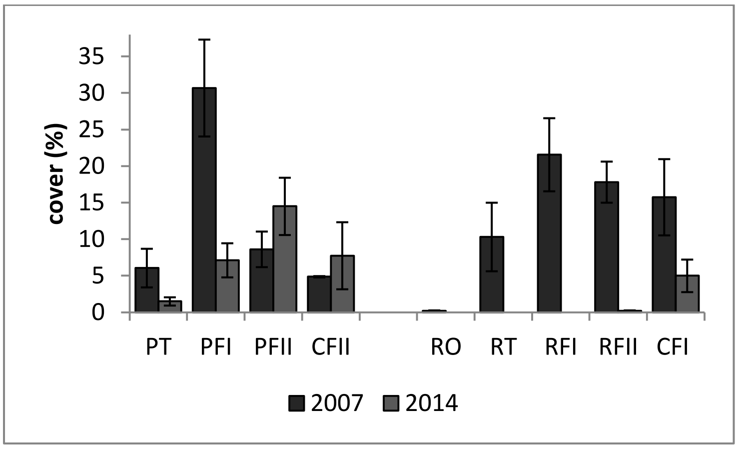

Figure 2-10 Changes of coverage of *Frangula alnus* for transects on which it occurred in both enclosures between 2007 and 2014. PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Table 2-6 Changes of coverage and steadiness of selected species in both enclosures from 2007 to 2014. C= Coverage, S= Steadiness, D= decrease of coverage, I= increase of coverage, (d)= disappeared in at least one plot, (a)= appeared in at least one plot, *= $p<0.05$, **= $p<0.01$. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

A: Przewalski enclosure

		HH		**PO**		**PT**		**PFI**		**PFII**		**CFII**	
		C	S	C	S	C	S	C	S	C	S	C	S
endangered species	*Allium carinatum*		(d)		(a)								
	Asperula tinctoria	D	(d)	D**	(d)	D	(d)						
	Danthonia decumbens	I*	(a)		(a)	I	(a)						
	Scabiosa canescens			I	(a)	I	(a)						
sensitive to grazing and trampling	*Anthericum ramosum*		(d)	I*		D		D		I		I	(d)
dominant Poaceae	*Brachypodium rupestre*	I	(a)			D		D*		D		D	
	Calamagrostis epigejos						(a)			D	(a)	D	(a)
	Calamagrostis varia					D	(d)	D	(a)	D			
	Molinia arundinacea											D	(d)
	Molinia caerulea					D	(d)	D	(d)				(a)
insensitive to grazing	*Polygala chamaebuxus*	I				I	(a)						
typical for open areas	*Bromus erectus*	D		D*		D	(a)						
	Carex caryophyllea	I	(a)		(a)	I	(a)			I	(a)		
	Carex humilis	D				I	(a)						
	Euphorbia cyparissias			I*		I	(a)			I	(a)	D	(d)
	Plantago media				(a)	I	(d)						
	Potentilla neumanniana			I	(d)		(a)						
	Prunella grandiflora	I		I*	(a)	I							
dominant in shrub layer	*Berberis vulgaris*					D	(d)			D		D	(a)
	Frangula alnus					D		D*	(d)	I	(a)	I	(a)
	Fraxinus excelsior					D	(d)				(a)	D	(d)
	Rhamnus cathartica				(a)	D	(a)	I	(a)	D		D	

B: Red deer enclosure

		KH		**RO**		**RT**		**RFI**		**RFII**		**CFI**	
		C	S	C	S	C	S	C	S	C	S	C	S
endangered species	*Allium carinatum*		(a)										
	Asperula tinctoria	D*	(d)	D*	(d)								
	Danthonia decumbens	I**	(a)	I**	(a)	I	(a)	I	(a)				
	Scabiosa canescens	D		D	(a)								
sensitive to grazing and trampling	*Anthericum ramosum*	I*	(a)	D*	(d)	D*	(d)	D*	(d)	D**	(d)	D	(a)
dominant Poaceae	*Brachypodium rupestre*		(a)	I*	(a)	I		I		I		D*	
	Calamagrostis epigejos							I*	(a)				
	Calamagrostis varia					I*	(a)						(a)
	Molinia arundinacea												
	Molinia caerulea			D	(d)			D				I	(d)
insensitive to grazing	*Polygala chamaebuxus*							D	(d)				
typical for open areas	*Bromus erectus*	D*		D**		I	(a)	D	(d)				
	Carex caryophyllea		(a)	I*	(a)								
	Carex humilis	I		D		I	(a)	D	(d)				
	Euphorbia cyparissias	I**	(a)	D		I	(a)	I	(a)	I			
	Plantago media			D	(a)								
	Potentilla neumanniana	D	(a)	I*	(a)								
	Prunella grandiflora		(a)	I	(a)								
dominant in shrub layer	*Berberis vulgaris*					D				I	(a)		
	Frangula alnus			D	(d)	D	(d)	D*	(d)	D*	(d)	D	
	Fraxinus excelsior					D	(d)	D	(d)	D	(d)		
	Rhamnus cathartica	D		D	(d)	D*	(d)	D	(d)	D	(d)		

Discussion

Development of vegetation, species number and vegetation structure and differences between horse and red deer grazing

As well as the reference sites open areas showed no clear trend due to grazing. The vegetation composition of the transition transects in both enclosures and one woody site in the Przewalski enclosure approximated to vegetation composition of open land. On the woody sites in the red deer enclosure no clear trend could be detected. The vegetation development in the Przewalski enclosure conformed with findings of several studies that pointed out that grazing with large herbivores creates a more open vegetation structure (Kooijman & van der Meulen 1996; Loucougaray *et al.* 2004; Bromisch 2005; Demartin 2005; Strohwasser 2005; Catorci *et al.* 2012). The vegetation development differs between both enclosures because of different grazing behaviour of red deer and Przewalski horses. Red deer prefers shrubs and Przewalski horses prefer grasses (Pantel 2011).

On certain sites of both enclosures the species number and Eveness increased. This rise could be the result of grazing because this effect could also be observed on sandy soils (Rüther & Venne 2005; Lühr 2007) and in heath and mesic grassland (Deléglise *et al.* 2011). However, on reference sites an increase of species number and Eveness took place. Therefore, the increase of these parameters in grazed areas could possibly be created by environmental influences. In the red deer enclosure the Eveness declined on all sites. Also, a decline of species number and Eveness could be detected in the case of grazing of xerothermic calcareous grassland (Bornkamm 2006).

The general trend was a decrease of the cover of grass in the Przewalski enclosure and an increase on the sites in the red deer enclosure. Photo documentation over five years confirms the results of this study (Pantel 2011). Only one site in the red deer enclosure showed a decrease. This site is located in an area where red deer browsed intensively. Bornkamm (2006) determined that due to grazing the proportions of graminoids were lowered and the proportion of herbs increased. For controlling dominant grasses the grazing of horses was more effective than that of sheep (Catorci *et al.* 2012). It was assumed that red deer browse grasses because they are regarded as mixed grazers (Rahmann 1998). In this study area red deer browse grasses ever since 2009, but merely in open areas of the enclosure (personal observation, Pantel 2011). For that reason, the cover of grass didn’t decrease in the red deer enclosure.

The grazing animals browse vegetation with different intensity. Due to grazing of red deer a rather irregular structure with long hassocks and areas grazed till sward emerged. In the Przewalski enclosure homogenous short swards alternated with almost undamaged vegetation. Loucougaray *et al.* (2004) noted that generally large herbivores grazed in a patchy way and produce a mosaic of vegetation. Intensively grazed areas alternated on small-scale with less intensively grazed areas (Bromisch 2005; Rüther & Venne 2005). Previously grazed short grass areas of high nutritive value were preferred by herbivores, Adler *et al.* (2001) termed this process “patch grazing”. Due to patch grazing a mosaic of short and tall vegetation patches with opposing growth forms and plant traits develops (Louault *et al.* 2005; Dumont *et al.* 2012).

There was no big impact of red deer on grass layer. Because of their nutrition physiology they favour fresh biomass and avoid old shoots (Pantel 2011). In contrast, horses grazed dry old biomass, especially during winter. The influence of horse grazing could be seen across the whole area. They preferred open areas, but dense structures were not basically avoided. In winter, horses change their food preferences and browse also young branches (Pantel 2011).

Except of one transect in the Przewalski enclosure the cover of shrubs decreased. This effect was much stronger in the red deer enclosure than in the Przewalski enclosure. The photo documentation of Pantel (2011) confirms this observation. Other studies could not find any impact of horse grazing on shrubs (Austin & Urness 1995; Menard *et al.* 2002; Lamoot *et al.* 2005). In the last two years the cover of shrubs increased again on one transect in the red deer enclosure. This was probably because since two years the supplement feeding in winter had to be enlarged as one animal died after winter. Due to extra feeding, grazing in the terrain diminishes or the diet selection changes (Piek 1998).

Development of selected species and differences between horse and red deer grazing

The selected endangered species reacted differently to grazing. The coverage of *Danthonia decumbens* increased primarily in the red deer enclosure. This grass species benefits from the fact that red deer browsed grass layer less strongly. *Asperula tinctoria* decreased on grazed transects but also on the reference sites. The endangered species *Scabiosa canescens* declined in the red deer enclosure and on one reference. Both declines seem to be a reaction to changing environmental conditions. In contrast, *Scabiosa canescens* benefits from horse grazing this species is a rosette species and these are favoured by grazing (Noy-Meir *et al.* 1989; Kahmen 2004). The coverage of *Allium carinatum* remained constant because the grazing animals did not eat it as it possesses essential oils (Dierschke & Briemle 2008).

Anthericum ramosum is considered to be sensitive to grazing (Rosquist & Prentice 2000) and decreased on almost all transects. Only in the Przewalski enclosure an increase could be found. Due to patch grazing of horses the species could find areas which were not grazed.

Primarily the dominant sweet grasses *Calamagrostis epigejos* and *Molinia caerulea* must be reduced to get the Pine forest more open. The coverage of dominant sweet grass species declined on all transects in the Przewalski enclosure. Horses prefer grass and other graminoid species. Especially *Molinia caerulea* is a preferred food of ponies (Putman *et al.* 1987). Pakeman (2004) found out that *Molinia caerulea* declined when grazing intensity increased. Several studies figured out that *Calamagrostis epigejos* decreased under grazing (de Bonte *et al.* 1999; Bromisch 2005; Rüther & Venne 2005; Korner *et al.* 2008; Kohyani *et al.* 2011). Due to low grass browsing in the red deer enclosure *Calamagrostis epigejos* increased.

Polygala chamaebuxus, a species characteristic for *Erico-Pinion* association (Sautter 2003) is considered to be insensitive to grazing. In contrast to this assumption, the coverage declined in the red deer enclosure. The reason for this could be the miss of thinning the grass layer. In the Przewalski enclosure an increase could be found. It is probably a response to changing environmental conditions because an increase of coverage was also observed on a reference site.

Particularly in open and transition areas the coverage of many species typical for open areas increased. In the Przewalski enclosure the effect was much stronger than in the red deer enclosure. After grazing ceased *Bromus erectus* spread out on a large scale (Dierschke 1985; Ellenberg & Leuschner 2010). As a result it was assumed that *Bromus erectus* declines by grazing. In this study, there was a decline in the Przewalski enclosure and an increase in the red deer enclosure. In a study of Bornkamm (2006) there was no decline of *Bromus erectus*. Other species typical for open areas, like *Carex caryophyllea, Carex humilis, Euphorbia cyparissias, Plantago media, Prunella grandiflora* and *Potentilla neumanniana* increased, too. An increase due to grazing for *Prunella vulgari*s (Willems 1983; Rieger 1996), *Euphorbia cyparissias* (Korner *et al.* 2008), *Potentilla neumanniana* (Rieger 1996), *Plantago media* and *Carex caryophyllea* (Rieger 1996; Bornkamm 2006) could also be found in other studies.

Conclusions

Grazing of pre-alpine Pine forests with large herbivores had a positive influence on vegetation and vegetation structure. A reduction of old grass stock and shrub layer took place and species diversity increased depending on the grazing animals. Przewalski horses diminished the shrub layer only weakly. In contrast, red deer were able to reduce the shrub layer much stronger, but not the grass layer. The results showed that for a more open character of vegetation reduction of grass layer is more important than reduction of shrub layer. Therefore, vegetation structure after eight years in the Przewalski enclosure was closer to the desired target than in the red deer enclosure.

Chapter 3

Vegetation development in the “Semi-open Pasture Landscape Höltigbaum” after 12 years of grazing management

Abstract

In Central Europe agricultural land declined due to developments in land cultivation techniques and changes in economic framework. That led to substantial losses of valuable open habitats in recent decades. Keeping open the remaining valuable habitats still presents a major problem for nature conservation. In recent years extensive grazing has become increasingly important as an alternative to mechanical management methods. A series of studies on “semi-open pasture landscapes” took place as an alternative management approach for extensively used landscape. In this study the project “Semi-open Pasture Landscape Höltigbaum” was on focus.

To analyse vegetation changes over time an indirect ordination method was used. Furthermore, statistical analyses were carried out with following parameters: species number, Eveness, grassland utilization indicator values (grazing, trampling tolerance, foraging value), cover of vascular plants, cover of cryptogams, cover of litter, average vegetation height and weighted Ellenberg values.

There were little changes in vegetation composition of poor grassland. Some sites developed towards poor grassland and on few sites succession has proceeded. In the first five years of grazing species number had increased followed by a decrease of species number. The development of habitat parameters showed an adaptation to grazing and confirmed the results of the multivariate analysis.

In conclusion, mixed grazing with cattle and sheep seems to be an ideal management tool for the maintenance of semi-natural landscape. The year round grazing maintained and

favoured structural diversity and the conservation of temporarily open and species-rich grasslands, dry grasslands and heathland was successful.

Introduction

In Central Europe agricultural land declined due to changes in land cultivation techniques and economic framework. That led to substantial losses of valuable open habitats in recent decades (Riecken *et al.* 2001). Particularly on marginal land and in so-called "peripheral areas" (Finck *et al.* 1998; Riecken *et al.* 2001; Härdtle *et al.* 2002) extensively used land was abandoned, whereas on productive sites agricultural land use was intensified. The decrease of semi-natural grasslands is one of the main problems for biodiversity conservation in Europe (Bignal & McCracken 1996; Pykälä 2000). An evaluation of red data books shows that a large proportion of endangered species and habitats are concentrated in extensively used agricultural areas and habitats, respectively (Hüppe 1997; Korneck *et al.* 1998; Riecken *et al.* 2004). Former military areas also contain considerable amounts of endangered plant and animal species (von Oheimb *et al.* 2006). If open habitats are abandoned, factors that determine habitat quality (e.g. light, temperature, provision of food) change and plants and animals typical for open landscape will go extinct (Härdtle *et al.* 2002).

Keeping open the remaining valuable habitats still presents a major problem for nature conservation. Traditionally used management treatments more and more achieved their limits. Often they did not have the desired success and restrict natural dynamics of habitats and their communities (von Oheimb *et al.* 2006). Additionally, it is becoming more and more difficult to finance the conservation management of these areas, mainly by mowing (Riecken *et al.* 1997; Tangen & Schmidt 1997; Völkl 1997; Werpachowski 2002). In recent years extensive grazing, as an alternative to mechanical management treatments, has been becoming increasingly important (Riecken *et al.* 1997). Unlike the past, extensive grazing methods are considered positively by experts (Oppermann & Luick 1999; Finck *et al.* 2002; Wagner *et al.* 2004; Pain 2005). Extensive grazing is a natural form of land use because in various natural landscapes in Europe wild large herbivores grazed for thousands of years (e.g. Geiser 1992; Bunzel-Drüke *et al.* 1994; Bunzel-Drüke M. 1997; Kampf 2000; Vera 2002).

In many European landscapes extensive grazing is an old traditional form of land use which has largely disappeared from our landscapes during the last two centuries (Kaule 2006). Due to changed economic framework extensive grazing often was abandoned or intensified. In Germany for example the so-called “Allmende” pastures have been largely disappearing since the beginning of 19th century (e.g. Beck 1996; Lederbogen *et al.* 2004; Poschlod 2015).

Under the framework of current agricultural policy and with limited financial resources large-scale pasture landscapes are seen as an appropriate method to preserve extensively used countryside (Finck *et al.* 2002). The objective of large-scale pasture landscapes is to combine both, economic and ecological demands, as opposed to traditional forms of agricultural practice (Härdtle *et al.* 2002). To maintain or to create highly diverse ecosystems, grazing at low stocking rates is required. Another important aspect is year-round grazing to keep the pastures in a semi-open state because in winter the animals graze less favoured plants to a greater extent (Eischeid *et al.* 2006). A series of studies on “semi-open pasture landscapes” as an alternative management approach for extensively used landscape took place in recent years. These have dealt with the problems and possibilities of a pasture strategy from different points of view (Assmann & Falke 1997; Finck *et al.* 1997; Riecken *et al.* 1997; Finck *et al.* 1998; Grell 1998; Riecken *et al.* 2001; Voß 2001).

The Project “Semi-open Pasture Landscape Höltigbaum” was established in 2000. The Höltigbaum is a former military training area and during military use a continuously changing mosaic of different habitats was evolving. There were pioneer communities of open ground, nutrient-poor grassland and more or less densely closed areas of shrub. After military use had ceased in 1992 considerable changes in vegetation took place. Trees and shrubs spread and the open landscape converted into a landscape of shrubby vegetation (Härdtle *et al.* 2002). For this reason, year-round grazing with a mixed herd of German grey heath and cattle was established. Following questions were on focus: (1) Can grazing maintain and promote open and species rich grasslands, dry grasslands and heathland? (2) What influence does grazing have on different habitat parameters and structural diversity?

Material & Methods

Study Site

The Trial and Development Project “Semi-open Pasture Landscape Höltigbaum” was carried out in the Höltigbaum Nature Reserve (55 m NN, annual precipitation 770 mm, mean annual temperature 8.6 °C). The Nature Reserve is located in the northeast of Hamburg and covers 540 ha. The project area encompasses 230 ha of this land, partly situated in the regional state of Schleswig-Holstein (ca. 180 ha) and partly in the territory of the city state of Hamburg (ca. 42 ha) (Figure 3-1). In the study area primarily sandy and loamy substrates predominate. Over a wide area mostly “pseudogleyic brown earths” are formed.

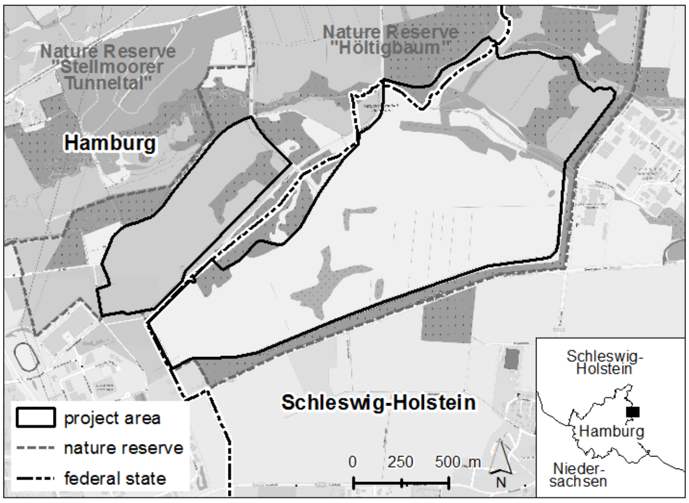

Figure 3-1 Project area „Semi-open Pasture Landscape Höltigbaum“ (©OpenStreetMap contributors).

Field methods

Within the study site 17 permanent plots (Table 3-1) were installed, designed as squares or transects. Permanent plots were selected primarily according to the criteria rarity and properties. Special attention was paid to pioneer habitats, heathland, nutrient-poor grassland and young successional stages. Furthermore, other large vegetation stands representatives for Höltigbaum have been considered. In addition, areas which were regarded to have opportunities for development were included. The vegetation relevés took place according to a three-stage pattern of increasing intensity (Mierwald 1994) (Figure 3-2). The focus of this study was on the vegetation development in subplots. These subplots had a size of 2 x 5 meters and were located at the four sides of each square (Figure 3-2) or along transects. In the subplots percentage cover values have been estimated according to semi-quantitative Londo-scale (Dierschke 1994). The nomenclature followed Rothmaler (2011). Vegetation relevés have been conducted in the years 2000 - 2003, 2005 and 2012. Before grazing started vegetation on the permanent plots had been primarily recorded. Two permanent plots (PP 8, PP 17) could not be found again in 2012, and therefore, these plots were excluded from analyses.

Table 3-1 List of permanent plots. *= no vegetation data for 2012, excluded from analyses.

Site	Design	Habitat type	Number of subplots
PP1	square	dry sandy grassland	4
PP2	transect	pond	9
PP3	square	nutrient-poor grassland with shrubs	4
PP4	square	dry nutrient-poor grassland	4
PP5	square	birch forest	4
PP6	square	wet meadow	4
PP7	square	oak-birch forest	4
PP8*	square	sandy heathland	4
PP9	square	nutrient-poor grassland	4
PP10	square	nutrient-poor grassland (with thistles)	4
PP11	transect	trampling grassland (path)	5
PP12	square	alder forest	4
PP13	transect	sedge reed,	6
PP14	square	dry sandy grassland	4
PP15	square	wet grassland fallow	4
PP16	transect	Juncus acutiflorus reed	10
PP17*	square	dry sandy grassland	4

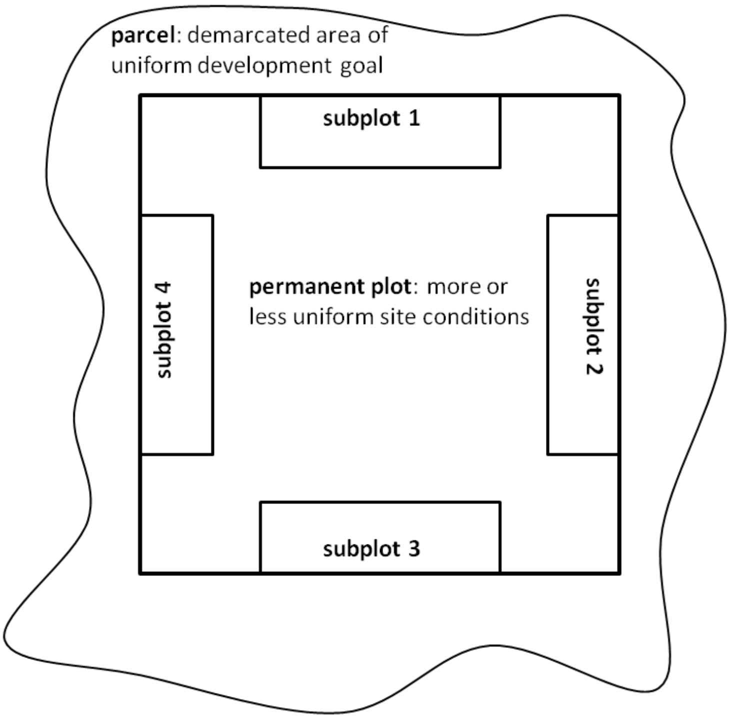

Figure 3-2 Three-stage processing mode for permanent plots (according to Mierwald 1994). Parcel: vegetation relevés according to Braun-Blanquet (1964), semi-quantitatively according to the refined scale of Reichelt & Wilmanns (1973); permanent plot (30 x 30 m): species list; subplot (2 x 5 m): 4 plots to avoid misinterpretations by vegetation contingencies, vegetation relevés according to Londo (1975).

Data analysis

The fifteen permanent plots were grouped into five habitat types (Table 3-2).

Table 3-2 List of habitat types and related sites.

Habitat type	Abbreviation	Related sites
poor grassland	PG	PP3, PP9, PP10
dry nutrient-poor grassland, heathland and trampling-communities	DNG, H, TC	PP1, PP4, PP11, PP14
wet grassland	WGr	PP6, PP15, PP16
temporary small waters and shores	TSW	PP2, PP13
woods and groves	WG	PP5, PP7, PP12

To analyse vegetation changes over time Detrended Correspondence Analysis (DCA) as an indirect ordination method (Hill & Gauch 1980) was used. The DCA was carried out with downweight rare species in PcOrd 5.17 (McCune & Mefford 2006). Mean species abundances per plot and year formed the basis of the main matrix. Furthermore, mean weighted Ellenberg indicator values per vegetation relevé for nutrient (N), light (L), moisture (F) and reaction (R) (Ellenberg *et al.* 2001) were estimated. Weighted values for grazing tolerance, trampling tolerance and foraging values were calculated, too. Grassland utilization indicator values can show the tolerance of plant stocks towards mechanical influences like trampling and feeding. Furthermore, the extent of reaction of vegetation to changed terms of use can be detected (Briemle *et al.* 2002). Besides, the species abundances of main matrix weighted Ellenberg indicator values, weighted grassland utilization indicator values, coverage of vascular plants, cryptogams (bryophytes and lichens) and litter as well as average vegetation height were included as habitat parameters to the second matrix. The diagram was presented as a biplot. Selected species were shown as vectors which pointed in direction of increasing abundance (Leyer & Wesche 2007). Also, appropriate to their correlation with axes, the habitat parameters were displayed as vectors (Ter Braak 1995). To illustrate the vegetation changes over time, vegetation relevés of different years were connected with arrows.

Additionally, the species number per transect and the Eveness were calculated. Eveness is the uniformity of the frequency, by which the species occur in a plot. This means, if all species occur with the same percentage, the value of Eveness is 1. The value of Eveness tends to zero if there are a lot of dominant species in a plot.

Furthermore, statistical analyses were carried out with following parameters: species number, Eveness, grassland utilization indicator values (grazing, trampling tolerance, foraging value), cover of vascular plants, cover of cryptogams, cover of litter, average vegetation height and weighted Ellenberg values. In 2005, no vegetation relevés took place for permanent plots 2, 5 and 12. Therefore, the single vegetation relevés of the year 2005 were not used for analyses.

Significant differences between the years were tested using Repeated Measures ANOVAs (RM-ANOVA) being robust against violation of assumptions (Field *et al.* 2012). The robust RM-ANOVA and following post hoc tests (for the omnibus test function rmanova() and for post hoc test function rmmcp() (Wilcox 2012)) were performed with R Software Version 3.0.3 (R Core Team 2014) using the web page of Rand Wilcox (URL: (http://dornsife.usc.edu/labs/rwilcox/software/). The groups were significantly different when confidence intervals do not overlap.

Results

Development of the five habitat types due to grazing

Figure 3-3 displays the ordination diagram of Detrended Correspondence Analysis (DCA) of vegetation data of the different habitats and years. Axis 1 represents 28.3% of the variance in the data set and Axis 2 represents 8.3%. The dry and wet open land areas were separated along the first axis. The plots of habitat type “wet grassland” and “temporary small waters and shores” are located at the right-hand side of the diagram. These plots were mainly characterised by a high average vegetation height and high proportions of nitrophilous and hygrophilous plant species. On the left-hand side the plots of habitat type “poor grassland” and “dry nutrient-poor grassland, heathland and trampling-communities” are placed. The plots at the left-hand side were mainly characterised by a high foraging value and mowing tolerance. The sites of habitat type “woods and groves” did not group together. Plots of alder forest (permanent plot 12) are arranged to wet areas. Plots of pioneer birch forest (permanent plot 5) are grouped to nutrient-poor and dry habitat types. The plots of oak-birch forest (permanent plot 7) are separated from the others along the second axis.

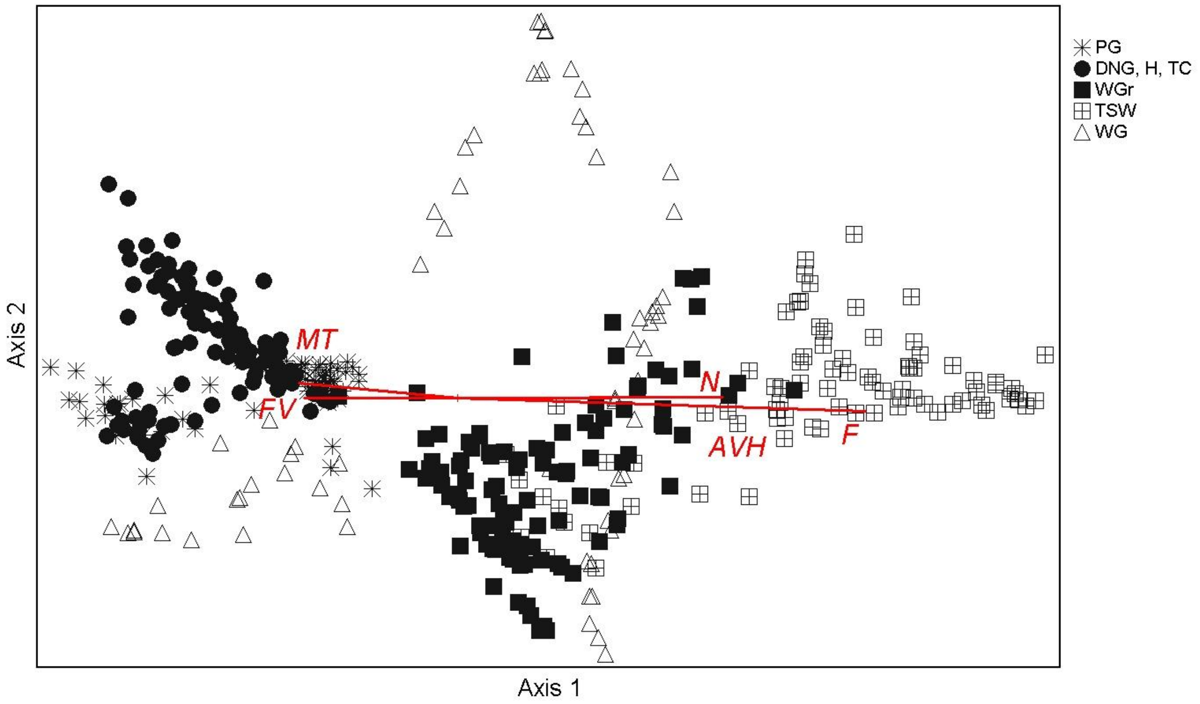

Figure 3-3 Detrended correspondence analysis (DCA) of 426 vegetation relevés on 15 permanent plots with 82 subplots in five habitat types. Weighted Ellenberg indicator values, habitat parameters and species were correlated with the axes. Axis 1 explains 28.3% of variance; Axis 2 explains 8.3% of variance. The length of gradient (Axis 1) is 7.5 SD. Cut-off-value for correlations of species abundances with axes: $r^2 > 0.3$. MT= mowing tolerance (r= -0.56), FV= foraging value (r= -0.56), AVH= average vegetation height (r= 0.55), N= weighted Ellenberg indicator Nitrogen (r= 0.73), F= weighted Ellenberg indicator Moisture (r= 0.91). PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

The ordination of vegetation changes in 15 permanent plots is presented in Figure 3-4. Plots of “wet grassland” and “temporary small waters and shores” are on the right-hand side and plots of “poor grassland” and “dry nutrient-poor grasslands, heathland and trampling-communities” on the left-hand side of the diagram. Sites on the right-hand side of the diagram were mainly characterised by *Lycopus europaeus, Juncus effusus* and high proportions of nitrophilous and hygrophilous plant species. On the left-hand side the plots were mainly characterised by high proportions of plant species with high foraging values. The plots 2, 3, 4, 11 and 14 showed no clear trend. The species composition of four plots (1, 5, 9 and 16) shifted to a varying extent mainly along Axis 1 to the right. A development in the opposite direction was found for another four plots (7, 10, 13 and 15). The plot 6 developed diagonally to the bottom right. The species composition of plot 12 shifted mainly along Axis 2.

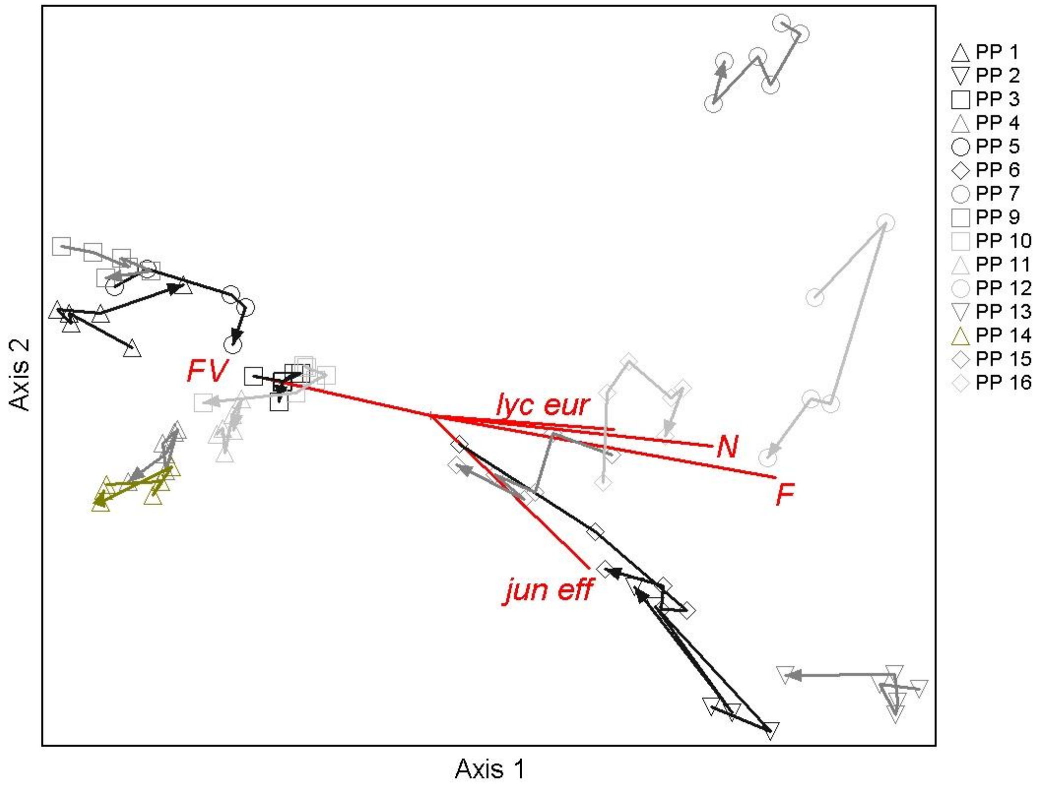

Figure 3-4 Detrended correspondence analysis (DCA) of vegetation progress on 15 permanent plots. Weighted Ellenberg indicator values, habitat parameters and species were correlated with the axes. Axis 1 explains 38.1% of variance; Axis 2 explains 14.1% of variance. The length of gradient (Axis 1) is 4.44 SD. Cut-off-value for correlations of species abundances with axes: $r^2 > 0.40$. Changes over time are marked through arrows, beginning with the initial state in the year 2000. The arrow head shows the year 2012. Correlations with first axis: lyc eur= *Lycopus europaeus* (r= 0.65), jun eff= *Juncus effuses* (r= 0.61), FV= Foraging value (r= -0.64), N= weighted Ellenberg indicator Nitrogen (r= 0.81), F= weighted Ellenberg indicator Moisture (r= 0.90). PP= permanent plot (see Table 3-1).

Figure 3-5 shows the mean species numbers per year for each habitat type. In Table 3-3 the results of the robust Repeated Measures ANOVAs (RM-ANOVA) and post-hoc tests (between first years and 2012) are summarised (see also Appendix 3-1). Species number increased on the sites of “poor grassland”. In “wet grassland” species number remained constant. For all other habitat types a decrease of species number was detected. Except “wet grassland”, on all these sites significant differences between the years were found.

Furthermore, each permanent plot was analysed. For almost all permanent plots significant differences could be noticed. However, many post-hoc tests achieved no result. Appendix 3-2 and Appendix 3-3 display statistical results of the robust RM-ANOVAs and the following post-hoc tests.

The Eveness values for all habitat types are presented in Appendix 3-4. The results of the robust Repeated Measures ANOVAs and post-hoc tests are summarised in Appendix 3-5. A decrease of Eveness was found in habitat type “dry nutrient-poor grassland, heathland and trampling-communities”. In all other habitat types Eveness increased. There were no significant differences between the years in “temporary small waters and shores” and “woods and groves”. Appendix 3-6 and Appendix 3-7 show statistical analysis of each permanent plot. Significant differences were detected for half of the plots. Post-hoc tests often achieved no result.

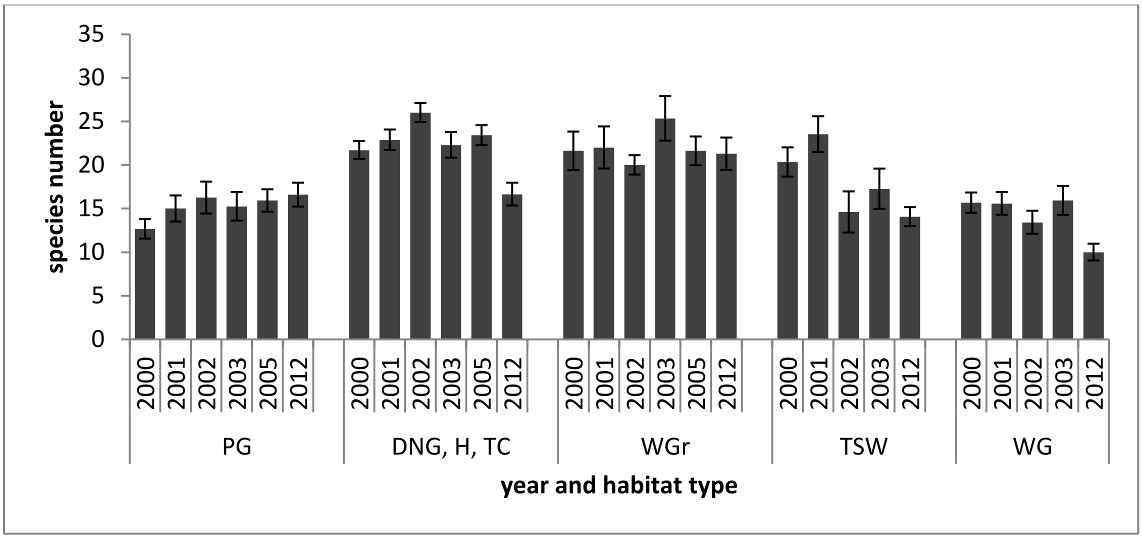

Figure 3-5 Mean species number and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Table 3-3 Differences in mean species number per habitat type. Results of the robust Repeated Measures ANOVA (RM - ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests between first years and 2012 are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	**RM-Anova**			**Differences between the years**				
	F	df		year	psihat	ci.upper	ci.lower	sig
PG	3.76*	2.65	18.54	2000 - 2012	-3.88	-7.39	-0.36	*
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	13.00***	3.33	33.29	2000 - 2012	-4.55	-7.16	-1.94	*
	F	df						
HG	0.84 n.s.	2.69	29.62					
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	7.28**	2.84	22.7	2000 - 2012	5.67	0.97	10.36	*
	F	df		year	psihat	ci.upper	ci.lower	sig
WG	4.72*	3.13	21.89	2002 - 2012	-1.88	-2.75	-1.00	*

Influence of grazing on habitat parameters and structural diversity

Grazing tolerant species increased on “poor grassland”, “dry nutrient-poor grassland, heathland and trampling-communities” as well as on “temporary small waters and shores” (Figure 3-6). For the habitat types “wet grassland” and “woods and groves” a decrease was found. Significant differences could be determined on “temporary small waters and shores” (Table 3-4, Appendix 3-8). Especially on permanent plot 2, the mean value of grazing tolerance rose from 2.9 to 4.7 (Appendix 3-9 and Appendix 3-10).

Mean value of trampling tolerance remained constant from 200 to 2012 on the sites of “poor grassland” (Appendix 3-11). In 2005, there was a slight decline. A decrease was found in “wet grassland”. In the remaining habitat types mean value of trampling tolerance increased. Significant differences could be detected for “poor grassland” and “temporary small waters and shores” (Appendix 3-12). Especially on permanent plot 2, the mean value of trampling tolerance rose from 3.9 to 6.1 (Appendix 3-13 and Appendix 3-14).

Appendix 3-15 displays the mean foraging value per year for each habitat type. On the sites of “temporary small waters and shores” foraging value increased. In the remaining habitat types the foraging value decreased. Significant differences could be determined for “temporary small waters and shores” (Appendix 3-16). Statistical analysis of each permanent plot could be found in Appendix 3-17 and Appendix 3-18. Significant differences were noticed for eight plots and post-hoc tests often achieved no result.

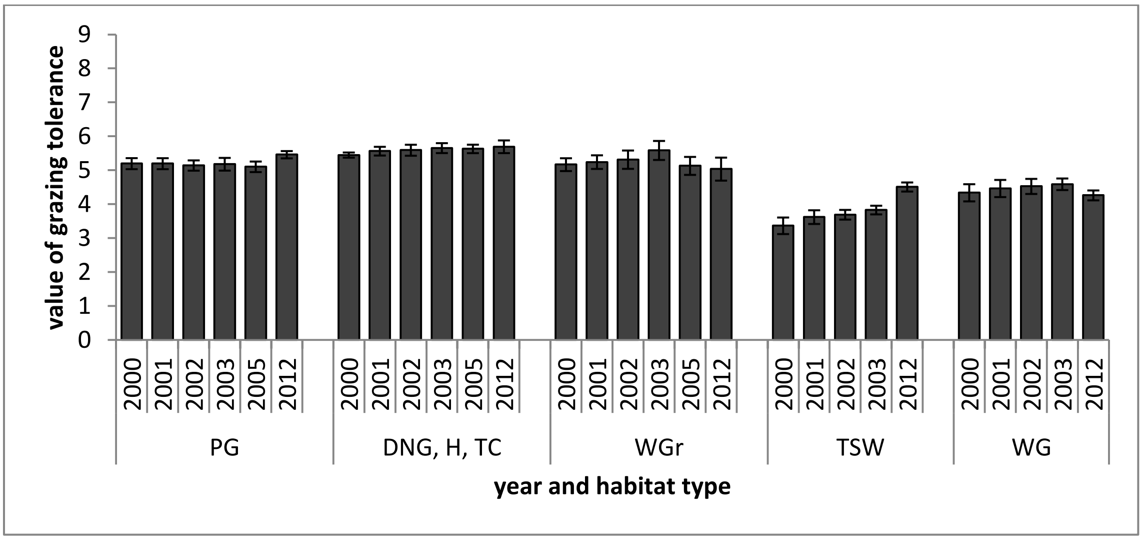

Figure 3-6 Values of grazing tolerance and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Table 3-4 Differences in value of grazing tolerance per habitat type. Results of the robust Repeated Measures ANOVA (RM - ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests between first years and 2012 are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	2.64 n.s.	2.63	18.42					
	F	df						
DNG, H, TC	1.32 n.s.	4.01	40.09					
	F	df						
HG	1.27 n.s.	2.32	25.51					
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	10.79**	1.43	11.43	2001 - 2012	-1.07	-2.01	-0.13	*
	F	df						
WG	0.58 n.s.	2.87	31.52					

Cover of vascular plants increased on “dry nutrient-poor grassland, heathland and trampling-communities” and “temporary small waters and shores” (Figure 3-7). On “wet grassland” and “woods and groves” a decline was detected. Cover of vascular plants stayed constant on “poor grassland”. Only the increase on “dry nutrient-poor grassland, heathland and trampling-communities” was significant (Table 3-5). Statistical analyses of each permanent plot are displayed in Appendix 3-19 and Appendix 3-20. Significant differences were determined in only five plots, but post-hoc tests achieved no result.

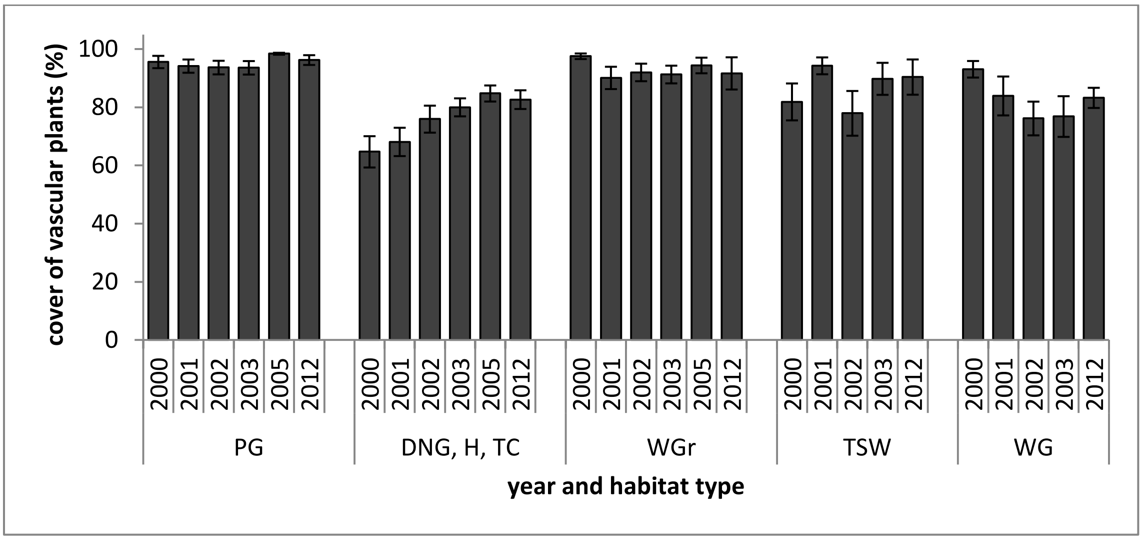

Figure 3-7 Cover of vascular plants (%) and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Table 3-5 Differences in cover of vascular plants (%) per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM - ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	2.93 n.s.	2.59	18.16					
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	7.97 ***	4.8	47.99	2000 - 2012	-17.00	-33.20	-0.80	*
	F	df						
WGr	0.98 n.s.	1.91	20.98					
	F	df						
TSW	1.71 n.s.	1.51	12.07					
	F	df						
WG	2.01 n.s.	2.79	19.5					

The cover of cryptogams (%) is illustrated in Figure 3-8. In Table 3-6 the results of the robust Repeated Measures ANOVAs and post-hoc tests (between the first years and 2012) are summarised (see also Appendix 3-21). The cover of cryptogams remained constant on “woods and groves”. On “wet grassland” and “temporary small waters and shores” an increase was found. At “poor grassland” and “dry nutrient-poor grassland, heathland and trampling-communities” the cover of cryptogams declined. Significant differences could be determined on “dry nutrient-poor grassland, heathland and trampling-communities”.

Appendix 3-22 and Appendix 3-23 show statistical analysis of each permanent plot. Significant differences were noticed for six plots, but post-hoc tests achieved no result.

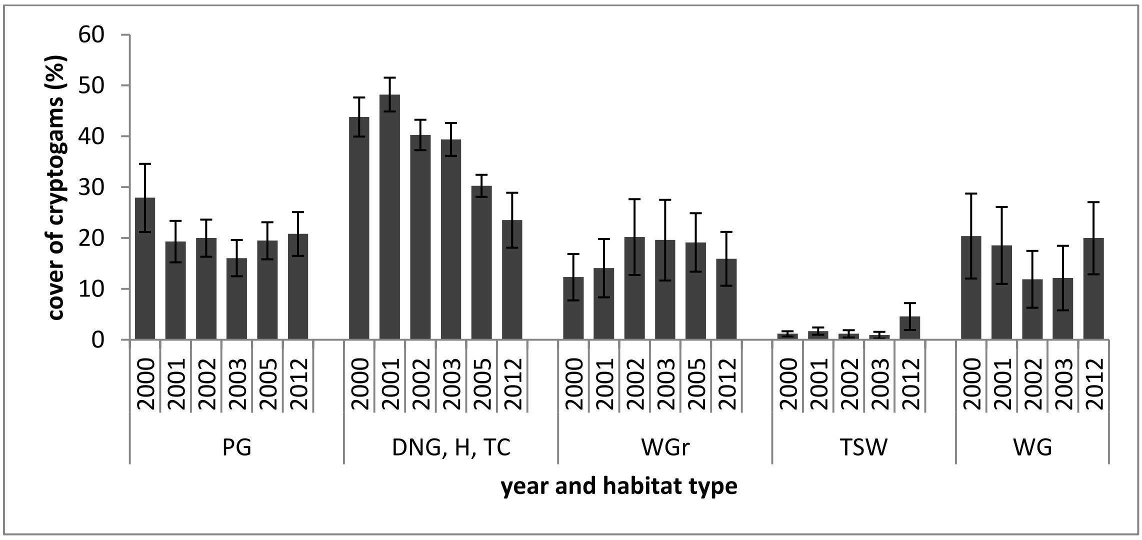

Figure 3-8 Cover of cryptogams (%) and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Table 3-6 Differences in cover of cryptogams (%) per habitat type. Results of the robust Repeated Measures ANOVA (RM - ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests between first years and 2012 are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	0.50 n.s.	3.71	26					
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	15.57***	4.97	49.7	2001 - 2012	31.36	9.48	53.24	*
	F	df						
HG	1.83 n.s.	2.01	22.14					
	F	df						
TSW	1.84 n.s.	1.32	10.56					
	F	df						
WG	0.34 n.s.	1.54	10.78					

Figure 3-9 shows the cover of the litter layer (%) per year for each habitat type. On “dry nutrient-poor grassland, heathland and trampling-communities” cover of litter stayed nearly constant. In the remaining habitat types cover of litter decreased. Significant differences could be detected for “wet grassland”, but post-hoc test achieved no result (Appendix 3-24).

Especially on permanent plots 6 and 15 cover of litter declined (Appendix 3-25 and Appendix 3-26).

Average vegetation height remained constant on “dry nutrient-poor grassland, heathland and trampling-communities” (Appendix 3-27). For all other habitat types a decrease could be determined. In 2003, vegetation height had the lowest values on all sites. Significant differences were determined mainly between 2003 and other years (Appendix 3-28). Statistical analyses of each permanent plot are shown in Appendix 3-29 and Appendix 3-30. Significant differences were noticed in only half of the plots and post-hoc tests often achieved no result.

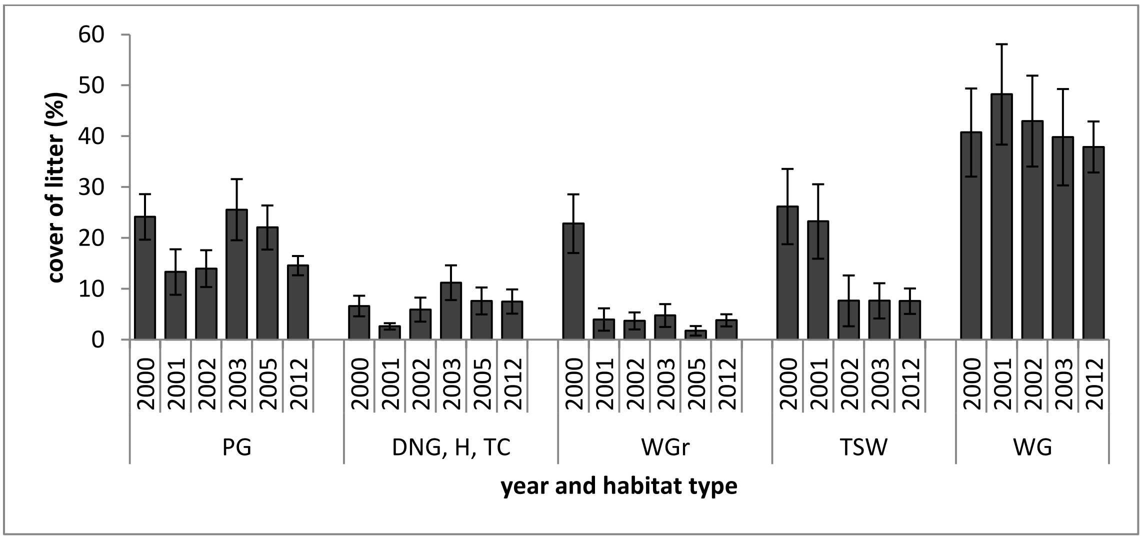

Figure 3-9 Cover of litter (%) and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Discussion

Development of the five habitat types due to grazing

Five permanent plots showed no clear vegetation development. Except one site of “temporary small waters and shores”, all plots can be assigned to dry and poor grassland. On these sites, there are no serious differences in species composition and abundances between 2000 and 2012. That confirms with findings that after five years of grazing no or only slight vegetation changes occurred (de Bonte *et al.* 1999; Stroh & Kratochwil 2004).

Species composition of four plots (7, 10, 13 and 15) of four different habitat types shifted to varying extent mainly along Axis 1 to the left. This means, vegetation composition of these areas approached to vegetation composition of poor grassland. One site, assigned to poor grassland, showed already 2005 the development towards a typical expression of a *Festuca rubra - Agrostis capillaris* association (von Oheimb *et al.* 2006). Also, the cover of thistle could be lowered on this plot. Zahn *et al.* (2003) found a decline of *Cirsium arvense* coverage due to grazing. One site of “woods and groves” also showed a positive vegetation change. The oak-birch forest is located in the immediate vicinity of wet grassland which was preferably used by cattle (Putfarken *et al.* 2008). Thus, the forest also was frequently used. Permanent plot 13, a sedge reed assigned to “temporary small waters and shores”, had showed no vegetation changes until 2005. Between 2005 and 2012 the plot was shifting along the first axis to the left. A change in the water regime appeared more likely than grazing influence. The permanent plot 15 was installed in an area of fallow wet grassland with periodically wet and degenerated soils. This plot showed a development in the direction of poor and dry grassland.

Species composition of another four plots (1, 5, 9 and 16) shifted to varying extent mainly along Axis 1 to the right. This means, vegetation composition of these areas moved away from vegetation composition of poor grassland. Succession advanced on plot 5 a birch pioneer forest on former neglected grassland site. On plot 16, assigned to wet grassland, the coverage of hygrophilous species could have risen. It is known that moisture-dependent plants are adapted to the impact of grazing or even rely on it (Barth *et al.* 2000). Two sites, one of “dry nutrient-poor grassland, heathland and trampling communities” and one of “poor grassland”, were affected by advanced birch growing. Between 2005 and 2012 there was a mechanical removal of birches on these sites. Hand (2011) and Eischeid *et al.* (2006) mentioned consecutive mechanical reduction of groves after the ending of the official project duration. But even after removal of birch, no increase in species number could be detected. This is in contrast to the statement of von Oheimb *et al.* (2006). They observed an increase in species richness in absence of birches, while the number of species declined in moderately to severely shaded areas.

Species number only increased on poor grassland. This result consists with other studies which showed that due to grazing species number on mesic grasslands increased (Bullock *et al.* 2001; Hellström *et al.* 2003; Pykälä 2005). An increase in species number on wet site could be recognised (Bokdam & Gleichman 2000; Wittig *et al.* 2000; Zahn *et al.* 2001; Zahn *et al.* 2003; Schaich & Konold 2006; Korner *et al.* 2008; Schaich & Barthelmes 2012) but this was not the case in this study. The outcome of this study did not confirm findings that due to grazing species richness of nutrient-rich sites will increase, whereas in nutrient-poor ones species richness will decrease (Proulx & Mazumder 1998). Zahn *et al.* (2003) noticed that after an initial increase species number decreased on less intensive used sites. However, on Höltigbaum the wet areas were still used intensively by cattle (personal observation) like Putfarken *et al.* (2008) pointed out. Until the project ended in 2005, species number had been remaining at least constant or increased. Only since then species number has been declining. A similar trend was found by Süss *et al.* (2011) on sandy ground. In the first six years of grazing, species number had remained relatively constant on a high level and in the last four years a decline occurred. Schaich & Konold (2006) could not find any significant changes in the parameter Eveness. In this study, Eveness increased in almost all habitat types. There was a positive effect of grazing on Eveness despite the decrease in species number. Grazing alters the competitive advantage between plant species both by direct removal of phytomass and by altering the light environment (Bullock & Marriott 2000). Therefore, the sites became more heterogeneous.

Influence of grazing on habitat parameters and structural diversity

Trampling of animals should cause changes in plant composition depending on intensity and soil conditions. Therefore, through grazing trampling-tolerant species should become more important and trampling-intolerant species should decrease (Nitsche & Nitsche 1994). The classification of plant species regarding their trampling tolerance is based primarily on the attributes plant height, growth form and life form (Briemle *et al.* 2002). An increase in trampling tolerance must therefore be interpreted as an increase of sod grasses and dwarf, prostrated herbs. The calculation of grassland utilization indicator values for Höltigbaum showed the adaption of vegetation composition to grazing. The grazing promoted trampling tolerant species but not everywhere to the same extent and not at all investigated areas. A marked increase of trampling tolerance, grazing tolerance and foraging value was found at the sites of "temporary small waters and shores". This is due to the intensive use of these sites by cattle. It is already known that cattle favour wet sites compared to dry sites (Bakker 2003; Stroh *et al.* 2004; Middleton *et al.* 2006). Putfarken *et al.* (2008) found out that on Höltigbaum cattle also preferred fresh to moist sites, while sheep preferred dry sites. Thus, poor grasslands recorded a relatively weak but consistent increase of trampling tolerance. Sheep were not able to cause greater soil wounding owing to their low body weight and small claws (Wittig *et al.* 2000; Voß 2001). The effect of increasing trampling and grazing tolerance due to cattle grazing was also detected in the Luxembourg Syr-wetlands (Schaich & Barthelmes 2012). Plant species, which are sensitive to trampling, found enough spatial and temporal niches because not all sites were constantly used by extensive grazing.

Heterogeneous development of the plots in the specific habitats is due to patch grazing. Loucougaray *et al.* (2004) noted that large herbivores grazed in a patchy way and produce a mosaic of vegetation. Intensively grazed areas alternated on small-scale with less intensively grazed areas (Bromisch 2005; Rüther & Venne 2005). Previously grazed short grass areas of high nutritive value were preferred by herbivores, Adler *et al.* (2001) termed this process "patch grazing". Due to patch grazing a mosaic of short and tall vegetation patches with opposing growth forms and plant traits is developing (Louault *et al.* 2005; Dumont *et al.* 2012).

The effects of patch grazing can also be seen in the development of different habitat parameters (cover of vascular plants, cryptogams, litter and vegetation height). Because of changing grazing intensities, the values of these parameters alternate between the years. Only on dry sites a steady increase in cover of vascular plants was found, whereas the cover of cryptogams continuously decreased. Probably, vascular plants could spread very well because of missing mechanical disturbances. Dry sites were preferably used by sheep which were not able to cause greater mechanical disturbances (Wittig *et al.* 2000; Voß 2001). The cryptogams presumably decreased because of the increased shadowing by vascular plants (Voß 2001). After grazing has started in 2000, cover of litter decreased on all open sites. This effect was also observed by others (Brunk *et al.* 2004; Schwabe *et al.* 2004; Storm & Bergmann 2004; Korner *et al.* 2008). Meanwhile, cover of litter increased on dry sites likely due to less intensive grazing. Also, the high temperatures in summer 2003, which induced enhanced plant death and consequently more dead plant material, could play a role. On wet grasslands, which were used intensively by cattle, the cover of litter decreased and remained on constant low level. Development of vegetation height showed no clear trend. The values alternated between the years on all sites. The very low vegetation height in 2003 is remarkable at all sites. Probably, the high temperatures in summer caused diminished plant growth. Furthermore, in 2002, vegetation height in “temporary small waters and shores” is remarkably high. This is due to the wet year 2002 (von Oheimb *et al.* 2006).

Conclusion

Under nature conservation aspects the effects of grazing on vegetation of Höltigbaum can be assessed predominantly positive. Year round grazing with a mixed herd of sheep and cattle maintained and favoured structural diversity in large parts on former military training area Höltigbaum. Conservation of temporarily open and species-rich grasslands, dry grasslands and heathland was successful. Almost on the entire study area the litter layer (accumulated during the fallow period) decreased significantly. Emergence of woody species could be delayed but not be stopped completely. Thus, accompanying measures, such as mechanical removal of woody species were applied. First success of these measures can already be seen on Höltigbaum. These positive effects could already be determined after five years of grazing (von Oheimb *et al.* 2006). Only species numbers which were positively influenced by grazing in the first five years decreased after twelve years of grazing. This development should be kept in mind. Nevertheless, mixed grazing with cattle and sheep seems to be an ideal management tool for the maintenance of semi-natural landscape.

Chapter 4

Comparison of long-term grazing experiments in Germany: a functional approach

Abstract

Semi-natural grasslands in Central Europe became threatened since the middle of the last century. Their high diversity in flora and fauna makes them extremely valuable for nature conservation. Large herbivore grazing is an established management treatment in a wide variety of natural areas in Europe. The plant functional trait approach is one possibility to receive general patterns. The functional approach is based on the assumption that plants with similar ecologically relevant trait attributes will respond to environmental changes in comparable ways. In the past two decades the use of plant functional traits was established to investigate processes in plant communities. During recent years several studies were addressing functional responses to management or were considering functional relationships between plant traits and changes in species frequency.

In this study various long-term grazing experiments should be compared using the functional approach. A comprehensive vegetation dataset of six different long-term grazing experiments was used to identify common trends. To analyse this data Nonmetric Multidimensional Scaling was used. The analysis showed that development of traits was convergent on single grazed sites for almost all sites and divergent on mixed grazed sites. On single grazed sites proportions of following trait attributes increased: preference eaten, short-term persistent seedbank, clonal growth yes, moderately grazing tolerant, moderately trampling tolerant, canopy height <0.3 m.

To conclude, it is important to ensure equal or quite similar grazing systems. Then, the functional approach is well suited for comparing grazed areas with various habitat types and different grazing animals. If areas have been coincidently grazed by two different species,

the functional traits tend to deviating developments. Therefore, mixed grazed areas should be considered individually, while single grazed areas are comparable very well.

Introduction

Semi-natural grasslands in Central Europe became threatened since the middle of the last century. From this time semi-natural grasslands have been fertilised, afforested or abandoned (Poschlod & Schumacher 1998; WallisDeVries *et al.* 2002). Their high diversity in flora and fauna attracts notice to nature conservation (Willems 1983; WallisDeVries *et al.* 2002). Large herbivore grazing is an established management treatment in a wide variety of natural areas in Europe (e.g. Bakker 1989; WallisDeVries *et al.* 1998; Olff *et al.* 1999; Adler *et al.* 2001; Redecker *et al.* 2002; von Oheimb *et al.* 2006; Gerken *et al.* 2008; Van Uytvanck *et al.* 2008; Metera *et al.* 2010; Süss *et al.* 2012). Many studies described changes in floristic composition in relation to grazing (see also Chapter 2 and 3 of this thesis), but their results are difficult to use in cross-regional comparisons or do not necessarily provide a better understanding of the mechanisms underlying the observed changes (Peco *et al.* 2005).

The plant functional trait approach is one possibility to receive general patterns (Kahmen & Poschlod 2008b). Plant functional traits are biological characteristics of plant species that respond to the dominant processes in an ecosystem (Keddy 1992; Kelly 1996; Gitay & Noble 1997; Lavorel *et al.* 2007). Species with similar trait attributions react similarly to changes in their environment (Gitay & Noble 1997). The functional approach is based on the assumption that plants with similar ecologically relevant trait attributes will respond to environmental changes in a similar way (McIntyre *et al.* 1995; Lavorel *et al.* 2007; Violle & Jiang 2009). Furthermore, traits are considered to be an adequate tool to investigate and predict community responses to environmental gradients (McGill *et al.* 2006; Webb *et al.* 2010). Functional approaches help to show underlying mechanisms leading to changes in plant species composition that could hardly be detected by mere floristic analyses (Drobnik 2011).

In the past two decades, the use of plant functional traits became established to study and understand the mechanisms responsible for the changes in plant communities (Lavorel & Garnier 2002; Diaz *et al.* 2004; McGill *et al.* 2006). In recent years several studies have addressed functional responses to management or have considered functional relationships between plant traits and changes in species frequency. Also, species and trait composition in a changing cultural landscape has been regarded (Cousins *et al.* 2003; Poschlod *et al.* 2003 and citations therein; Kahmen & Poschlod 2004; Louault *et al.* 2005; Navarro *et al.* 2006; Díaz *et al.* 2007; Gross *et al.* 2007; Kahmen & Poschlod 2008a; b; Römermann *et al.* 2009; Saatkamp *et al.* 2010; Catorci *et al.* 2013; Lauterbach *et al.* 2013; Catorci *et al.* 2014; Purschke *et al.* 2014; Vandewalle *et al.* 2014). Many studies on plant functional responses have been indirect analyses that examine the vegetation with regard to trait distribution (e.g. Diaz *et al.* 1998; Lavorel *et al.* 1999b; McIntyre *et al.* 1999; Köhler 2001; Kahmen *et al.* 2002; Kahmen & Poschlod 2004; Fukami *et al.* 2005). Trait response to grazing was analysed in temperate (Diaz *et al.* 1992; McIntyre *et al.* 1995; Lavorel *et al.* 1999a; Bullock *et al.* 2001; Dupré & Diekmann 2001), Mediterranean (Noy-Meir *et al.* 1989; Hadar *et al.* 1999; Sternberg *et al.* 2000; Catorci *et al.* 2014) and arid grasslands (Landsberg *et al.* 1999). There were general findings that grazing management selects for smaller species, short-lived species and species with high SLA values. In the reviews of McIntyre *et al.* (1999) and Peco *et al.* (2005) traits are listed which react to grazing. These studies often compared grazing experiments with the same grazers or equal habitat types (e.g. Díaz *et al.* 2001). Comparisons between different grazing systems, habitat types and grazers have been rarely performed until now. Nothing is known about differences or common trends when grazing experiments differ in various conditions.

Therefore, in this study various long-term grazing experiments should be compared. They differ in used animal species, grazing systems (single or mixed grazing) and habitat types. It was assumed, that various grazers promoted a diverse functional trait composition due to their different foraging behaviours. To detect differences or general patterns, a functional analysis was conducted. This analysis was chosen because study areas differ in their abiotic conditions and occurring plant species. Thus, a comparison of changes in floristic composition in relation to grazing was not possible. A comprehensive vegetation dataset of six different long-term grazing experiments was used to identify common trends. Following questions should be considered: (1) Are there any general patterns due to grazing? (2) How did plant functional traits change in relative importance over time?

Material & Methods

Study site

The comparative functional analysis was conducted with data from six different long-term grazing experiments (Table 4-1). All of the study sites have different conditions regarding grazing and habitats (Table 4-2). In Augsburg a pine forest is browsed separately by horses and red deer. On former military training area Höltigbaum different habitat types are grazed by sheep and cattle simultaneously. The fen meadow in Allgäu is pastured by cattle. The wet meadows in Lower Bavaria are grazed by cattle as well. Dry nutrient-poor grassland on Swabian Alb is browsed separately by horses and sheep. The former oak wood pasture in Solling-Vogler is pastured by Exmoor-ponies and Heck cattle simultaneously.

Table 4-1 Geographic and climatic characterisation of the 6 study sites. Altitude (m a.s.l.), precipitation (mm/year), mean annual temperature (°C), coordinates and abbreviations.

Area	Location	Number of sites	Coordinates	m a.s.l.	mm/year	°C
Allgäu in Bavaria	Pfefferbichl	2	N 47° 37' 39.7'' E 10° 46' 56.3''	800	1500	6-7
Swabia in Bavaria	Augsburg	8	N 48° 16' 26.9'' E 10° 54' 17.9''	509	830	8.1
Hamburg and Schleswig-Holstein	Höltigbaum	15	N 53° 37' 03.0'' E 10° 11' 23.2''	55	770	8.6
Lower Bavaria	Rohrstetten	1	N 48° 50' 41.7" E 13° 9' 11.7"	360-700	940 - 1100	5.6-8.1
Lower Bavaria	Liebmannsberg	1	N 48° 48' 41.9" E 13° 12' 5.6"	360-700	940 - 1100	5.6-8.1
Lower Bavaria	Ebenöd	1	N 48° 48' 0.2" E 13° 11' 28.9"	360-700	940 - 1100	5.6-8.1
Lower Bavaria	Kopfsberg	1	N 48° 43' 13.9" E 13° 11' 8.5"	360-700	940 - 1100	5.6-8.1
Baden-Wuerttemberg	St. Johann	2	N 48° 28' 56.1" E 9° 17' 7.2"	760	1000	6.5
Lower Saxony	Solling-Vogler	19	N 51° 41' 10.7" E 9° 29' 45.5"	290	1050	7

Table 4-2 Habitat and grazing management characterisation of the 6 study sites. Plot Abb.= Abbreviation of Plots, single= sites are grazed by only one animal species, mixed= sites are coincidently grazed by two species.

Location	Type of grazing	Start of grazing	Last record of permanent plots	Duration (years)	Plot Abb.	Habitat type
Augsburg	single, horse and red deer	2007	2014	8	A2	nutrient-poor grassland
					A3	nutrient-poor grassland
					A4	pine forest
					A5	pine forest
					A8	nutrient-poor grassland
					A9	nutrient-poor grassland
					A10	pine forest
					A11	pine forest
Pfefferbichl	single, cattle	2000	2012	12	Al2	fen meadow
					Al4	fen meadow
Höltigbaum	mixed, cattle and sheep	2000	2012	12	H1	dry nutrient-poor grassland
					H2	temporary small waters
					H3	poor grassland
					H4	dry nutrient-poor grassland
					H5	woods and groves
					H6	wet grassland
					H7	woods and groves
					H8	poor grassland
					H9	poor grassland
					H10	dry nutrient-poor grassland
					H11	woods and groves
					H12	temporary small waters
					H13	dry nutrient-poor grassland
					H14	wet grassland
					H15	wet grassland
Rohrstetten	single, cattle	1996	2013	17	NB1	wet grassland
Liebmannsberg	single, cattle	1996	2013	17	NB2	wet grassland
Ebenöd	single, cattle	1996	2013	17	NB3	wet grassland
Kopfsberg	single, cattle	1996	2013	17	NB4	wet grassland
St. Johann	single, sheep and horse	2000, 2006	2013	13, 7	SA1	nutrient-poor grassland
					SA2	nutrient-poor grassland
Solling-Vogler	mixed, cattle and horse	2000	2011	11	S1	dry grassland
					S2	dry grassland
					S3	dry grassland
					S4	oak forest
					S5	wet grassland
					S6	wet grassland
					S7	oak forest
					S8	oak forest
					S9	oak forest
					S10	oak forest
					S11	oak forest
					S12	oak forest
					S13	oak forest
					S14	oak forest
					S15	oak forest
					S16	oak forest
					S17	oak forest
					S18	oak forest
					S19	dry grassland

Field methods

The scientific monitoring on these sites did not take place for longer times. Therefore, renewed vegetation relevés took place in the years 2011 to 2014. Vegetation relevés were conducted using the methods of the first records (Table 4-3). The nomenclature followed Rothmaler (2011).

Table 4-3 Design and used methods of the study sites.

Location	Size of plots	Design	Cover values estimate according to
Pfefferbichl	1m x 1m	transects	extended Braun-Blanquet after Pfadenhauer *et al.* (1986)
Augsburg	2m x 2m	transects	Braun-Blanquet (1964)
Höltigbaum	2m x 5m	squares, transects	Londo-scale (Dierschke 1994)
Rohrstetten	4m x 4m	squares	extended Braun-Blanquet after Pfadenhauer *et al.* (1986)
Liebmannsberg	4m x 4m	squares	extended Braun-Blanquet after Pfadenhauer *et al.* (1986)
Ebenöd	4m x 4m	squares	extended Braun-Blanquet after Pfadenhauer *et al.* (1986)
Kopfsberg	4m x 4m	squares	extended Braun-Blanquet after Pfadenhauer *et al.* (1986)
St. Johann	2m x 2m	transects	Schmidt *et al.* (1974)
Solling-Vogler	5m x 5m	squares	percentage values

Data analysis

Data on plant traits were extracted from the databases LEDA (Knevel *et al.* 2003, www.leda-traitbase.org; Kleyer *et al.* 2008), BIOPOP (Poschlod *et al.* 2003; Jackel *et al.* 2006) and Biolflor (Klotz *et al.* 2002, http://www2.ufz.de/biolflor/index.jsp) (Table 4-4). Gaps in the data set were partly supplemented with data from gray literature (unpublished measurements from master theses a.o. of the working group). If more than one data entry for one species was available for one trait, the mean out of these values were taken for metric traits. Categorical traits were ranked according to appropriate rules (e.g. most frequently mentioned category was taken or when several entries on seed shedding were available, then the earliest mentioned month was taken as month of seed shedding minimum and the latest mentioned month as month of seed shedding maximum).

Table 4-4 Selected plant functional traits. Trait description, data sources, missing values. 560 species in total.

Trait	Attribute	Data source	% missing value
lifespan	short long	LEDA	0
life form	chamaephyte geophyte hemicryptophyte hydrophyte nanophanerophyte phanerophyte therophyte	LEDA	0
leaf distribution	regular semi-rosette rosette	LEDA	0
canopy height	<0.3 m 0.3-0.6 m >0.6 m	LEDA	0
SLA	<20 mm^2/mg 20-25 mm^2/mg >25 mm^2/mg	LEDA	9
clonal growth	yes no	BioPop	16
minimum bud bank depth	< -10 cm -10-0 cm 1-10 cm >10 cm	LEDA	18
seed bank	present transient short-term persistent long-term persistent	LEDA	13
maximum seed shedding	spring summer autumn winter	LEDA	21
preference	poisonous avoided eaten preferred food	BioPop	22
grazing tolerance	intolerant moderately tolerant well tolerant	Biolflor	30
trampling tolerance	intolerant moderately tolerant well tolerant	Biolflor	30

Since the multivariate distribution of the trait data was not known, Nonmetric Multidimensional Scaling (NMDS) was chosen as an indirect ordination method without underlying model of variable distribution. The NMDS is a rank based method of multivariate analysis that can be used if not normally distributed data or irregularly scaled data were available (Leyer & Wesche 2007). This indirect method was selected to analyse all traits and sites together for the first and last sampling dates. Twelve functional traits were selected for analysis (Table 4-4): lifespan, life form, leaf distribution, canopy height, SLA, clonal growth, minimum bud bank depth, seed bank, seed shedding maximum, preference, grazing tolerance, trampling tolerance. These traits were chosen because of their relevance regarding grazing influence, disturbance and competitive ability. Attribute proportions per trait were weighted by species abundances. Only those species for which a complete trait matrix was available were included in calculation of weighted trait values. The NMDS was carried out in PcOrd 5.17 (McCune & Mefford 2006) with the following configurations: Euclidean distance, three dimensions, best solution of 500 runs, stability criterion = 0.0005, random starting configuration. After the calculation, the ordination diagram was rotated so that the first axis pointed in direction of the time gradient. Furthermore, mean weighted Ellenberg indicator values per vegetation relevé for nutrient (N), light (L), moisture (F), and reaction (R) were estimated (Ellenberg *et al.* 2001). In addition to the time gradient, the weighted Ellenberg indicator values were included as habitat parameters to the second matrix. Additionally, the attribute proportions of all traits were correlated with both axes. The variance of the data set, which was represented by the two axes, was calculated by Euclidean distances after rotation.

In some cases analyses were not possible because the influence of several parameters was to strong. Thus, these parameters were deleted from the data set. Vegetation data for the first years of grazing in Solling-Vogler were not available. Therefore, analyses for this area were performed with data from the third grazing year.

For traits which had a Pearson correlation coefficient greater than 0.5 univariate statistics were carried out. Significant differences between the first and last year of grazing were tested using Wilcoxon-signed-rank-Tests. The Wilcoxon-signed-rank-Tests were implemented with IBM SPSS Statistics 22 for Windows (Bühl 2014). These tests could not be performed with data of Solling-Vogler because of no existing replications per site (no subplots).

Results

First analysis was performed with all sites and all traits. Thereby, no uniform trend could be found (Appendix 4-1 and Appendix 4-2). Also, the major part of variance in data was not explained by the axis which was correlated with time. Therefore, the data set was divided into two parts. The first new data set contained single grazed sites and the second set included mixed grazed sites.

Ordination diagram of NMDS for single grazed sites and all traits is presented in Figure 4-1. After calculation the diagram was rotated, so that Axis 1 points in the direction of temporal changes in trait composition between the first and last year of grazing (NMDS-time-axis). Axis 1 represents 50.8% and Axis 2 represents 37.5% of the variance in the data set. Pearson correlation coefficient ≥ |0.5| between both axes and attribute proportions are represented by the arrows in Figure 4-1. Direction of correlation is reflected by orientation of arrows. Most of the sites showed a directed development along the first axis. For two sites (A2, SA2) a positive development along the second axis and simultaneously a negative development along the first axis could be found. A negative trend along both axes could be noticed for the sites of fen meadow in Allgäu. One site (A4) developed positive along the first and the second axis and another site (A8) showed no development. No consistent trend could be found regarding the different habitat types. For example, some sites of wet grasslands developed positive (NB1, NB2, NB3, NB4) along the first axis others showed a negative development (Al2, Al4). The nutrient-poor grassland (A2, A3, A8, A9, SA1, SA2) showed also divergent trends. Differences between different grazers could not be detected. Cattle grazed sites (NB1, NB2, NB3, NB4), horse grazed sites (A3, A5), red deer grazed sites (A9, A10, A11) and one sheep grazed site (SA1) showed a similar development along the first axis. The strength of correlation between attribute proportions of all plant traits and both axes is presented in Table 4-5. Results of Wilcoxon-signed-rank-Tests (Appendix 4-3) between first and last year of grazing confirmed with the findings of NMDS.

Following plant traits were positively correlated (Pearson correlation coefficient ≥ |0.5|) with first axis: chamaephyte, canopy height <0.3 m, clonal growth, short-term persistent seed bank, preference eaten, moderately grazing tolerant, moderately trampling tolerant (Table 4-5). The proportions of these plant trait attributes increased on transects which showed a positive development along the first axis (Appendix 4-3). Following plant traits were negatively correlated (Pearson correlation coefficient ≥ |0.5|) with first axis: nanophanerophyte, phanerophyte, regular leaf distribution, canopy height >0.6 m, no clonal growth, preference poisonous, grazing intolerant, trampling intolerant (Table 4-5). The proportions of these plant trait attributes decreased on transects which showed a positive development along the first axis (Appendix 4-3).

Following plant traits were positively correlated (Pearson correlation coefficient ≥ |0.5|) with second axis: specific leaf area 20-25 mm^2/mg, minimum budbank depth 1-10 cm, maximum seed shedding autumn, preference eaten, well grazing tolerant, well trampling tolerant (Table 4-5). Following plant traits were negatively correlated (Pearson correlation coefficient ≥ |0.5|) with second axis: specific leaf area <20 mm^2/mg, minimum budbank depth >10 cm, maximum seed shedding summer, preference avoided, grazing intolerant, trampling intolerant (Table 4-5).

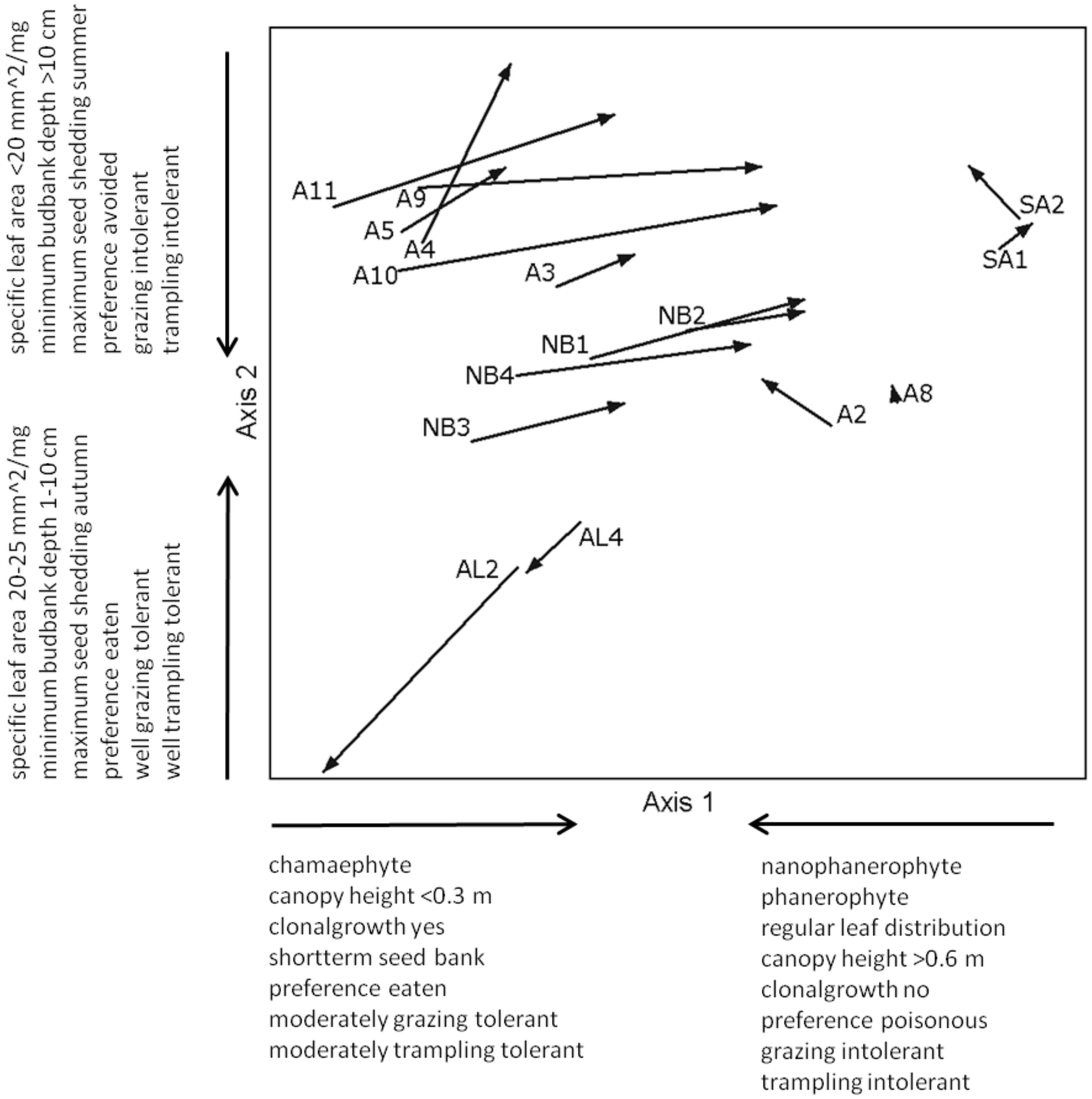

Figure 4-1 Ordination diagram of Nonmetric Multidimensional Scaling (NMDS) of all traits and single grazed sites. Attribute proportions per trait related to species abundances. The diagram was rotated in direction of the time gradient. Arrow base refers to the beginning of grazing and arrowhead refers to the last vegetation relevé. Pearson correlation coefficients of attribute proportions with the NMDS axes are visualised by the direction of the arrows. NMDS configuration: Euclidean distance, 3 dimensions, best solution of 500 runs, stability criterion = 0.0005, random starting configuration. Variance represented by Axis 1 = 50.8% and Axis 2 = 37.5%. A= Augsburg, Al= Allgäu, NB= Lower Bavaria, SA= Swabian Alb.

Table 4-5 Pearson Correlation coefficient between tested functional traits of single grazed sites and both axes. Correlation coefficients ≥ |0.5| printed in bold type.

Trait	Characteristic	Correlation coefficient with first axis	Correlation coefficient with second axis
lifespan	lifesshort	0,459	-0,081
	lifeslong	-0,454	0,090
life form	chamaephyte	**0,519**	0,135
	geophyte	-0,251	0,130
	hemicryptophyte	-0,033	**-0,672**
	hydrophyte	-0,317	**-0,688**
	nanophyte	**-0,586**	0,481
	phanerophyte	**-0,502**	0,497
	therophyte	0,282	0,001
leaf distribution	regular	**-0,835**	-0,210
	semirosette	0,041	-0,333
	rosette	0,298	0,424
canopy height in m	<0,3	**0,556**	-0,020
	0,3-0,6	0,344	-0,275
	>0,6	**-0,667**	0,221
specific leaf area in mm^2/mg	<20	-0,243	**-0,546**
	20-25	0,040	**0,784**
	>25	0,297	-0,116
clonalgrowth	yes	**0,704**	0,452
	no	**-0,704**	-0,452
minimum budbank depth in cm	<-10	-0,065	-0,003
	-10-0	-0,223	0,294
	1-10	0,430	**0,789**
	>10	-0,487	**-0,704**
seed bank	longterm	0,105	-0,187
	present	-0,136	-0,463
	shortterm	**0,504**	-0,039
	transient	-0,299	0,278
maximum seed shedding	spring	-0,265	0,123
	summer	-0,215	**-0,900**
	autumn	0,124	**0,625**
	winter	0,303	0,326
preference	eaten	**0,747**	**0,586**
	avoided	-0,497	**-0,809**
	poisonous	**-0,612**	0,406
	preferred	-0,336	0,188
grazing tolerance	intolerant	**-0,806**	**-0,536**
	moderately tolerant	**0,928**	-0,031
	well tolerant	-0,235	**0,722**
trampling tolerance	intolerant	**-0,652**	**-0,536**
	moderately tolerant	**0,901**	0,105
	well tolerant	-0,483	**0,597**

Analysis of the second data set (mixed grazed sites) showed no convergent development (Appendix 4-4 and Appendix 4-5). Also, the major part of variance in data was not explained by the axis correlated with time. Therefore, the data set was divided into two parts again. Thus, for the areas Höltigbaum and Solling-Vogler NMDS was carried out individually.

In Figure 4-2 the ordination diagram of NMDS is displayed for all traits and sites of Höltigbaum. After calculation the ordination diagram was rotated, so that Axis 1 points in direction of the time gradient. Graphic display was made with first and third axis because most of the variance in data was explained by them. Axis 1 represents 64.4% and Axis 3 represents 16.6% of the variance in the data set. The arrows in Figure 4-2 represent Pearson correlation coefficients ≥ |0.5| between both axes and attribute proportions. The orientation of arrows displayed the direction of correlation. Five sites showed a positive development along the first axis. Three sites passed through an opposite development over the years. A positive trend along the third axis could be found for another three sites. And the remaining four sites developed negatively along the third axis. Regarding the different habitat types no uniform trend could be observed. Correlation of attribute proportions of all plant traits with both axes is displayed in Table 4-6. Results of NMDS were confirmed by results of Wilcoxon-signed-rank-Tests (Appendix 4-6) between the first and the last year of grazing.

Following plant traits were positively correlated (Pearson correlation coefficient ≥ |0.5|) with first axis: hemicryptophyte, leaf distribution semi-rosette, canopy height <0.3 m, preference eaten, moderately trampling tolerant (Table 4-6). Following plant traits were negatively correlated (Pearson correlation coefficient ≥ |0.5|) with first axis: nanophanerophyte, regular leaf distribution, canopy height >0.6 m, no clonal growth, minimum budbank depth -10-0-cm, minimum budbank depth >10 cm, longterm seed bank, maximum seed shedding summer, preference avoided, grazing intolerant, trampling intolerant (Table 4-6).

Following plant traits were positively correlated (Pearson correlation coefficient ≥ |0.5|) with third axis: canopy height 0.3-0.6 m (Table 4-6). Following plant traits were negatively correlated (Pearson correlation coefficient ≥ |0.5|) with third axis: no clonal growth, minimum budbank depth <-10 cm, preference poisonous, moderately grazing tolerant (Table 4-6).

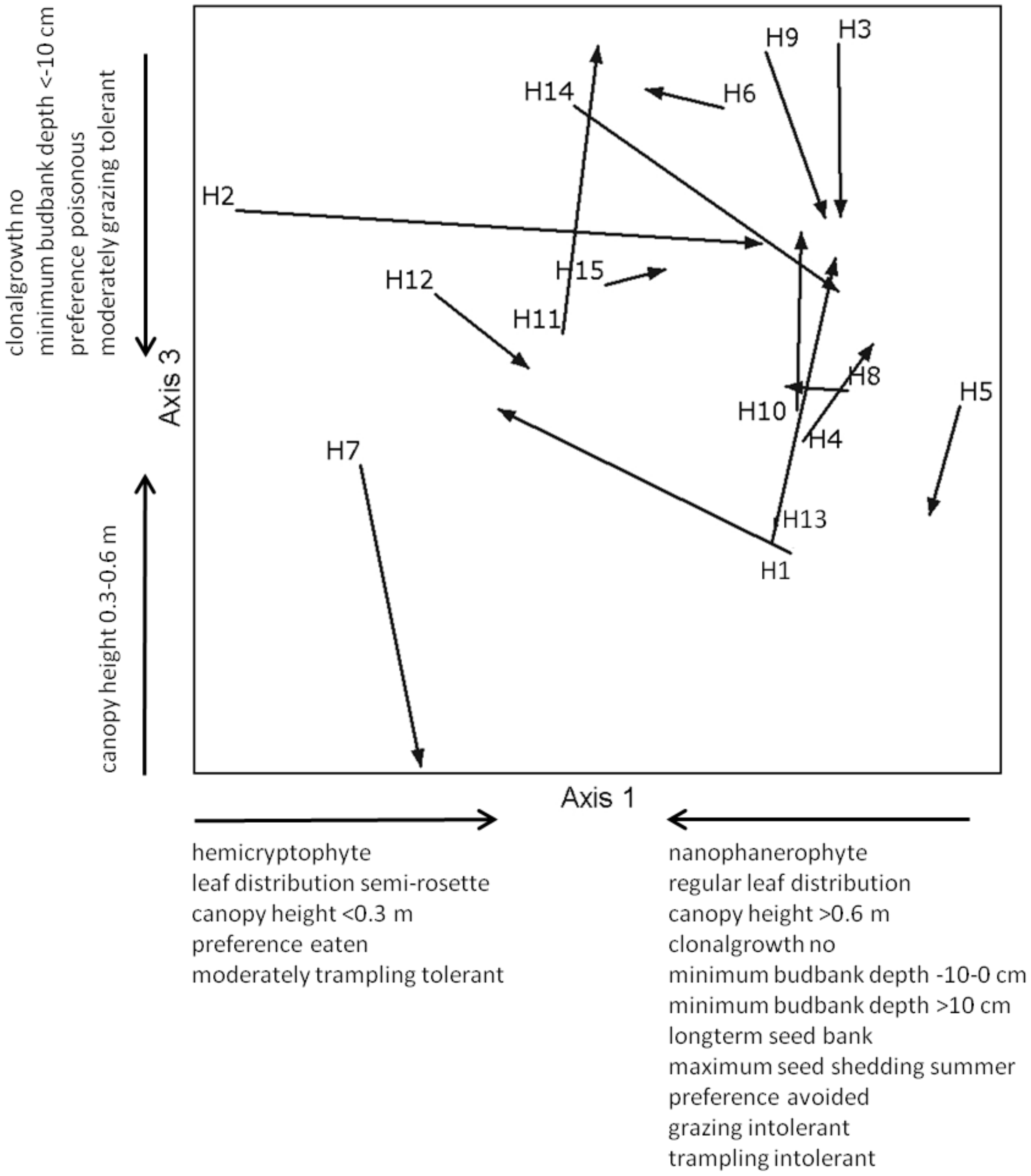

Figure 4-2 Ordination diagram of Nonmetric Multidimensional Scaling (NMDS) of all traits on Höltigbaum. Attribute proportions per trait related to species abundances. The diagram was rotated in direction of the time gradient. Arrow base refers to the beginning of grazing and arrowhead refers to the last vegetation relevé. Pearson correlation coefficients of attribute proportions with the NMDS axes are visualised by the direction of the arrows. NMDS configuration: Euclidean distance, 3 dimensions, best solution of 500 runs, stability criterion = 0.0005, random starting configuration. Variance represented by Axis 1 = 64.4% and Axis 3 = 16.6%. H= Höltigbaum.

Table 4-6 Pearson Correlation coefficient between tested functional traits of Höltigbaum and both axes. Correlation coefficients ≥ |0.5| printed in bold type.

Trait	Characteristic	Correlation coefficient with first axis	Correlation coefficient with second axis
lifespan	lifesshort	-0,308	-0,099
life form	chamaephyte	-0,071	-0,316
	geophyte	-0,411	0,214
	hemicryptophyte	**0,731**	0,203
	hydrophyte	-0,279	0,060
	nanophyte	**-0,521**	-0,421
	phanerophyte	0,181	-0,355
	therophyte	-0,348	-0,096
leaf distribution	regular	**-0,773**	-0,386
	semirosette	**0,573**	0,464
	rosette	0,318	-0,100
canopy height in m	<0,3	**0,750**	-0,434
	0,3-0,6	-0,039	**0,723**
	>0,6	**-0,875**	-0,138
specific leaf area in mm^2/mg	<20	-0,212	-0,214
	20-25	0,060	0,281
	>25	0,250	-0,040
clonalgrowth	no	**-0,588**	**-0,522**
minimum budbank depth in cm	<-10	-0,381	**-0,542**
	-10-0	**-0,724**	-0,210
	>10	**-0,620**	-0,156
seed bank	longterm	**-0,510**	0,151
	present	0,101	-0,162
	shortterm	0,410	-0,273
	transient	-0,022	0,171
maximum seed shedding	spring	-0,435	-0,144
	summer	**-0,678**	-0,112
	winter	0,145	-0,354
preference	eaten	**0,799**	0,084
	avoided	**-0,594**	0,233
	poisonous	-0,434	**-0,605**
	preferred	-0,380	-0,128
grazing tolerance	intolerant	**-0,867**	-0,240
	moderately tolerant	0,184	**-0,747**
	well tolerant	0,001	0,409
trampling tolerance	intolerant	**-0,889**	-0,133
	moderately tolerant	**0,734**	-0,008
	well tolerant	0,132	0,148

The ordination diagram of NMDS for all traits and sites of Solling-Vogler, is presented in Figure 4-3. After calculation, the ordination diagram was rotated, so that Axis 1 shows the time gradient (negative correlation). Graphic display was made with first and third axis because most of the variance in data was explained by them. Axis 1 represents 23.5% of the variance in the data set, whereas most of the variance is represented by Axis 3 (46.6%). Pearson correlation coefficients ≥ |0.5| between both axes and attribute proportions are represented by the arrows in Figure 4-3. Direction of correlation is reflected by orientation of arrows. A negative trend along the first axis could be found for six sites. One plot developed positively along the first axis. Seven sites showed a negative development along the third axis. The remaining four sites are positively oriented along the third axis. With regard to different habitat types no convergent development could be found. The intensity of correlation between attribute proportions of all plant traits and both axes is presented in Table 4-7.

Following plant traits were positively correlated (Pearson correlation coefficient ≥ |0.5|) with first axis: lifespan long, phanerophyte, canopy height >0.6 m, preference poisonous (Table 4-7). Following plant traits were negatively correlated (Pearson correlation coefficient ≥ |0.5|) with first axis: lifespan short, hemicryptophyte, canopy height 0.3-0.6 m (Table 4-7).

Following plant traits were positively correlated (Pearson correlation coefficient ≥ |0.5|) with third axis: hemicryptophyte, leaf distribution semi-rosette, canopy height <0.3 m, specific leaf area 20-25 mm^2/mg, preference eaten, moderately grazing tolerant, moderately trampling tolerant, well trampling tolerant (Table 4-7). Following plant traits were negatively correlated (Pearson correlation coefficient ≥ |0.5|) with third axis: geophytes, nanophanerophyte, leaf distribution regular, canopy height >0.6 m, specific leaf area <20 mm^2/mg, minimum budbank depth -10-0 cm, minimum budbank depth >10 cm, preference poisonous, grazing intolerant, trampling intolerant (Table 4-7).

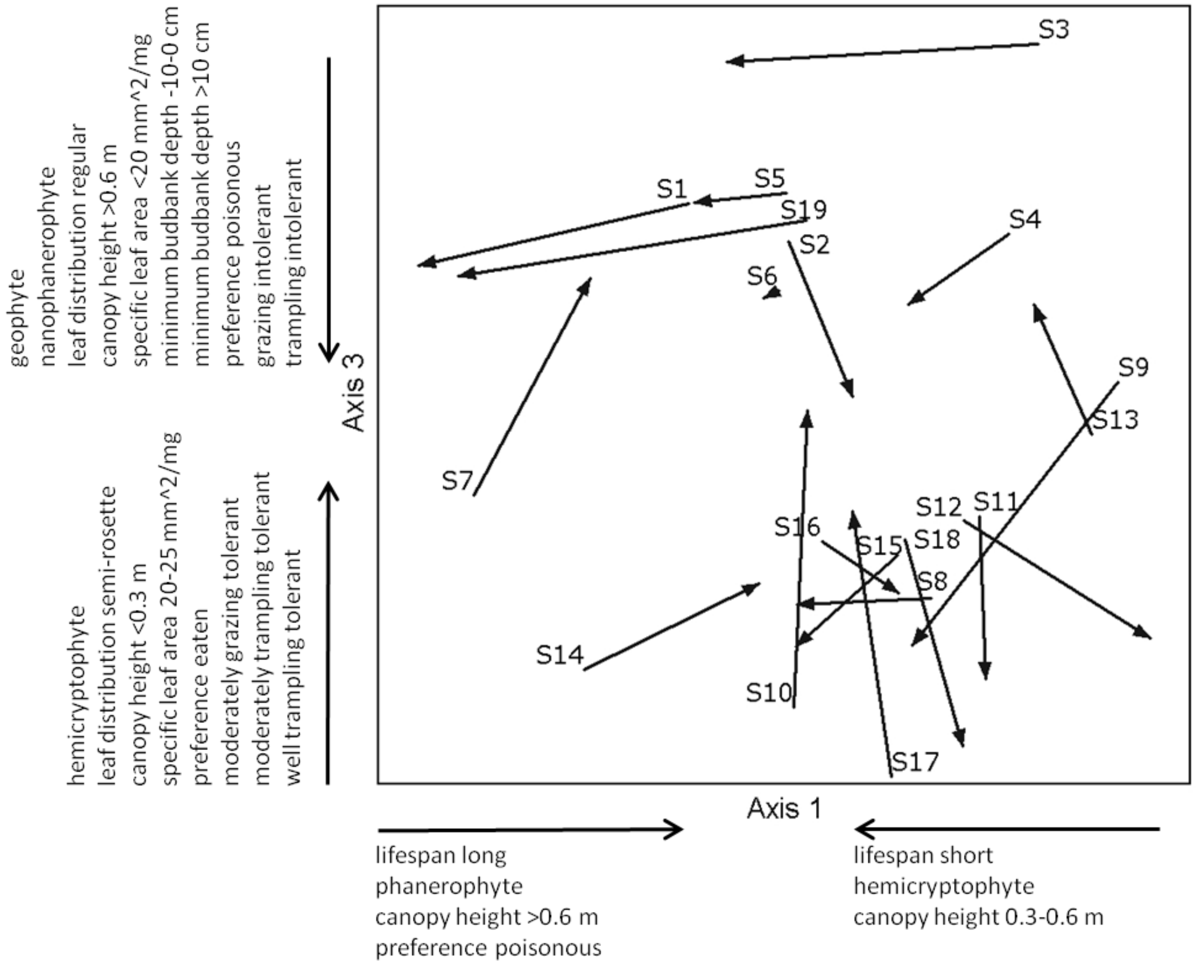

Figure 4-3 Ordination diagram of Nonmetric Multidimensional Scaling (NMDS) of all traits in Solling-Vogler. Attribute proportions per trait related to species abundances. The diagram was rotated in direction of the time gradient (negative correlated). Arrow base refers to the beginning of grazing and arrowhead refers to the last vegetation relevé. Pearson correlation coefficients of attribute proportions with the NMDS axes are visualised by the direction of the arrows. NMDS configuration: Euclidean distance, 3 dimensions, best solution of 500 runs, stability criterion = 0.0005, random starting configuration. Variance represented by Axis 1 = 23.5% and Axis 3 = 46.6%. S= Solling-Vogler.

Table 4-7 Pearson Correlation coefficient between tested functional traits of Solling-Vogler and both axes. Correlation coefficients ≥ |0.5| printed in bold type.

Trait	Characteristic	Correlation coefficient with first axis	Correlation coefficient with third axis
lifespan	lifesshort	**-0,770**	0,251
	lifeslong	**0,770**	-0,251
life form	chamaephyt	0,353	0,432
	geophyt	0,273	**-0,748**
	hemicryptophyt	**-0,610**	**0,690**
	nanophanerophyt	0,448	**-0,654**
	phanerophyt	**0,606**	-0,127
	therophyt	-0,326	-0,254
leaf distribution	regular	0,346	**-0,600**
	semirosette	-0,239	**0,580**
	rosette	-0,282	0,157
canopy height in m	<0,3	0,159	**0,813**
	0,3-0,6	**-0,855**	0,158
	>0,6	**0,586**	**-0,846**
specific leaf area in mm^2/mg	<20	0,497	**-0,771**
	20-25	-0,147	**0,507**
	>25	-0,409	0,437
clonalgrowth	yes	-0,229	0,190
	no	0,229	-0,190
minimum budbank depth in cm	<-10	0,329	0,003
	-10-0	-0,056	**-0,569**
	>10	0,181	**-0,503**
seed bank	longterm	-0,376	0,440
	present	0,221	0,277
	shortterm	-0,228	0,126
	transient	0,239	-0,316
maximum seed shedding	spring	0,165	0,223
	summer	0,249	0,062
	autumn	-0,053	-0,183
	winter	-0,231	0,132
preference	eaten	-0,049	**0,877**
	avoided	-0,382	-0,099
	poisonous	**0,595**	**-0,824**
	preferred	-0,435	-0,107
grazing tolerance	intolerant	-0,027	**-0,595**
	moderately tolerant	-0,062	**0,782**
	well tolerant	0,098	-0,235
trampling tolerance	intolerant	0,083	**-0,932**
	moderately tolerant	0,023	**0,682**
	well tolerant	-0,162	**0,675**

Discussion

Are there any general patterns?

The focus of the study was on time gradient in order to discuss general changes in trait composition which are caused by grazing. No uniform trend could be found when analysing all six grazing systems. Therefore, the data set was divided into two parts. A difference between grazing systems after separating the data in single grazed sites and mixed grazed sites could be observed. Development of traits was convergent on single grazed sites for almost all sites and divergent on mixed grazed sites.

Even within habitat types there are heterogeneous trends. Bullock *et al.* (2001) obtained similar findings. The response to grazing can vary, even within the same grassland, depending on which type of grazing was considered. In fact, main forces in grazing experiments selecting plant functional traits and strategies were grazing intensity, timing and stock type (Lavorel *et al.* 1999a; Lavorel *et al.* 1999b; de Bello *et al.* 2007; Catorci *et al.* 2012). Catorci *et al.* (2012) pointed out that equal stocking rates lead to similar reaction in plant functional traits. Stewart & Pullin (2008) pointed out that the intensity of grazing is more important than the species of grazer. In this study no differences in functional trait development with regard to different grazers could be detected. It was assumed, that various grazers promoted a diverse functional trait composition due to their different foraging behaviours. However, this assumption could not be confirmed in this study. Despite various grazing animals and different habitat types functional traits showed the same trends. Grazing intensity should be taken into account, as heavily grazed grasslands differ from more moderately grazed sites in having a deviating combination of individual traits (Dupré & Diekmann 2001). Values of functional diversity were similar when grazing pressure was comparable (Navas & Violle 2009; Catorci *et al.* 2012). Fluctuating levels of grazing intensity result in non-uniformity of functional response (e.g. McIntyre *et al.* 1995; McIntyre & Lavorel 2001). Both studied mixed grazing systems both several hundred hectares in size and the intensity of use is not consistent on the whole area (see also Chapter 3).

However, the effects of grazing are also dependent on the type of grazer and their selective feeding behaviour (Rook *et al.* 2004; Nolte *et al.* 2014), the type of grazed ecosystem and its productivity (Olff & Ritchie 1998; Pakeman 2004; Bakker *et al.* 2006) as well as on the grazing history of the region (Milchunas & Lauenroth 1993). On mixed grazed sites, types of grazers differing in their selective feeding behaviour often were installed. Therefore, plant functional traits frequently developed divergent. Plant functional traits could not show a convergent development due to alternating use of different grazers. Other parameters like regional climatic conditions (Vesk & Westoby 2001; de Bello *et al.* 2005), grazing history (Milchunas & Lauenroth 1993) and site productivity (Olff & Ritchie 1998; Pakeman 2004; Bakker *et al.* 2006) should not play any role as they should be equal on mixed grazed sites.

Changes in relative importance of plant functional traits

The study of life-history traits may help to answer the question which attributes are important with respect to the studied grazing regimes or other disturbances (Dupré & Diekmann 2001). Grazing-tolerant species often show rapid plagiotropic new sprout, storage organs and usually high SLA values. Species that avoid grazing damage are characterised by a very small height (especially rosette plants), by chemical or physical defences or by a phenological development that has already been completed before grazing usually starts. Díaz *et al.* (2007) demonstrated that worldwide grazing favoured annual over perennial species, short plants over tall ones, prostrate over erect plants, stoloniferous and rosette architecture over tussock architecture.

As mentioned before, in this study convergent developments could be found, especially on single grazed sites. Only one red deer grazed site in Augsburg showed no development in terms of functional traits. The reason for this is probably the lack of grazing in this area (see Chapter 2). For cattle grazed wet grassland in Lower Bavaria, the dry horse and red deer grazed sites in Augsburg and the sheep grazed site of the Swabian Alb a similar response to grazing could be detected. There are no differences in plant functional trait development between the various grazing animals. On the mixed grazed areas only wet grassland sites of Höltigbaum showed a convergent development along time axis. These sites are intensively used by cattle and are avoided by sheep (Putfarken *et al.* 2008). Thus, they were mainly grazed by one species and react like other single grazed sites.

On all sites, which developed positively along with time along Axis 1, the proportions of palatable plants increased. This rather unusual development could already be detected in Mediterranean grasslands. There, cover of highly palatable species was enhanced due to horse grazing (Catorci *et al.* 2012). This was in contrast to a lot of former studies. Wehsarg (1954) pointed out that higher grazing pressure on palatable plant species and therewith decreasing competiveness of these species may lead to an increase of toxic and palatable species in abundance and cover on grazed grasslands. Less-preferred species protected by low digestibility, secondary metabolites and morphological traits (e.g. thorns, spines) usually increased in cover (Distel & Boó 1996; Augustine & McNaughton 1998; Sternberg *et al.* 2000; Evju *et al.* 2009). Maybe, plants with low digestibility were sensitive to trampling and therefore declined in coverage. Thus, palatable plants could have a competitive advantage and increase in coverage. Nevertheless, also plants considered to be unpalatable or poisonous were eaten by grazing animals to some extent. *Anthericum ramosum* illustrates an example because it was eaten by horses and sheep in Augsburg (personal observation, see Chapter 2) although being considered as poisonous to livestock (foraging value 1 according to Briemle *et al.* (2002)).

The study has shown that species with a short-term persistent seed bank were promoted by grazing. Kahmen & Poschlod (2008b) also found a relative and absolute increase of species with a persistent seed bank. A persistent seed bank is a competitive strategy when soil disturbances through grazers occur randomly (Kahmen & Poschlod 2008b). Besides, grazing favoured species with a high capacity for vegetative reproduction (Oksanen & Ranta 1992; Vandvik 2004). As grazing encouraged those species with a certain grazing tolerance and vegetative growth represents such a tolerance strategy. It is known that grazing could prevent seed set by many grassland species (Coulson *et al.* 2001) and therefore, favour clonal species. In this and other studies an increase of clonal species could be detected (Landsberg *et al.* 1999; Barth *et al.* 2000; Wittig *et al.* 2000; Peco *et al.* 2005; Catorci *et al.* 2012). The expected increase of grazing and trampling tolerant species (Jackel *et al.* 2006) could be confirmed. The classification of plant species regarding their trampling tolerance is based primarily on the attributes plant height, growth form and life form (Briemle *et al.* 2002). An increase in trampling tolerance therefore must be interpreted as an increase of sod grasses and dwarf, prostrated herbs. Proportion of plants with a height lower than 0.3 m rose as a result of grazing. Plant height often is related to response to grazing. Small plant height is a known mechanism of grazing avoidance (Gibson 1988; Sala 1988; Noy-Meir *et al.* 1989; Belsky 1992; Diaz *et al.* 1992; Fernandez Ales *et al.* 1993). Due to smaller height plants are not eaten and have a competitive advantage.

The fen meadow in Allgäu showed a concurrent development in the opposite of time axis. No effect of grazing could be seen on both sites regardless those who previously were fallow or used as litter meadow. Proportions of functional trait attributes which were not related to grazing increased. Possibly the grazing pressure was too low on these sites over the years and the plants did not need to react to grazing. For example, plant height did not developed consistently at low grazing intensity (Louault *et al.* 2005).

Conclusions

A functional approach is, with reservations, well suited for comparing grazed areas with various habitat types and different grazing animals. Particularly, it is important to ensure equal or quite similar grazing systems. Especially, areas coincidently grazed by two different species tend to deviating developments in functional traits. This impedes a comparison, even within these areas. Therefore, mixed grazed areas should be considered individually, while single grazed areas are comparable very well. In order to find out if there are diverging developments of functional traits, due to the foraging behaviour of grazers, further investigations are necessary. The development of functional traits should be observed on sites of the same habitat type which are consequently grazed by different animals.

Chapter 5

Conclusions & Perspectives

Semi-natural grasslands belong to the most species-rich habitats in Central Europe (Poschlod & Schumacher 1998; Poschlod & WallisDeVries 2002; WallisDeVries *et al.* 2002). Since the middle of the last century semi-natural grasslands have been becoming increasingly threatened by increasing intensification of agricultural practices started on a large scale. They have been fertilized, afforested or abandoned (Poschlod & Schumacher 1998; WallisDeVries *et al.* 2002). Due to rising costs for the management (e.g. mowing) of semi-natural grasslands cheaper alternatives like grazing were on focus (Riecken *et al.* 1997; Kämmer 2001; Lühr 2007). There are very insufficient scientific studies about the comparison of different grazers. Studies about grazing occur mostly over a relatively short time period (often three years) (e.g. Redecker *et al.* 2002; Gilhaus *et al.* 2014).

The thesis at hand analyses different long-term grazing experiments with focus on the following questions: (1) What impacts do different grazing animals have on the same habitat type? (**Chapter 2**) (2) How did the vegetation develop on areas of still existing, but no longer scientifically monitored grazing experiments? Are there changes compared to results of former investigations? (**Chapter 3**) (3) Are there any similar patterns in functional traits considering different habitat types and grazing systems? (**Chapter 4**)

What impacts do different grazing animals have on the same habitat type?

The objective was to figure out if Przewalski horses and red deer are suitable to maintain and promote a semi-open Pine forest (**Chapter 2**). Therefore, the vegetation, vegetation structure and selected species were analysed. Grazing of pre-alpine Pine forests with large herbivores had a positive influence on vegetation and vegetation structure. A reduction of old grass stock and shrub layer took place and species diversity increased depending on the grazing animals. Przewalski horses diminished the shrub layer only weakly. In contrast, red deer were able to reduce the shrub layer much stronger, but not the grass layer. The results showed that a reduction of grass layer is more important than reduction of shrub layer to receive a more open character of vegetation. Therefore, vegetation structure after eight years in the Przewalski enclosure was closer to the desired target than in the red deer enclosure. Besides, this grazing experiment showed the importance of long-term observations because negative effects in the red deer enclosure occurred only after the first funding period of five years. Supplementary feeding in winter had to be performed due to animal welfare aspects. Thus, the impacts of grazing on vegetation changed. Former positive effects (decreasing shrub layer) moved into reverse. These changes could be detected relatively early because of on-going scientific monitoring. Nature conservation objectives could not be reached any more and the concept had to be adapted (giving up red deer grazing). This grazing experiment was inspired by the concept of “New Wilderness” (**Chapter 1**) and taking all together the concept is well suited to maintain semi-open Pine forests.

How did the vegetation develop on areas of still existing, but no longer scientifically monitored grazing experiments? Are there changes compared to results of former investigations?

The aim was to control the results of grazing experiments which are still existing, but no longer scientifically monitored. For this purpose, renewed vegetation relevés were carried out on the area of the project “Semi-open pasture landscape Höltigbaum” (**Chapter 3**). This grazing experiment was inspired by the concept of “Semi-open Pasture Landscape” (**Chapter 1**). The impact of grazing by a mixed herd of cattle and sheep on the vegetation, on different habitat parameters and on structural diversity was analysed. Under nature conservation aspects the effects of grazing on vegetation of Höltigbaum can be assessed predominantly positive. Year round grazing with a mixed herd of sheep and cattle maintained and favoured structural diversity in large parts on former military training area Höltigbaum. Conservation of temporarily open and species-rich grasslands, dry grasslands and heathland was successful. Almost on the entire study area the litter layer (accumulated during the fallow period) decreased significantly. Emergence of woody species could be delayed but not be stopped completely. Thus, accompanying measures such as mechanical removal of woody species were applied. First success of these measures can already be seen on Höltigbaum. Almost all results of former investigations (von Oheimb *et al.* 2006) could be confirmed. Therefore, the most important trends and changes occurred already within five years of grazing. Only species numbers which were positively influenced by grazing during the first five years decreased after twelve years of grazing. Nevertheless, the concept of "Semi-open Pasture Landscape" (**Chapter 1**) seems to be an ideal management tool for the maintenance of semi-natural landscapes.

Are there any similar patterns in functional traits considering different habitat types and grazing systems?

To answer this question a comparative functional analysis of different grazing systems was conducted (**Chapter 4**). This analysis was chosen because study areas differ in their abiotic conditions and occurring plant species and grazing regime as well as grazers. Thus, a comparison of changes in floristic composition in relation to grazing was not possible. A comprehensive vegetation dataset of six different long-term grazing experiments was used to identify common trends. General patterns could be observed. Namely, single grazed sites differ from mixed grazed sites. Development of functional trait attributes was convergent on almost all single grazed sites and divergent on mixed grazed sites. A functional approach is, with reservations, well suited for comparing grazed areas with various habitat types. Particularly, it is important to ensure equal or quite similar grazing systems. Especially, areas coincidently grazed by two different species tend to deviating developments in functional traits. This impedes a comparison, even within these areas. Therefore, mixed grazed areas should be considered individually, while single grazed areas are comparable very well. One single grazed site showed an increase in proportions of functional trait attributes which were not related to grazing. Probably, the grazing pressure was too low on these sites. This area was not scientifically monitored for a long time and this development could not be detected. This reflects the importance of accompanying investigations. Thereby, negative trends could be recognised early and appropriate measures (e.g. increased stocking rate) could be taken.

Main Conclusion

The thesis at hand was focused on scientific monitoring and comparability of long-term grazing experiments in Nature Conservation. Grazing experiments are very dynamic systems and need an adequate observation. Essential trends could be detected already after a few years of grazing (**Chapter 2, 3**). However, unexpected considerable changes could appear only after longer periods of grazing (**Chapter 2, 3**). Therefore, prolonged monitoring is important to recognise negative trends “in time” and countermeasures could take place at an early stage. The comparison of different grazing systems was not easy. Only if certain requirements (e.g. similar grazing systems) are fulfilled comparisons between different habitats and grazers are possible (**Chapter 4**). On mixed grazed areas a divergent development of functional trait attributes was found (**Chapter 4**). Certain diversity is intended on such areas and the divergent floristic development (**Chapter 3**) is compatible with the development of functional traits (**Chapter 4**). It was assumed, that various grazers promoted a diverse functional trait composition due to their different foraging behaviours. However, this assumption could not be confirmed in this study. Despite various grazing animals and different habitat types functional traits showed the same trends (**Chapter 4**). This study showed the importance of scientific monitoring of grazing experiments in Nature Conservation.

Perspectives

Grazing as a management tool in nature conservation will further gain importance due to financial benefits. Based on the current thesis, proposals for future research may be set up.

- In order to find out if there are diverging developments of functional traits, due to the foraging behaviour of grazers, further investigations are necessary. The development of functional traits should be observed on sites of the same habitat type which are consequently grazed by different animals.
- Grazing experiments are very dynamic systems and it is difficult to predict which developments occur in these areas. Therefore, predictions should be considered carefully.

- Grazing systems should be adapted continuously to changing conditions.
- Additional measures should be taken into consideration if the development does not proceed as desired.
- If possible, every grazing experiment should be scientifically monitored. If this is not possible for financial reasons, at least the initial state should be recorded. That facilitates evaluation at a later time.
- In the first years scientific monitoring should take place more frequently. If the development proceeds as desired, intervals of five years are appropriate.

Summary

Semi-natural grasslands are among the most species-rich and endangered ecosystems in Central Europe. Most of the Central European grasslands are man-made. Since the middle of the last century semi-natural grasslands have been becoming threatened when intensification of agricultural practice increased. They have been fertilized, afforested or abandoned. The maintenance of remaining semi-natural grasslands by management is one main task in European nature conservation. Traditional management methods (e.g. mowing, mulching) encounter their logistical and financial limits and grazing represent possible economically and ecologically viable alternatives for the conservation of open areas. There are very insufficient scientific studies about the comparison of different grazers and studies about grazing occur mostly over a relatively short time period (often three years). Therefore, the present study focused on scientific monitoring and comparability of long-term grazing experiments in Nature Conservation.

Chapter 2 dealt with the grazing effects of large herbivores on a pre-alpine Pine forest. In the Nature Reserve “Stadtwald Augsburg” year-round grazing with Przewalski horses and red deer should maintain these Pine forests. The vegetation development of both types of grazing and the difference between the grazers were on focus. To analyse vegetation changes over time an indirect ordination method was used. In order to document the effects of grazing on grass and shrub layer, mean values of grass and shrub species abundances were calculated. Additionally, the development of selected plant species was analysed. Vegetation composition of some sites in the Przewalski enclosure developed towards vegetation composition of open land. In the red deer enclosure the decline of shrub layer was greater than in the Przewalski enclosure. The decline of grass layer was greater in the Przewalski enclosure than in the red deer enclosure. These results can also be seen in the development of selected plant species. Vegetation structure after eight years in the Przewalski enclosure was closer to the desired target than in the red deer enclosure.

Chapter 3 focused on the vegetation development in the “Semi-open Pasture Landscape Höltigbaum” after twelve years of grazing management. Vegetation development after five years of grazing and after twelve years of grazing was compared. Analyses were conducted

with particular attention to the influence of grazing on different habitat parameters and structural diversity. There were little changes in vegetation composition of poor grassland. Some sites developed towards poor grassland and on few sites succession advanced. In the first five years of grazing species number had been increasing followed by a decrease of species number. The development of habitat parameters showed an adaptation to grazing and confirmed the results of the multivariate analysis. These positive effects could already be determined after five years of grazing. The mixed grazing with cattle and sheep seems to be an ideal management tool for the maintenance of semi-natural landscape. The year round grazing maintained and favoured structural diversity and the conservation of temporarily open and species-rich grasslands, dry grasslands and heathland was successful.

In chapter 4 a comparative analysis of six long-term grazing experiments in Germany was performed. By comparing long-term grazing experiments with a trait-based approach general patterns of grassland development due to grazing should be worked out. The change of plant functional traits in relative importance over time was taken into account as well. The functional approach was chosen because study areas differ in their abiotic conditions and occurring plant species. A comprehensive vegetation dataset of six different long-term grazing experiments was used to identify common trends. To analyse this data Nonmetric Multidimensional Scaling was used. The analysis showed that the development of traits was convergent on single grazed sites for almost all sites and divergent on mixed grazed sites. On single grazed sites proportions of following trait attributes increased: short-term persistent seedbank, clonal growth, preference eaten, moderately grazing tolerant, moderately trampling tolerant, canopy height <0.3 m. It is important to ensure equal or quite similar grazing systems. Then the functional approach is well suited for comparing grazed areas with various habitat types and different grazing animals. If areas have been coincidently grazed by two different species, the functional traits tend to deviating developments. Therefore, mixed grazed areas should be considered individually, while single grazed areas are comparable very well.

Finally, in Chapter 5 the results of the previous chapters were reviewed and concluding remarks were given. Essential trends could be detected already after a few years of grazing. However, unexpected considerable changes could appear only after longer periods of grazing. Therefore, prolonged monitoring is important to recognise negative trends in timely

manner and countermeasures could take place at an early stage. Comparison of different grazing systems was complex. If certain requirements (e.g. similar grazing systems) are fulfilled, even comparisons between different habitats and grazers were possible. On mixed grazed areas divergent development of functional trait attributes was found. Certain diversity is intended on such areas and the divergent floristic development was compatible with the development of functional traits. This study showed the importance of scientific monitoring of grazing experiments in Nature Conservation.

Zusammenfassung

Artenreiches Grünland gehört zu den bedrohten Ökosystemen in Mitteleuropa. Die meisten mitteleuropäischen Wiesen sind durch die Aktivitäten des Menschen entstanden. Seit Mitte des letzten Jahrhunderts sind diese Flächen immer mehr bedroht. Sie werden intensiviert, aufgeforstet oder fallen brach. Daher ist die Erhaltung des verbleibenden artenreichen Grünlandes eine Hauptaufgabe des europäischen Naturschutzes. Traditionelle Managementmethoden wie Mähen oder Mulchen stoßen mehr und mehr an ihre logistischen und finanziellen Grenzen. Die Beweidung stellt eine mögliche Alternative für die Erhaltung von Offenflächen dar, die sowohl ökonomisch als auch ökologisch tragfähig ist. Wissenschaftliche Studien sind lediglich in unzureichendem Umfang vorhanden und werden oft nur über relativ kurze Zeiträume ausgeführt. Daher konzentriert sich die vorliegende Studie auf die wissenschaftliche Begleitung und die Vergleichbarkeit von Langzeitbeweidungsversuchen im Naturschutz.

Kapitel 2 befasste sich mit den Auswirkungen der Beweidung mit großen Pflanzenfressern auf einen prä-alpinen, lichten Kiefernwald. Im Naturschutzgebiet „Stadtwald Augsburg“ soll eine Ganzjahresweide mit Przewalski-Pferden und Rotwild diese lichten Kiefernwälder erhalten. Im Fokus waren die Vegetationsentwicklung der beweideten Fläche und die Unterschiede zwischen den beiden Tierarten. Um die Vegetationsveränderungen über die Zeit zu analysieren, wurde ein indirektes Ordinationsverfahren angewendet. Die Auswirkungen der Beweidung auf die Gras- und Strauchschicht wurde ebenfalls dokumentiert. Zusätzlich wurde die Entwicklung ausgewählter Pflanzenarten verfolgt. Die Vegetationszusammensetzung einiger Flächen im Pferdegatter zeigte eine Annäherung an die Vegetationszusammensetzung von Offenflächen. Der Rückgang der Strauchschicht war im Rotwildgatter stärker als im Pferdegatter. Dafür nahm im Pferdegatter die Grasschicht mehr ab als im Rotwildgatter. Diese Ergebnisse sind auch in den Entwicklungen von ausgewählten Pflanzenarten zu sehen. Nach acht Jahren der Beweidung ist die Vegetationsstruktur im Pferdegatter näher am gewünschten Ziel als die des Rotwildgatters.

Kapitel 3 konzentrierte sich auf die Vegetationsentwicklung der „Halboffenen Weidelandschaft Höltigbaum“ nach zwölfjähriger Beweidung. Es wurde die

Vegetationsentwicklung nach fünf Jahren mit der nach zwölf Jahren Beweidung verglichen. Ein besonderes Augenmerk der Analysen lag auf dem Einfluss der Beweidung auf verschiedene Habitatparameter und die Strukturvielfalt. Die Vegetationszusammensetzung des mageren Grünlandes veränderte sich wenig. Einige Flächen entwickelten sich in Richtung mageres Grünland und auf anderen Flächen schritt die Sukzession voran. Die Artenzahlen erhöhten sich in den ersten fünf Jahren der Beweidung und sanken danach ab. Die Entwicklung der Habitatparameter zeigte eine Anpassung an die Beweidung und bestätigte die Ergebnisse der multivariaten Analyse. Die hauptsächlich positiven Entwicklungen konnten bereits nach fünf Jahren der Beweidung festgestellt werden. Die gemischte Beweidung mit Rindern und Schafen scheint ein geeignetes Managementverfahren zur Erhaltung halboffener Landschaften zu sein. Die Ganzjahresweide begünstigt die strukturelle Vielfalt und trägt zur Erhaltung offener artenreiche Wiesen, Trockenrasen und Heideflächen bei.

In Kapitel 4 wurde eine vergleichende Analyse von sechs Langzeitbeweidungsversuchen in Deutschland durchgeführt. Mit diesem funktionellen Vergleich sollten weidebedingte Muster in der Grünlandentwicklung herausgefunden werden. Auch von Interesse war, wie sich einzelne funktionelle Merkmale unter Beweidung verändern. Der funktionelle Ansatz wurde gewählt, da sich die untersuchten Gebiete in ihren abiotischen Bedingungen und vorkommenden Pflanzenarten unterschieden. Die Daten wurden mithilfe von Nonmetric Multidimensional Scaling ausgewertet. Es zeigte sich, dass die Entwicklung von Merkmalen auf einzelbeweideten Flächen konvergent und auf mischbeweideten Flächen divergent war. Die Anteile von Arten mit folgenden Merkmalen stiegen auf den einzelbeweideten Flächen an: kurzfristig dauerhafte Samenbank, klonales Wachstum, Bevorzugung gefressen, mittlere Beweidungstoleranz, mittlere Tritttoleranz, Wuchshöhe < 0,3 m. Wenn Weidesysteme gleich sind oder sich ähneln, ist ein Vergleich zwischen Flächen mit verschiedenen Lebensraumtypen und unterschiedlichen Weidetieren möglich. Werden Flächen gleichzeitig von zwei verschiedenen Arten beweidet, neigen funktionelle Merkmale zu divergenter Entwicklung. Daher sollten gemischt beweidete Flächen individuell betrachtet werden, während einzeln beweidete Flächen gut miteinander vergleichbar sind.

In Kapitel 5 werden schließlich die Ergebnisse zusammengefasst und Schlussfolgerungen gezogen. Die wesentlichen Trends können bereits nach ein paar Jahren der Beweidung erkannt werden. Erhebliche Veränderungen können auch erst nach längerer Weidezeit auftreten. Damit man negative Trends rechtzeitig erkennen kann und geeignete Gegenmaßnahmen frühzeitig starten können, ist ein langanhaltendes Monitoring nötig. Der Vergleich verschiedener Weidesysteme war jedoch nicht einfach. Es mussten gewisse Voraussetzungen gegeben sein, um einen Vergleich zwischen verschiedenen Habitaten und Weidetieren zu ermöglichen. Auf gemischt beweideten Flächen kam es zu einer divergenten Entwicklung der funktionellen Merkmale. In dieser Entwicklung zeigt sich die gewollte Strukturvielfalt dieser Flächen. Mit dieser Studie konnte gezeigt werden, dass die wissenschaftliche Begleitung von Beweidungsversuchen im Naturschutz von großer Bedeutung ist.

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Appendices

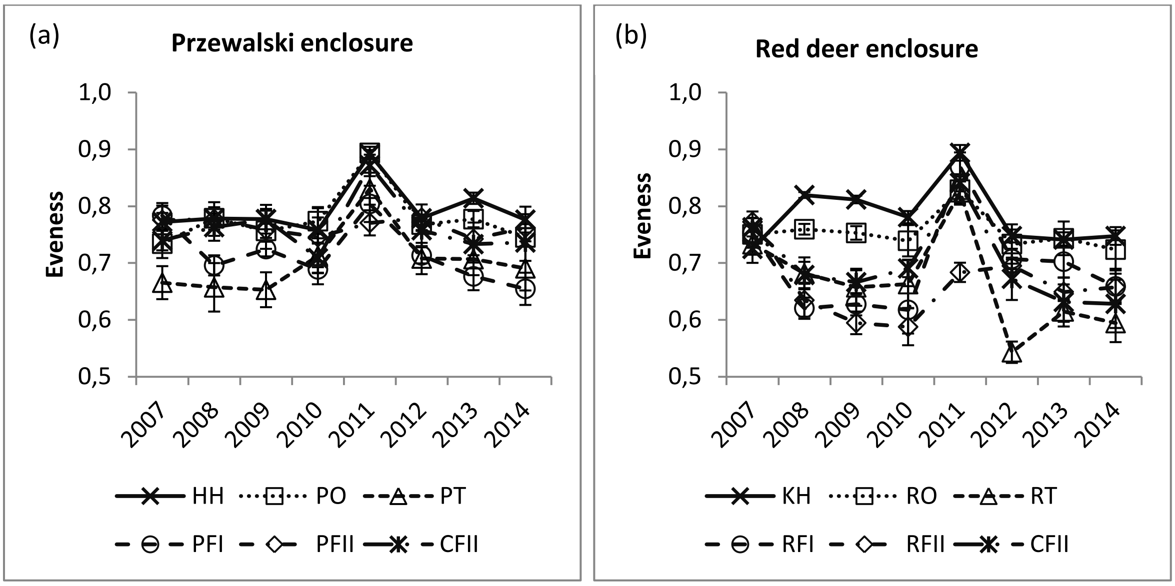
Appendix 2-1 **Differences in mean species number per transect between the years. Results of the One-way Repeated Measures ANOVA (RM – ANOVA) and post-hoc test Bonferroni for each transect.** Only significant results of post-hoc tests are shown. If the assumption of sphericity was violated Greenhouse & Geisser (1959) correction was used. F= test statistic, df= degrees of freedom, diff.= differences; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	**RM - Anova**		**Diff. between the years**		**Site**	**RM - Anova**		**Diff. between the years**	
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
HH	6.46***	7	2008 - 2011	-5.00*	**KH**	16.60***	7	2007 - 2012	-7.00**
			2008 - 2013	-5.25*				2007 - 2014	-3.75*
			2009 - 2011	-3.00*				2008 - 2009	-2.00*
			2010 - 2011	-6.00*				2008 - 2012	-4.88*
								2009 - 2012	-6.88***
								2012 - 2013	5.13**
	F	df	year	deviation (I-J)		F	df		
PO	4.87***	7	no result		**RO**	2.15 *n.s.*	7		
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
PT	9.50**	1.91	2010 - 2012	-2.38*	**RT**	4.47**	7	2008 -2014	3.25***
			2010 - 2013	-3.00*				2009 -2014	2.75**
			2010 - 2014	-3.50*					
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
PFI	2.33*	7	no result		**RFI**	5.91**	2.79	2009 -2014	1.63**
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
PFII	4.58*	2.54	2007 - 2010	1.75*	**RFII**	7.67*	2.55	2013 - 2014	2.38*
			2010 - 2013	-1.88*					
			2010 - 2014	-1.88*					
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
CFII	5.23*	1.66	2007 - 2008	2.00*	**CFI**	7.49**	3.56	2007 - 2010	2.00*

Appendix 2-2 Differences in mean species number between the sites in the years 2007 and 2014. Results of robust ANOVA and post-hoc-test. df= degrees of freedom, psihat= test statistic, se= standard error, ci= confidence interval, sig.= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

		2007					2014				
		robust ANOVA					robust ANOVA				
		test statistic		df	effect size		test statistic		df	effect size	
		81.06***		11; 23.5	0.904		100.60***		11; 23	0.758	
		post-hoc-test					post-hoc-test				
Comparison		psihat	se	ci.lower	ci.upper	sig.	psihat	se	ci.lower	ci.upper	sig.
HH	PO	10.67	1.56	5.83	15.17	*	6.17	1.85	-1.50	12.67	n.s.
HH	PT	19.33	3.00	8.83	27.00	*	14.83	3.76	4.17	26.17	*
HH	PFI	24.50	1.30	20.00	27.83	*	24.83	1.24	18.67	30.00	*
HH	PFII	24.83	1.38	20.00	28.50	*	24.17	1.15	18.50	29.00	*
HH	CFII	21.67	1.54	15.67	26.67	*	23.17	1.31	18.00	29.00	*
HH	KH	10.67	1.29	6.33	15.33	*	7.00	1.33	0.00	12.67	n.s.
HH	RO	3.67	1.62	-2.83	11.33	n.s.	0.33	1.52	-6.83	7.33	n.s.
HH	RT	22.83	1.45	16.50	28.00	*	24.17	1.85	16.33	30.50	*
HH	RFI	23.83	1.72	17.67	29.00	*	25.67	1.22	18.83	32.17	*
HH	RFII	22.17	1.63	16.33	26.17	*	25.67	1.25	20.33	31.33	*
HH	CFI	24.83	1.59	19.83	29.83	*	25.33	1.60	18.83	32.33	*
PO	PT	8.67	2.91	-1.33	16.17	n.s.	8.67	3.91	-3.17	19.67	n.s.
PO	PFI	13.83	1.09	10.00	17.33	*	18.67	1.63	12.00	22.83	*
PO	PFII	14.17	1.19	10.17	18.50	*	18.00	1.56	13.17	22.00	*
PO	CFII	11.00	1.36	6.00	16.33	*	17.00	1.68	11.50	21.17	*
PO	KH	0.00	1.08	-3.17	6.00	n.s.	0.83	1.69	-5.33	5.00	n.s.
PO	RO	-7.00	1.46	-13.50	1.00	n.s.	-5.83	1.85	-12.17	1.00	n.s.
PO	RT	12.17	1.26	6.50	17.00	*	18.00	2.13	10.17	24.17	n.s.
PO	RFI	13.17	1.57	7.17	18.00	*	19.50	1.61	13.33	25.17	*
PO	RFII	11.50	1.46	6.00	15.50	*	19.50	1.63	14.17	24.17	*
PO	CFI	14.17	1.42	9.83	19.83	*	19.17	1.91	13.33	24.33	*
PT	PFI	5.17	2.79	-1.50	13.83	n.s.	10.00	3.66	-2.00	19.83	n.s.
PT	PFII	5.50	2.82	-2.50	13.83	n.s.	9.33	3.63	-2.00	19.00	n.s.
PT	CFII	2.33	2.90	-6.00	11.50	n.s.	8.33	3.68	-2.83	18.83	n.s.
PT	KH	-8.67	2.78	-15.67	0.67	n.s.	-7.83	3.69	-19.17	1.67	n.s.
PT	RO	-15.67	2.95	-25.00	-4.83	*	-14.50	3.76	-26.50	-4.00	n.s.
PT	RT	3.50	2.86	-4.50	12.83	n.s.	9.33	3.91	-2.50	19.67	n.s.
PT	RFI	4.50	3.00	-5.17	13.83	n.s.	10.83	3.65	0.33	21.83	*
PT	RFII	2.83	2.95	-6.00	11.83	n.s.	10.83	3.66	0.33	21.33	*
PT	CFI	5.50	2.93	-2.50	14.83	n.s.	10.50	3.79	-1.33	21.50	n.s.
PFI	PFII	0.33	0.82	-2.33	3.00	n.s.	-0.67	0.74	-3.50	3.33	n.s.
PFI	CFII	-2.83	1.06	-6.67	0.33	n.s.	-1.67	0.97	-4.67	2.67	n.s.
PFI	KH	-13.83	0.66	-15.67	-10.50	*	-17.83	0.99	-22.67	-13.50	*
PFI	RO	-20.83	1.18	-25.67	-14.17	*	-24.50	1.24	-30.00	-16.33	*
PFI	RT	-1.67	0.93	-6.33	2.83	n.s.	-0.67	1.63	-6.83	5.17	n.s.
PFI	RFI	-0.67	1.31	-5.50	3.67	n.s.	0.83	0.84	-3.17	5.67	n.s.
PFI	RFII	-2.33	1.19	-6.83	0.50	n.s.	0.83	0.88	-2.17	6.17	n.s.
PFI	CFI	0.33	1.13	-2.67	4.50	n.s.	0.50	1.33	-3.33	6.17	n.s.
PFII	CFII	-3.17	1.16	-7.00	0.50	n.s.	-1.00	0.85	-3.50	1.83	n.s.
PFII	KH	-14.17	0.81	-16.67	-10.50	*	-17.17	0.87	-21.17	-14.33	*
PFII	RO	-21.17	1.27	-26.50	-14.00	*	-23.83	1.15	-28.67	-18.33	*
PFII	RT	-2.00	1.04	-6.50	2.00	n.s.	0.00	1.56	-5.50	4.67	n.s.
PFII	RFI	-1.00	1.39	-6.50	3.00	n.s.	1.50	0.70	-2.33	5.17	n.s.
PFII	RFII	-2.67	1.28	-7.33	0.50	n.s.	1.50	0.75	-1.33	4.83	n.s.
PFII	CFI	0.00	1.22	-3.33	4.67	n.s.	1.17	1.24	-2.17	4.83	n.s.
CFII	KH	-11.00	1.05	-14.17	-6.83	*	-16.17	1.08	-21.17	-12.83	*
CFII	RO	-18.00	1.43	-24.17	-10.00	*	-22.83	1.31	-27.67	-17.00	*
CFII	RT	1.17	1.23	-4.00	6.33	n.s.	1.00	1.68	-5.00	5.50	n.s.
CFII	RFI	2.17	1.55	-4.00	7.17	n.s.	2.50	0.94	-2.17	6.33	n.s.
CFII	RFII	0.50	1.44	-5.00	5.33	n.s.	2.50	0.98	-0.67	6.33	n.s.
CFII	CFI	3.17	1.39	-1.33	9.00	n.s.	2.17	1.39	-2.33	6.17	n.s.
KH	RO	-7.00	1.17	-12.17	0.00	n.s.	-6.67	1.33	-11.67	-0.33	*
KH	RT	12.17	0.91	7.17	16.00	*	17.17	1.69	11.17	23.67	*
KH	RFI	13.17	1.30	7.00	16.83	*	18.67	0.96	14.50	23.00	*
KH	RFII	11.50	1.18	6.33	14.00	*	18.67	1.00	15.50	23.17	*
KH	CFI	14.17	1.12	10.50	18.50	*	18.33	1.41	14.17	23.50	*
RO	RT	19.17	1.34	12.17	24.50	*	23.83	1.85	16.33	30.67	*
RO	RFI	20.17	1.63	12.83	26.00	*	25.33	1.22	18.00	31.00	*
RO	RFII	18.50	1.53	10.50	23.67	*	25.33	1.25	20.00	30.67	*
RO	CFI	21.17	1.49	14.00	26.83	*	25.00	1.60	18.67	30.00	*
RT	RFI	1.00	1.46	-5.67	7.33	n.s.	1.50	1.61	-4.50	7.00	n.s.
RT	RFII	-0.67	1.35	-6.17	4.17	n.s.	1.50	1.63	-3.67	7.83	n.s.
RT	CFI	2.00	1.30	-3.33	8.50	n.s.	1.17	1.91	-5.33	7.50	n.s.
RFI	RFII	-1.67	1.64	-8.00	3.83	n.s.	0.00	0.85	-3.83	5.67	n.s.
RFI	CFI	1.00	1.60	-4.00	7.33	n.s.	-0.33	1.31	-4.83	4.33	n.s.
RFII	CFI	2.67	1.49	-1.00	8.17	n.s.	-0.33	1.33	-4.67	4.17	n.s.

Appendix 2-3 **Eveness-values and standard error per transect in (a) Przewalski enclosure and (b) Red deer enclosure in the years 2007 to 2014.** HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.



Appendix 2-4 **Differences in Eveness-values per transect between 2007 and 2014. Results of the Wilcoxon Signed-Rank test.** Significant results printed in bold type (p<0.05). Z= test statistic, N= 8. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	Z	p-value	Site	Z	p-value
HH	0.00	1.000	**KH**	-1.54	0.123
PO	-0.14	0.889	**RO**	-0.56	0.575
PT	-0.70	0.484	**RT**	-2.38	**0.017**
PFI	-2.24	**0.025**	**RFI**	-1.96	0.050
PFII	-0.84	0.400	**RFII**	-2.38	**0.017**
CFII	-0.14	0.889	**CFI**	-2.10	**0.036**

Appendix 2-5 Differences in Eveness-values per transect between the years. Results of the One-way Repeated Measures ANOVA (RM – ANOVA) and post-hoc Bonferroni-test for each transect. Only significant results of post-hoc tests are shown. If the assumption of sphericity was violated Greenhouse & Geisser (1959) correction was used. F= test statistic, df= degrees of freedom, diff.= differences; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	RM - Anova		Diff. between the years		Site	RM - Anova		Diff. between the years	
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
HH	2.99*	7	no result		**KH**	7.40***	7	2007 - 2008	-0.09**
								2007 - 2009	-0.09**
								2008 - 2012	0.07**
								2008 - 2013	0.08*
								2009 - 2013	0.07*
PO	2.28*	2.90	no result		**RO**	0.34 *n.s.*	3.03		
PT	1.47 *n.s.*	2.55			**RT**	8.18***	7	2007 - 2012	0.19**
								2008 - 2012	0.14*
								2011 - 2014	0.10*
PFI	3.96**	7	no result		**RFI**	5.84**	3.08	2013 - 2014	0.04*
PFII	0.49 *n.s.*	2.67			**RFII**	9.79***	7	2007 - 2008	0.14*
								2007 - 2009	0.18**
								2007 - 2010	0.19**
								2007 - 2011	0.09*
								2007 - 2012	0.08*
								2009 - 2012	-0.10*
CFII	1.74 *n.s.*	1.91			**CFI**	2.43 *n.s.*	1.52		

Appendix 2-6 Differences in Eveness-values between the sites in the years 2007 and 2014. Results of robust ANOVA and post-hoc-test. df= degrees of freedom, psihat= test statistic, se= standard error, ci= confidence interval, sig.= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

		2007					**2014**				
		robust ANOVA					robust ANOVA				
		test statistic		df	effect size		test statistic		df	effect size	
		29.40*		11; 23.6	0.535		3.49**		11; 23.3	0.690	
		post-hoc-test					post-hoc-test				
Comparison		psihat	se	ci.lower	ci.upper	sig.	psihat	se	ci.lower	ci.upper	sig.
HH	PO	0.04	0.03	-0.07	0.15	n.s.	0.04	0.03	-0.06	0.14	n.s.
HH	PT	0.11	0.03	-0.01	0.23	n.s.	0.09	0.05	-0.08	0.25	n.s.
HH	PFI	0.00	0.03	-0.15	0.08	n.s.	0.12	0.04	-0.01	0.27	n.s.
HH	PFII	-0.01	0.02	-0.10	0.13	n.s.	0.01	0.04	-0.14	0.14	n.s.
HH	CFII	0.03	0.02	-0.05	0.12	n.s.	0.05	0.05	-0.11	0.18	n.s.
HH	KH	0.05	0.02	-0.03	0.12	n.s.	0.03	0.03	-0.08	0.13	n.s.
HH	RO	0.03	0.02	-0.07	0.10	n.s.	0.04	0.03	-0.08	0.21	n.s.
HH	RT	0.05	0.05	-0.11	0.16	n.s.	0.19	0.05	0.03	0.33	*
HH	RFI	0.01	0.02	-0.08	0.17	n.s.	0.11	0.03	-0.01	0.25	n.s.
HH	RFII	0.00	0.03	-0.10	0.09	n.s.	0.13	0.04	0.01	0.27	*
HH	CFI	0.01	0.02	-0.08	0.10	n.s.	0.16	0.06	-0.02	0.34	n.s.
PO	PT	0.07	0.03	-0.08	0.21	n.s.	0.05	0.04	-0.11	0.17	n.s.
PO	PFI	-0.04	0.04	-0.18	0.08	n.s.	0.08	0.03	-0.02	0.23	n.s.
PO	PFII	-0.05	0.03	-0.17	0.12	n.s.	-0.03	0.03	-0.12	0.09	n.s.
PO	CFII	0.00	0.03	-0.12	0.11	n.s.	0.01	0.04	-0.12	0.15	n.s.
PO	KH	0.02	0.03	-0.10	0.10	n.s.	-0.01	0.02	-0.09	0.09	n.s.
PO	RO	-0.01	0.03	-0.14	0.08	n.s.	0.00	0.02	-0.09	0.17	n.s.
PO	RT	0.02	0.05	-0.18	0.14	n.s.	0.15	0.04	0.02	0.30	*
PO	RFI	-0.03	0.03	-0.15	0.17	n.s.	0.07	0.02	-0.02	0.25	n.s.
PO	RFII	-0.03	0.03	-0.18	0.08	n.s.	0.08	0.02	-0.01	0.18	n.s.
PO	CFI	-0.03	0.03	-0.15	0.08	n.s.	0.11	0.05	-0.05	0.28	n.s.
PT	PFI	-0.11	0.03	-0.27	0.00	n.s.	0.03	0.05	-0.14	0.23	n.s.
PT	PFII	-0.12	0.02	-0.25	0.05	n.s.	-0.08	0.05	-0.23	0.10	n.s.
PT	CFII	-0.08	0.02	-0.19	0.05	n.s.	-0.04	0.06	-0.23	0.15	n.s.
PT	KH	-0.06	0.02	-0.19	0.06	n.s.	-0.06	0.05	-0.20	0.10	n.s.
PT	RO	-0.08	0.02	-0.20	0.04	n.s.	-0.05	0.05	-0.21	0.17	n.s.
PT	RT	-0.05	0.05	-0.25	0.08	n.s.	0.09	0.06	-0.08	0.32	n.s.
PT	RFI	-0.10	0.02	-0.23	0.09	n.s.	0.02	0.05	-0.13	0.21	n.s.
PT	RFII	-0.11	0.03	-0.25	0.03	n.s.	0.03	0.05	-0.13	0.21	n.s.
PT	CFI	-0.10	0.02	-0.22	0.02	n.s.	0.06	0.07	-0.14	0.29	n.s.
PFI	PFII	-0.02	0.03	-0.10	0.16	n.s.	-0.11	0.04	-0.26	0.03	n.s.
PFI	CFII	0.03	0.03	-0.06	0.15	n.s.	-0.07	0.05	-0.24	0.06	n.s.
PFI	KH	0.05	0.03	-0.03	0.17	n.s.	-0.09	0.04	-0.22	0.02	n.s.
PFI	RO	0.03	0.03	-0.06	0.16	n.s.	-0.08	0.04	-0.23	0.10	n.s.
PFI	RT	0.05	0.05	-0.11	0.20	n.s.	0.07	0.05	-0.12	0.22	n.s.
PFI	RFI	0.01	0.03	-0.07	0.18	n.s.	-0.01	0.03	-0.15	0.13	n.s.
PFI	RFII	0.00	0.03	-0.09	0.12	n.s.	0.01	0.04	-0.15	0.12	n.s.
PFI	CFI	0.01	0.03	-0.07	0.12	n.s.	0.04	0.06	-0.17	0.22	n.s.
PFII	CFII	0.05	0.02	-0.09	0.13	n.s.	0.04	0.05	-0.13	0.18	n.s.
PFII	KH	0.07	0.02	-0.09	0.13	n.s.	0.02	0.03	-0.09	0.12	n.s.
PFII	RO	0.04	0.02	-0.11	0.11	n.s.	0.03	0.03	-0.10	0.20	n.s.
PFII	RT	0.07	0.05	-0.15	0.16	n.s.	0.17	0.05	0.02	0.34	*
PFII	RFI	0.02	0.02	-0.12	0.19	n.s.	0.10	0.03	-0.03	0.26	n.s.
PFII	RFII	0.02	0.02	-0.15	0.10	n.s.	0.11	0.03	-0.03	0.24	n.s.
PFII	CFI	0.02	0.02	-0.14	0.11	n.s.	0.14	0.06	-0.03	0.31	n.s.
CFII	KH	0.02	0.02	-0.06	0.08	n.s.	-0.02	0.04	-0.14	0.12	n.s.
CFII	RO	0.00	0.02	-0.11	0.07	n.s.	-0.01	0.04	-0.16	0.20	n.s.
CFII	RT	0.02	0.05	-0.15	0.11	n.s.	0.14	0.06	-0.04	0.30	n.s.
CFII	RFI	-0.03	0.02	-0.12	0.15	n.s.	0.06	0.04	-0.08	0.24	n.s.
CFII	RFII	-0.03	0.02	-0.13	0.05	n.s.	0.08	0.05	-0.06	0.22	n.s.
CFII	CFI	-0.02	0.02	-0.11	0.06	n.s.	0.11	0.06	-0.08	0.31	n.s.
KH	RO	-0.02	0.02	-0.11	0.05	n.s.	0.01	0.03	-0.09	0.16	n.s.
KH	RT	0.00	0.05	-0.16	0.10	n.s.	0.16	0.04	0.02	0.31	*
KH	RFI	-0.05	0.02	-0.11	0.14	n.s.	0.08	0.03	-0.02	0.22	n.s.
KH	RFII	-0.05	0.02	-0.12	0.04	n.s.	0.09	0.03	-0.01	0.19	n.s.
KH	CFI	-0.04	0.02	-0.10	0.05	n.s.	0.12	0.05	-0.03	0.30	n.s.
RO	RT	0.02	0.05	-0.13	0.13	n.s.	0.14	0.04	-0.08	0.31	n.s.
RO	RFI	-0.02	0.02	-0.09	0.14	n.s.	0.07	0.03	-0.11	0.22	n.s.
RO	RFII	-0.03	0.02	-0.10	0.07	n.s.	0.08	0.03	-0.10	0.20	n.s.
RO	CFI	-0.02	0.02	-0.08	0.11	n.s.	0.11	0.05	-0.14	0.29	n.s.
RT	RFI	-0.05	0.05	-0.14	0.23	n.s.	-0.08	0.04	-0.22	0.09	n.s.
RT	RFII	-0.05	0.05	-0.16	0.13	n.s.	-0.06	0.05	-0.23	0.09	n.s.
RT	CFI	-0.05	0.05	-0.13	0.15	n.s.	-0.03	0.06	-0.23	0.15	n.s.
RFI	RFII	0.00	0.03	-0.19	0.09	n.s.	0.01	0.03	-0.14	0.14	n.s.
RFI	CFI	0.00	0.02	-0.17	0.09	n.s.	0.04	0.05	-0.16	0.23	n.s.
RFII	CFI	0.01	0.03	-0.07	0.12	n.s.	0.03	0.06	-0.13	0.20	n.s.

Appendix 2-7 Differences in mean cover of grasses per transect between the years. Results of the One-way Repeated Measures ANOVA (RM – ANOVA) and post-hoc Bonferroni-test for each transect. Only significant results of post-hoc tests are shown. If the assumption of sphericity was violated Greenhouse & Geisser (1959) correction was used. F= test statistic, df= degrees of freedom, diff.= differences; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	**RM - ANOVA**		**Diff. between the years**		**Site**	**RM - ANOVA**		**Diff. between the years**	
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
HH	5.54**	3.16	2007 - 2009	29.19*	**KH**	4.87*	2.18	2007 - 2009	-19.25*
			2007 - 2010	36.19**				2009 - 2010	20.94*
								2009 - 2011	21.13*
								2009 - 2014	23.81*
	F	df				F	df		
PO	*1.93* n.s.	2.90			**RO**	1.60 n.s.	7		
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
PT	7.37**	2.26	2007 - 2010	34.62*	**RT**	4.54*	3.03	2007 - 2013	-18.25*
	F	df	year	deviation (I-J)		F	df		
PFI	6.04***	7	2007 - 2014	17.38*	**RFI**	1.96 n.s.	2.43		
	F	df				F	df	year	deviation (I-J)
PFII	2.72 n.s.	2.43			**RFII**	14.60***	2.49	2007 - 2012	-20.38*
								2008 - 2012	-20.94*
								2009 - 2012	-20.81*
	F	df				F	df		
CFII	1.87 n.s.	1.92			**CFI**	3.20 n.s.	2.17		

Appendix 2-8 Differences in mean cover of grass between the sites in the years 2007 and 2014. Results of robust ANOVA and post-hoc-test. df= degrees of freedom, psihat= test statistic, se= standard error, ci= confidence interval, sig.= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

		2007					**2014**				
		robust ANOVA					robust ANOVA				
		test statistic		df	effect size		test statistic		df	effect size	
		15.07***		11; 22.5	0.804		8.87***		11; 21.7	0.660	
		post-hoc-test					post-hoc-test				
Comparison		psihat	se	ci.lower	ci.upper	sig.	psihat	se	ci.lower	ci.upper	sig.
HH	PO	9.42	4.70	-8.00	30.08	n.s.	8.75	11.16	-30.83	45.58	n.s.
HH	PT	2.58	10.89	-30.83	33.42	n.s.	22.50	8.91	-10.33	51.75	n.s.
HH	PFI	22.00	5.04	7.83	41.83	*	33.25	6.90	6.50	55.58	*
HH	PFII	29.67	5.16	4.50	48.17	*	23.33	7.90	-6.42	44.33	n.s.
HH	CFII	16.42	9.08	-1.67	45.83	n.s.	13.33	7.94	-13.50	41.42	n.s.
HH	KH	6.50	4.15	-4.50	16.83	n.s.	3.50	7.36	-28.42	27.17	n.s.
HH	RO	-9.25	4.75	-28.08	6.42	n.s.	-1.50	8.95	-42.67	24.42	n.s.
HH	RT	31.58	5.21	10.00	44.17	*	2.83	6.25	-21.08	32.50	n.s.
HH	RFI	16.00	6.83	-4.50	37.83	n.s.	7.25	10.01	-30.67	40.33	n.s.
HH	RFII	28.83	6.42	13.08	52.75	*	3.25	6.18	-20.25	22.42	n.s.
HH	CFI	10.08	4.51	-7.50	25.33	n.s.	0.50	8.00	-29.67	25.25	n.s.
PO	PT	-6.83	10.33	-47.17	24.75	n.s.	13.75	11.30	-18.01	54.67	n.s.
PO	PFI	12.58	3.69	-2.17	32.17	n.s.	24.50	9.78	-3.75	57.00	n.s.
PO	PFII	20.25	3.85	-7.50	39.83	n.s.	14.58	10.51	-15.00	50.75	n.s.
PO	CFII	7.00	8.40	-13.25	38.42	n.s.	4.58	10.54	-25.33	46.33	n.s.
PO	KH	-2.92	2.32	-18.17	8.58	n.s.	-5.25	10.11	-34.17	28.42	n.s.
PO	RO	-18.67	3.27	-38.08	-0.17	*	-10.25	11.33	-57.00	29.08	n.s.
PO	RT	22.17	3.91	-3.75	37.75	n.s.	-5.92	9.34	-28.75	36.58	n.s.
PO	RFI	6.58	5.90	-13.75	26.00	n.s.	-1.50	12.18	-40.00	39.75	n.s.
PO	RFII	19.42	5.41	2.67	42.42	*	-5.50	9.29	-27.50	26.58	n.s.
PO	CFI	0.67	2.91	-17.50	14.25	n.s.	-8.25	10.59	-39.58	27.92	n.s.
PT	PFI	19.42	10.49	-11.58	58.92	n.s.	10.75	7.11	-11.50	31.92	n.s.
PT	PFII	27.08	10.55	-11.83	63.08	n.s.	0.84	8.09	-29.67	23.58	n.s.
PT	CFII	13.83	12.92	-23.50	59.92	n.s.	-9.17	8.13	-35.25	14.92	n.s.
PT	KH	3.92	10.09	-25.50	37.75	n.s.	-19.00	7.56	-42.83	4.09	n.s.
PT	RO	-11.83	10.35	-43.58	26.50	n.s.	-24.00	9.12	-67.33	1.34	n.s.
PT	RT	29.00	10.57	-4.83	63.58	n.s.	-19.67	6.49	-36.83	13.33	n.s.
PT	RFI	13.42	11.46	-20.25	52.25	n.s.	-15.25	10.16	-52.08	21.59	n.s.
PT	RFII	26.25	11.22	-8.50	65.67	n.s.	-19.25	6.42	-35.83	-1.08	*
PT	CFI	7.50	10.24	-24.50	41.25	n.s.	-22.00	8.19	-47.08	4.42	n.s.
PFI	PFII	7.67	4.26	-18.92	24.83	n.s.	-9.92	5.79	-31.08	3.50	n.s.
PFI	CFII	-5.58	8.60	-25.92	22.33	n.s.	-19.92	5.85	-38.42	3.00	n.s.
PFI	KH	-15.50	2.95	-31.17	-8.83	*	-29.75	5.03	-46.92	-13.75	*
PFI	RO	-31.25	3.75	-49.58	-17.75	*	-34.75	7.16	-76.08	-12.67	*
PFI	RT	9.58	4.32	-17.50	19.50	n.s.	-30.42	3.20	-38.67	-4.58	*
PFI	RFI	-6.00	6.18	-27.50	16.33	n.s.	-26.00	8.44	-53.42	5.00	n.s.
PFI	RFII	6.83	5.71	-11.83	28.75	n.s.	-30.00	3.06	-36.75	-19.00	*
PFI	CFI	-11.92	3.44	-31.92	-1.00	*	-32.75	5.94	-52.25	-10.33	*
PFII	CFII	-13.25	8.67	-32.08	22.25	n.s.	-10.00	7.00	-27.08	13.50	n.s.
PFII	KH	-23.17	3.15	-37.00	-0.50	*	-19.83	6.33	-38.00	2.08	n.s.
PFII	RO	-38.92	3.91	-63.67	-13.33	*	-24.83	8.13	-64.83	3.25	n.s.
PFII	RT	1.92	4.46	-18.50	29.00	n.s.	-20.50	5.00	-27.33	9.42	n.s.
PFII	RFI	-13.67	6.28	-34.92	19.08	n.s.	-16.08	9.28	-45.83	16.17	n.s.
PFII	RFII	-0.83	5.82	-17.42	32.83	n.s.	-20.08	4.92	-25.17	-1.08	*
PFII	CFI	-19.58	3.61	-35.67	4.42	n.s.	-22.83	7.08	-40.67	4.50	n.s.
CFII	KH	-9.92	8.10	-35.00	0.17	n.s.	-9.83	6.38	-32.50	9.00	n.s.
CFII	RO	-25.67	8.43	-54.25	-6.33	*	-14.83	8.17	-60.50	8.50	n.s.
CFII	RT	15.17	8.70	-17.83	29.17	n.s.	-10.50	5.06	-23.83	17.42	n.s.
CFII	RFI	-0.42	9.76	-31.75	23.83	n.s.	-6.08	9.31	-37.50	25.08	n.s.
CFII	RFII	12.42	9.47	-17.67	38.42	n.s.	-10.08	4.98	-22.42	4.33	n.s.
CFII	CFI	-6.33	8.29	-36.17	9.75	n.s.	-12.83	7.12	-33.25	8.17	n.s.
KH	RO	-15.75	2.42	-30.33	-4.17	*	-5.00	7.61	-43.42	20.42	n.s.
KH	RT	25.08	3.23	6.42	31.67	*	-0.67	4.09	-10.33	30.75	n.s.
KH	RFI	9.50	5.48	-6.00	26.83	n.s.	3.75	8.82	-23.67	39.50	n.s.
KH	RFII	22.33	4.94	14.58	41.92	*	-0.25	3.99	-8.00	13.67	n.s.
KH	CFI	3.58	1.90	-6.75	12.50	n.s.	-3.00	6.46	-22.75	20.00	n.s.
RO	RT	40.83	3.97	20.58	59.42	*	4.33	6.54	-9.25	45.17	n.s.
RO	RFI	25.25	5.94	6.17	47.58	*	8.75	10.19	-22.92	63.83	n.s.
RO	RFII	38.08	5.46	23.25	62.58	*	4.75	6.48	-9.17	42.00	n.s.
RO	CFI	19.33	2.99	5.42	37.17	*	2.00	8.24	-19.92	43.67	n.s.
RT	RFI	-15.58	6.32	-32.00	8.50	n.s.	4.42	7.92	-35.33	31.58	n.s.
RT	RFII	-2.75	5.86	-13.75	21.25	n.s.	0.42	0.93	-27.17	3.00	n.s.
RT	CFI	-21.50	3.68	-34.92	0.92	n.s.	-2.33	5.17	-31.67	12.17	n.s.
RFI	RFII	12.83	7.34	-8.75	35.83	n.s.	-4.00	7.87	-30.83	22.00	n.s.
RFI	CFI	-5.92	5.75	-29.08	11.33	n.s.	-6.75	9.37	-41.33	22.58	n.s.
RFII	CFI	-18.75	5.25	-39.42	-6.58	*	-2.75	5.09	-17.83	11.83	n.s.

Appendix 2-9 Differences in mean cover of shrubs per transect between the years. Results of the One-way Repeated Measures ANOVA (RM – ANOVA) and post-hoc LSD-test for each transect. Only significant results of post-hoc tests are shown. If the assumption of sphericity was violated Greenhouse & Geisser (1959) correction was used. F= test statistic, df= degrees of freedom, diff.= differences; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

Site	**RM - Anova**		**Diff. between the years**		**Site**	**RM - Anova**		**Diff. between the years**	
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
PT	3.96*	2.07	2007 - 2012	9.62*	**RT**	7.12**	2.14	2007 - 2010	15.37*
			2007 - 2013	9.68*				2007 - 2011	25.18*
			2008 - 2011	15.31*				2007 - 2013	49.00**
			2008 - 2012	16.50*				2007 - 2014	53.81**
			2008 - 2013	16.56*				2008 - 2009	17.25*
			2008 - 2014	20.56*				2008 - 2010	23.56**
								2008 - 2011	33.38**
								2008 - 2013	57.19**
								2008 - 2014	62.00**
								2009 - 2013	39.94*
								2009 - 2014	44.76**
								2010 - 2013	33.63*
								2010 - 2014	38.44*
								2011 - 2013	23.82**
								2011 - 2014	28.63**
	F	df	year	deviation (I-J)		F	df	year	deviation (I-J)
PFI	4.20*	2.18	2007 - 2013	31.87**	**RFI**	10.83**	1.77	2007 - 2009	16.25*
			2007 - 2014	31.93**				2007 - 2010	28.62**
			2008 - 2013	19.44*				2007 - 2011	30.63**
			2008 - 2014	19.50*				2007 - 2012	31.00**
			2009 - 2013	21.62*				2007 - 2013	24.81**
			2009 - 2014	21.69*				2007 - 2014	25.25**
			2012 - 2013	13.68*				2008 - 2009	17.56*
			2013 - 2014	13.75*				2008 - 2010	29.94**
								2008 - 2011	31.94**
								2008 - 2012	32.31*
								2008 - 2013	26.13*
								2008 - 2014	26.56*
								2009 - 2010	12.38*
								2009 - 2011	14.38*
								2009 - 2012	14.75*
	F	df				F	df	year	deviation (I-J)
PFII	1.69 n.s.	2.24			**RFII**	6.48**	7	2007 - 2013	25.56**
								2007 - 2014	32.00**
								2008 - 2012	18.13*
								2008 - 2013	32.38**
								2008 - 2014	38.82**
								2009 - 2013	23.51*
								2009 - 2014	29.94*
								2011 - 2014	23.25*
								2012 - 2014	20.69*
	F	df				F	df		
CFII	0.49 n.s.	2.01			**CFI**	2.15 n.s.	2		

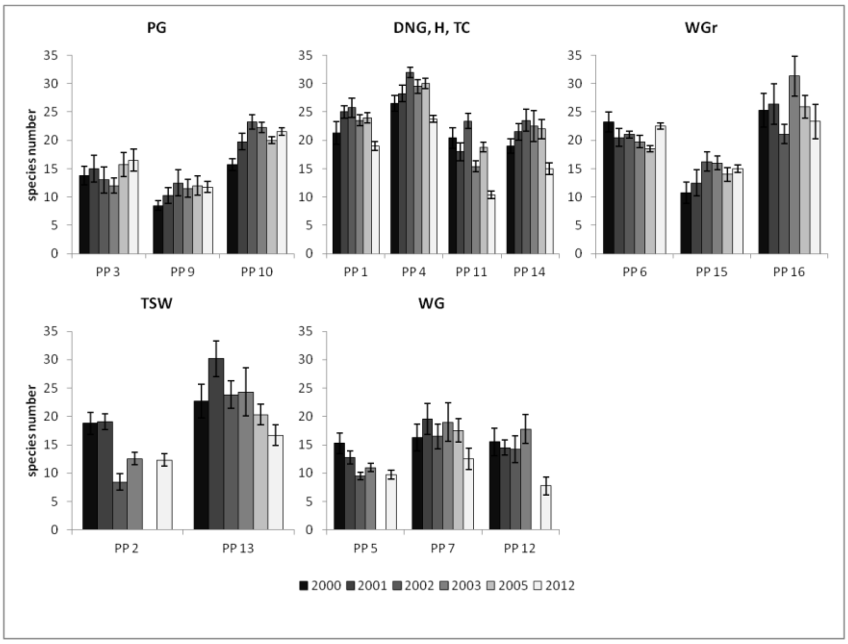
Appendix 2-10 Differences in mean cover of shrubs between the sites in the years 2007 and 2014. Results of robust ANOVA and post-hoc-test. df= degrees of freedom, psihat= test statistic, se= standard error, ci= confidence interval, sig.= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. HH= Hasenheide, PO= Przewalski open, PT= Przewalski transition, PFI= Przewalski Forest I, PFII= Przewalski Forest II, CFII= Control Forest II, KH= Königsbrunner Heide, RO= Red deer open, RT= Red deer transition, RFI= Red deer Forest I, RFII= Red deer Forest II, CFI= Control Forest I.

		2007			2014				
		robust ANOVA			robust ANOVA				
		test statistic	df	effect size	test statistic		df	effect size	
		2.15 n.s.	7; 16.7	0.437	3.71*		7; 16.9	0.674	
					post-hoc-test				
Comparison					psihat	se	ci.lower	ci.upper	sig.
PT	PFI				-1.16	5.95	-21.75	34.52	n.s.
PT	PFII				-20.66	10.12	-46.32	18.84	n.s.
PT	CFII				-40.49	11.89	-76.92	5.68	n.s.
PT	RT				4.51	6.17	-12.90	39.10	n.s.
PT	RFI				6.43	5.95	-18.90	40.18	n.s.
PT	RFII				-9.91	9.53	-35.99	32.43	n.s.
PT	CFI				-18.66	8.98	-48.90	20.60	n.s.
PFI	PFII				-19.50	9.46	-43.92	9.82	n.s.
PFI	CFII				-39.33	11.34	-75.83	-3.25	*
PFI	RT				5.67	5.01	-9.83	22.26	n.s.
PFI	RFI				7.59	4.74	-15.08	24.01	n.s.
PFI	RFII				-8.75	8.82	-33.42	17.26	n.s.
PFI	CFI				-17.50	8.23	-46.08	6.18	n.s.
PFII	CFII				-19.83	13.98	-58.41	22.25	n.s.
PFII	RT				25.17	9.60	-0.33	49.50	n.s.
PFII	RFI				27.09	9.46	-5.58	50.58	n.s.
PFII	RFII				10.75	12.04	-23.40	44.75	n.s.
PFII	CFI				2.00	11.61	-34.90	31.50	n.s.
CFII	RT				45.00	11.45	10.17	79.33	*
CFII	RFI				46.92	11.34	8.50	81.42	*
CFII	RFII				30.58	13.56	-9.00	69.50	n.s.
CFII	CFI				21.83	13.18	-20.75	61.08	n.s.
RT	RFI				1.92	5.01	-22.42	15.42	n.s.
RT	RFII				-14.42	8.97	-37.58	8.92	n.s.
RT	CFI				-23.17	8.39	-54.08	-1.50	*
RFI	RFII				-16.33	8.82	-39.42	13.33	n.s.
RFI	CFI				-25.08	8.23	-53.42	2.67	n.s.
RFII	CFI				-8.75	11.09	-42.17	20.25	n.s.

Appendix 3-1 **Differences in mean species number per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type.** Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heaths and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PG	3.76*	2.65	18.54	2000 - 2012	-3.88	-7.39	-0.36	*
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	13.00***	3.33	33.29	2000 - 2012	-4.55	-7.16	-1.94	*
				2001 - 2012	4.55	0.06	9.03	*
				2002 - 2012	6.09	3.02	9.16	*
				2003 - 2012	8.82	4.26	13.38	*
				2004 - 2012	5.09	2.74	7.44	*
				2005 - 2012	6.73	4.33	9.13	*
	F	df						
WGr	0.84 n.s.	2.69	29.62					
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	7.28**	2.84	22.7	2000 - 2012	5.67	0.97	10.36	*
				2001 - 2002	8.11	2.61	13.61	*
				2001 - 2003	6.56	0.20	12.91	*
				2001 - 2012	9.00	0.93	17.07	*
	F	df		year	psihat	ci.upper	ci.lower	sig
WG	4.72*	3.13	21.89	2001 - 2003	5.75	0.67	10.83	*
				2002 - 2012	-1.88	-2.75	-1.00	*

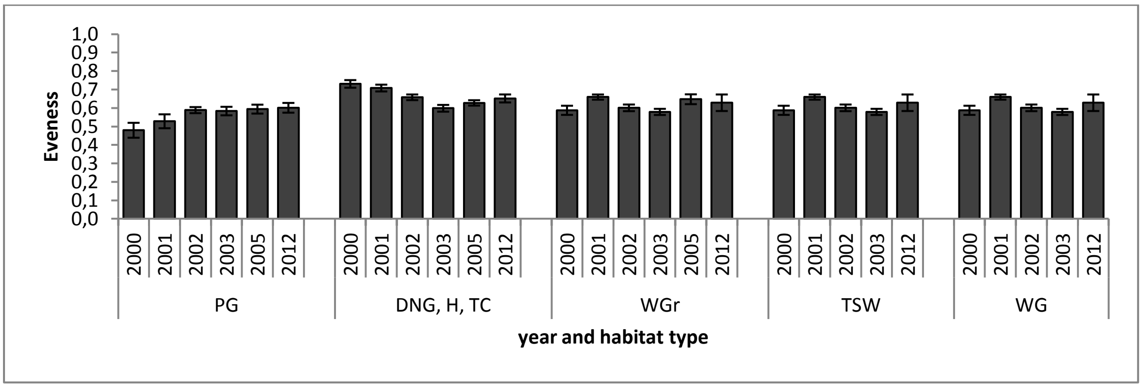
Appendix 3-2 **Mean species number and standard error per permanent plot in the years 2000 to 2012.** PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heaths and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-3 Differences in mean species number per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP1	4.44*	4.97	14.91	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	21.53***	3.05	18.28	2000 - 2002	10.86	4.74	16.97	*
				2000 - 2003	6.57	0.21	12.93	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	7.51**	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP4	7.04**	4.87	14.6	post-hoc test achieved no result				
	F	df						
PP5	4.87 n.s.	1.84	5.53					
	F	df						
PP6	2.33 n.s.	5	15					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP7	9.22***	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP9	3.48*	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP10	9.02***	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP11	15.29***	4.39	8.78	2002 - 2003	7.67	0.61	14.72	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP12	4.38*	2.83	8.48	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP13	4.63*	3.73	11.2	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP14	6.48*	2.6	7.79	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	4.84*	2.59	7.77	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP16	4.21*	2.59	12.93	2002 - 2005	-4.50	-8.01	-0.99	*

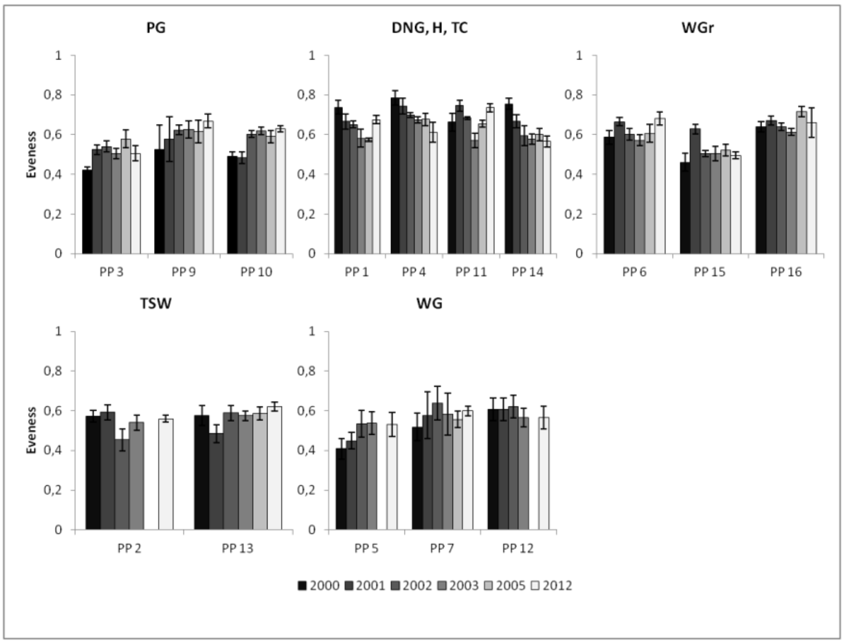
Appendix 3-4 Eveness value and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-5 Differences in Eveness value per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PG	6.43***	4.16	29.1	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	7.58***	4.2	42.01	2000 - 2003	0.13	0.03	0.23	*
				2000 - 2005	0.11	0.01	0.22	*
				2001 - 2003	0.12	0.03	0.21	*
				2001 - 2005	0.08	0.01	0.15	*
				2002 - 2003	0.05	0.00	0.10	*
	F	df		year	psihat	ci.upper	ci.lower	sig
HG	3.41**	5	55	2000 - 2005	-0.08	-0.15	-0.02	*
				2001 - 2003	0.08	0.01	0.15	*
				2003 - 2012	-0.09	-0.17	-0.01	*
	F	df						
TSW	0.47 n.s.	2.86	22.91					
	F	df						
WG	1.65 n.s.	3.77	26.41					

Appendix 3-6 Eveness-value and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heaths and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



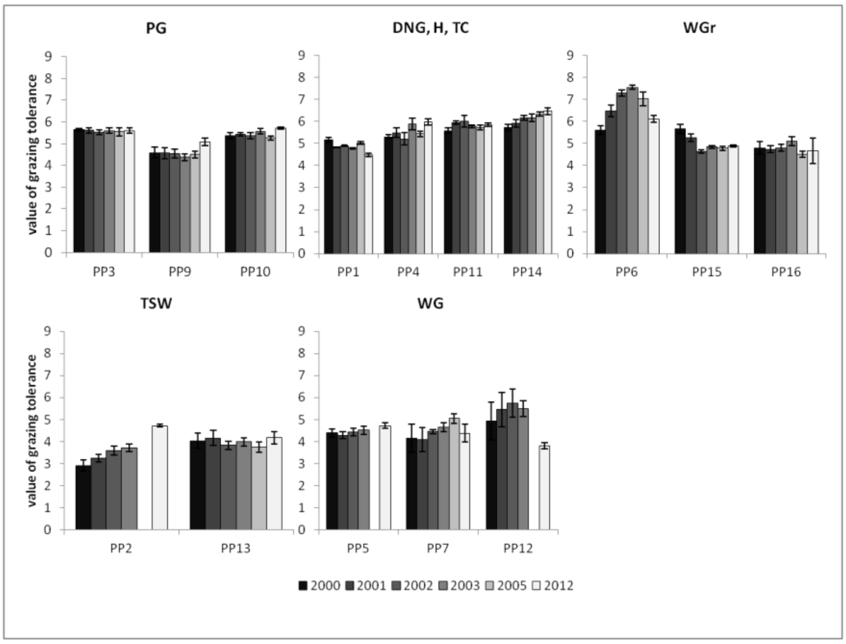
Appendix 3-7 **Differences in Eveness-value per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot.** F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP1	7.16**	4.05	12.15	post-hoc test achieved no result				
	F	df						
PP2	1.66 n.s.	2.71	16.26					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	4.59**	5	15	post-hoc test achieved no result				
	F	df						
PP4	2.98 n.s.	3.88	11.63					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP5	4.82*	2.25	6.75	post-hoc test achieved no result				
	F	df						
PP6	1.92 n.s.	5	15					
	F	df						
PP7	0.7 n.s.	1.47	4.41					
	F	df						
PP9	0.75 n.s.	2.44	7.31					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP10	7.42 **	3.41	10.22	post-hoc test achieved no result				
	F	df						
PP11	2.62 n.s.	5	10					
	F	df						
PP12	0.34 n.s.	4	12					
	F	df						
PP13	1.53 n.s.	5	15					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP14	5.19**	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	6.67**	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP16	4.39**	4.34	21.69	2000 - 2005	-0.10	-0.15	-0.04	*
				2002 - 2012	-0.11	-0.18	-0.03	*
				2003 - 2012	-0.12	-0.16	-0.08	*

Appendix 3-8 **Differences in value of grazing tolerance per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type.** Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	2.64 n.s.	2.63	18.42					
	F	df						
DNG, H, TC	1.32 n.s.	4.01	40.09					
	F	df						
WGr	1.27 n.s.	2.32	25.51					
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	10.79**	1.43	11.43	2001 - 2012	-1.07	-2.01	-0.13	*
				2002 - 2012	-0.80	-1.38	-0.22	*
				2003 - 2012	-0.73	-1.42	-0.04	*
	F	df						
WG	0.58 n.s.	2.87	31.52					

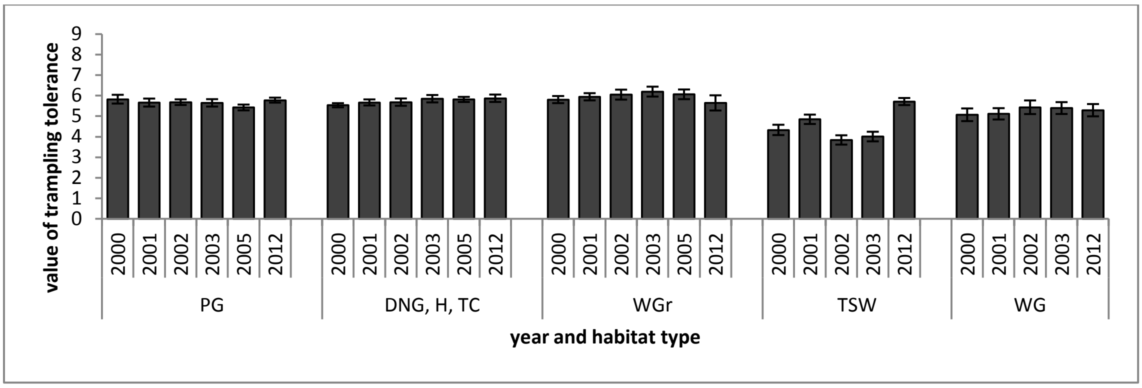
Appendix 3-9 Grazing tolerance and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heaths and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-10 Differences in grazing tolerance per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP1	13.72***	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	44.62***	2.68	16.07	2000 - 2012	-2.00	-3.09	-0.91	*
				2001 - 2012	-1.55	-2.48	-0.61	*
				2002 - 2012	-1.07	-1.73	-0.40	*
				2003 - 2012	-1.00	-1.73	-0.26	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	0.35 n.s.	2.38	7.13	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP4	4.15*	4.83	14.48	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP5	14.19***	4	12	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP6	19.71***	4.57	13.71	2000 - 2002	-1.69	-3.35	-0.04	*
	F	df						
PP7	0.86 n.s.	2.17	6.52					
	F	df						
PP9	3.14 n.s.	1.53	4.58					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP10	4.57**	5	15	post-hoc test achieved no result				
	F	df						
PP11	0.90 n.s.	1.53	3.05					
	F	df						
PP12	2.67 n.s.	4	12					
	F	df						
PP13	0.5 n.s.	5	15					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP14	5.84**	3.83	11.49	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	13.98***	4.76	14.29	post-hoc test achieved no result				
	F	df						
PP16	0.68 n.s.	2.61	13.03					

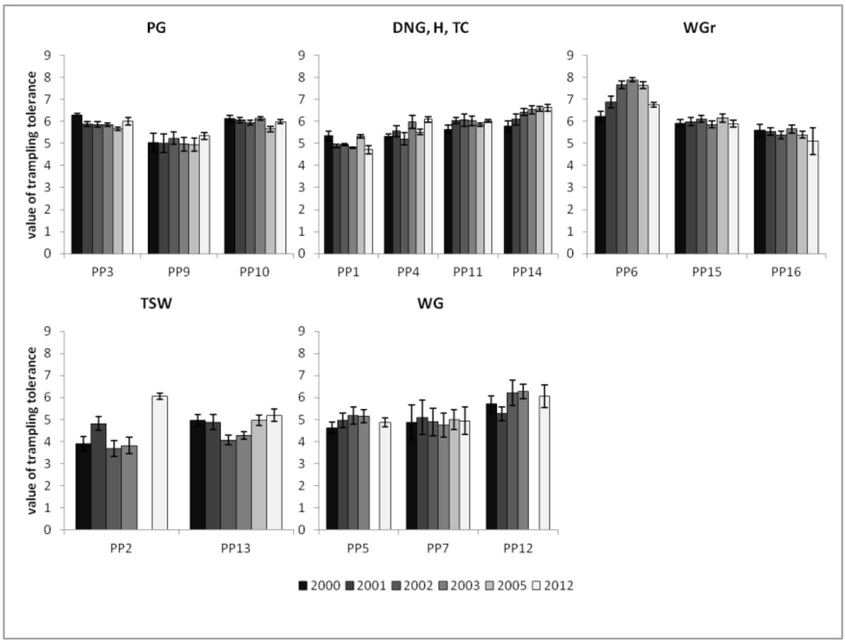
Appendix 3-11 Values of trampling tolerance and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-12 Differences in value of trampling tolerance per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PG	3.56*	3.66	25.62	2005 - 2012	-0.36	-0.71	-0.01	*
	F	df						
DNG, H, TC	2.11 n.s.	4.01	40.11					
	F	df						
WGr	0.20 n.s.	2.38	26.15					
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	12.95***	2.09	16.69	2001 - 2002	0.88	0.26	1.51	*
				2001 - 2003	0.72	0.00	1.43	*
	F	df						
WG	2.61 n.s.	3.5	24.49					

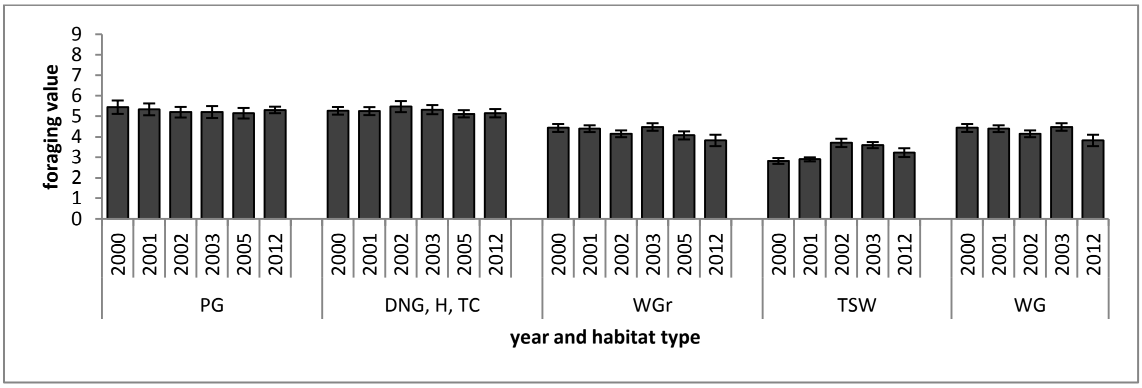
Appendix 3-13 Trampling tolerance and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heaths and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-14 Differences in trampling tolerance per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP1	7.32**	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	21.65***	2.95	17.72	2000 - 2012	-2.32	-3.62	-1.02	*
				2002 - 2012	-2.56	-5.06	-0.05	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	7.63**	3.94	11.83	2000 - 2005	0.63	0.03	1.22	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP4	4.84**	5	15	post-hoc test achieved no result				
	F	df						
PP5	2.73 n.s.	4	12					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP6	15.02***	5	15	post-hoc test achieved no result				
	F	df						
PP7	0.39 n.s.	4.68	14.05					
	F	df						
PP9	0.7 n.s.	1.69	5.07					
	F	df						
PP10	2.40 n.s.	2.17	6.51					
	F	df						
PP11	0.98 n.s.	2.3	4.59					
	F	df						
PP12	1.60 n.s.	4	12					
	F	df						
PP13	3.50 n.s.	2.47	7.41					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP14	5.46 *	2.47	7.41	post-hoc test achieved no result				
	F	df						
PP15	1.91 n.s.	4.7	14.09					
	F	df						
PP16	0.38 n.s.	4.46	22.28					

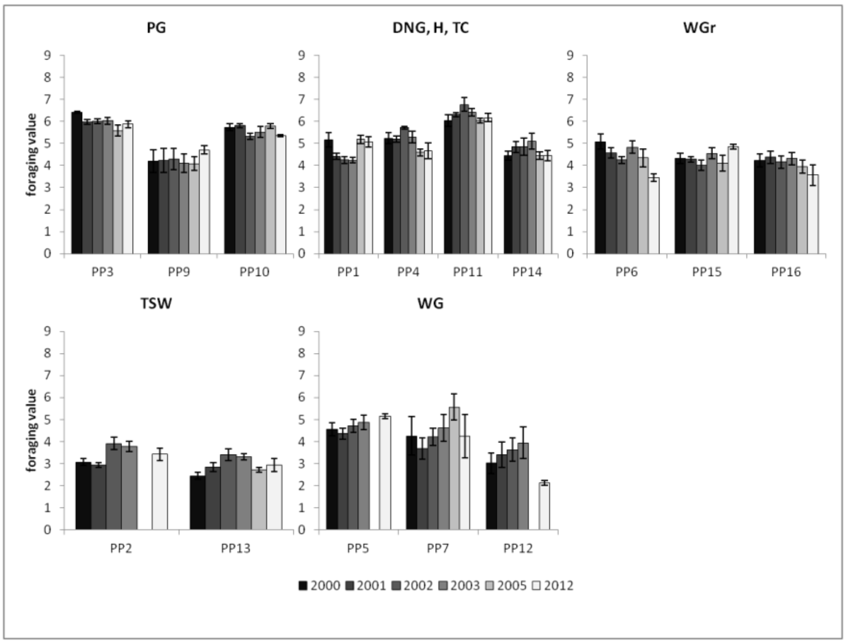
Appendix 3-15 Foraging values and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-16 Differences in foraging value per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	1.36 n.s.	3.59	25.11					
	F	df						
DNG, H, TC	0.46 n.s.	2.68	26.84					
	F	df						
WGr	2.06 n.s.	2.82	31.02					
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	5.89**	2.4	19.17	2000 - 2002	-0.85	-1.58	-0.11	*
				2000 - 2003	-0.84	-1.28	-0.41	*
				2001 - 2003	-0.72	-1.34	-0.09	*
	F	df						
WG	1.06 n.s.	2.87	31.52					

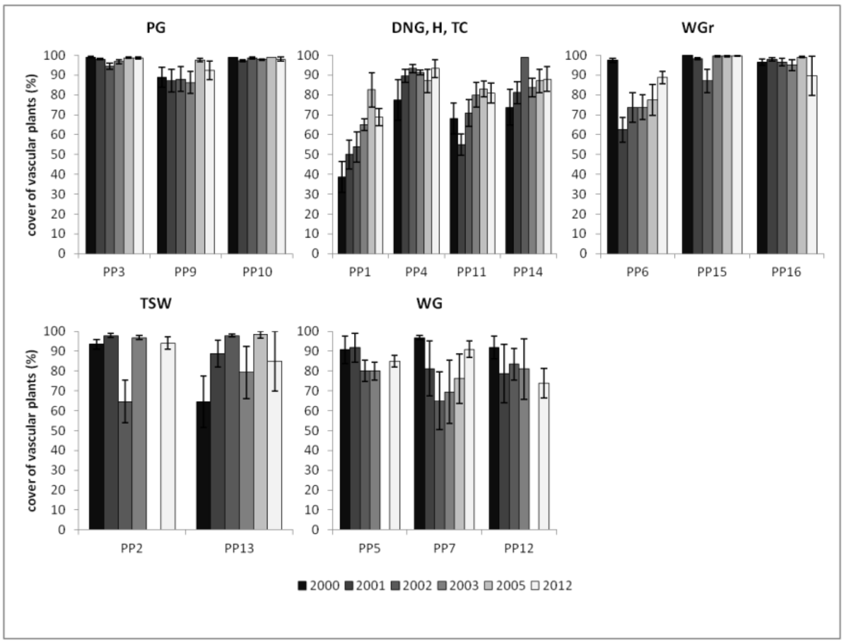
Appendix 3-17 Foraging value and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-18 Differences in foraging value per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP1	9.62**	3.86	11.57	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	4.16*	2.67	16.01	2000 - 2003	-0.84	-1.53	-0.16	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	5.65**	5	15	post-hoc test achieved no result				
	F	df						
PP4	3.82 n.s.	1.59	4.77					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP5	7.28**	4	12	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP6	6.42*	2.89	8.68	post-hoc test achieved no result				
	F	df						
PP7	1.18 n.s.	5	15					
	F	df						
PP9	0.87 n.s.	1.64	4.92					
	F	df						
PP10	3.25 n.s.	3.46	10.37					
	F	df						
PP11	2.26 n.s.	3.65	7.29					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP12	3.38*	4	12	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP13	4.99**	5	15	post-hoc test achieved no result				
	F	df						
PP14	1.38 n.s.	5	15					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	5.84**	5	15	post-hoc test achieved no result				
	F	df						
PP16	1.63 n.s.	4.31	21.56					

Appendix 3-19 Cover of vascular plants (%) and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



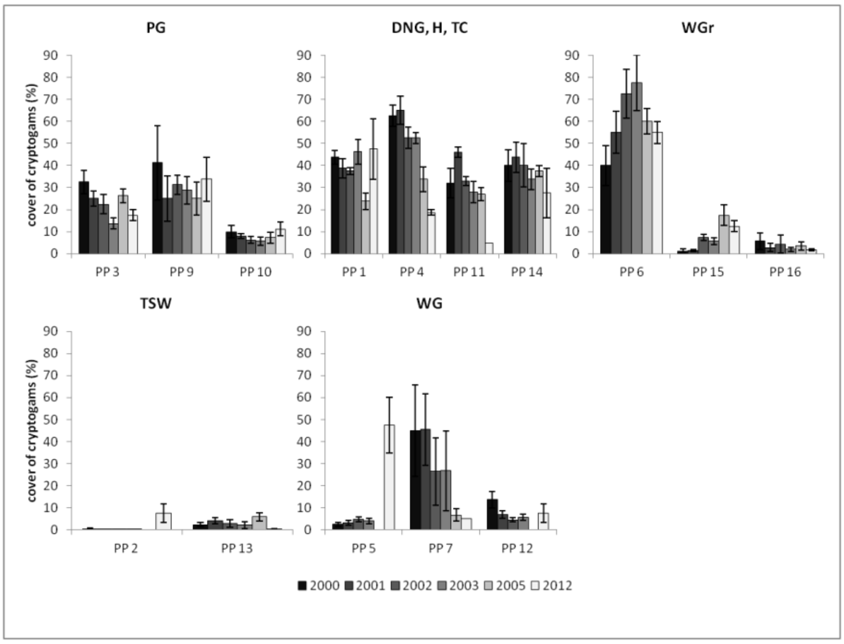
Appendix 3-20 Differences in cover of vascular plants (%) per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP1	20.69***	4.77	14.3	post-hoc test achieved no result				
	F	df						
PP2	4.47 n.s.	1.1	6.58					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	5.71 **	3.95	11.85	post-hoc test achieved no result				
	F	df						
PP4	1.98 n.s.	2.88	8.63					
	F	df						
PP5	2.03 n.s.	4	12					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP6	9.39***	5	15	post-hoc test achieved no result				
	F	df						
PP7	1.34 n.s.	5	15					
	F	df						
PP9	1.63 n.s.	5	15					
	F	df						
PP10	1.61 n.s.	4.32	12.96					
	F	df						
PP11	3.25 n.s.	5	10					
	F	df						
PP12	0.4 n.s.	2.81	8.43					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP13	5.7*	2	6.01	post-hoc test achieved no result				
	F	df						
PP14	4.77 n.s.	2.15	6.45					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	6.13**	3.63	10.9	post-hoc test achieved no result				
	F	df						
PP16	1.43 n.s.	4.23	21.14					

Appendix 3-21 Differences in cover of cryptogams (%) per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	0.50 n.s.	3.71	26					
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	15.57***	4.97	49.7	2001 - 2005	15.45	3.08	27.83	*
				2001 - 2012	31.36	9.48	53.24	*
				2003 - 2012	21.82	5.76	37.88	*
	F	df						
WGr	1.83 n.s.	2.01	22.14					
	F	df						
TSW	1.84 n.s.	1.32	10.56					
	F	df						
WG	0.34 n.s.	1.54	10.78					

Appendix 3-22 Cover of cryptogams (%) and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



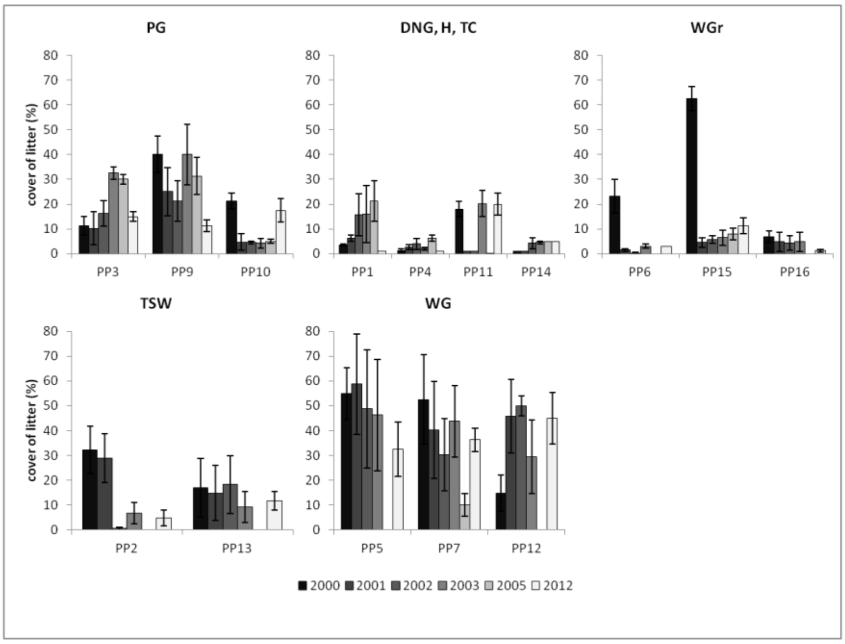
Appendix 3-23 Differences in cover of cryptogams (%) per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df						
PP1	1.56 n.s.	1.67	5.01					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	24.14 **	1	6	post-hoc test achieved no result				
	F	df						
PP3	2.86 n.s.	4.85	14.55					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP4	12.88***	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP5	12.67*	1.07	3.22	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP6	6.64**	3.77	11.31	post-hoc test achieved no result				
	F	df						
PP7	2.60 n.s.	5	15					
	F	df						
PP9	0.49 n.s.	1.81	5.42					
	F	df						
PP10	0.74 n.s.	3.66	10.98					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP11	30.21***	3.44	6.88	post-hoc test achieved no result				
	F	df						
PP12	2.16 n.s.	2.18	6.53					
	F	df						
PP13	3.48 n.s.	2.84	8.52					
	F	df						
PP14	0.84 n.s.	5	15					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	7.22**	3.96	11.89	post-hoc test achieved no result				
	F	df						
PP16	1.78 n.s.	3.81	19.05					

Appendix 3-24 Differences in cover of litter (%) per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df						
PG	2.33 n.s.	3.59	25.16					
	F	df						
DNG. H. TC	0.83 n.s.	2.08	20.8					
	F	df		year	psihat	ci.upper	ci.lower	sig
HG	5.80*	1.06	11.68	post-hoc test achieved no result				
	F	df						
TSW	2.47 n.s.	2.12	16.93					
	F	df						
WG	0.41 n.s.	3.14	21.98					

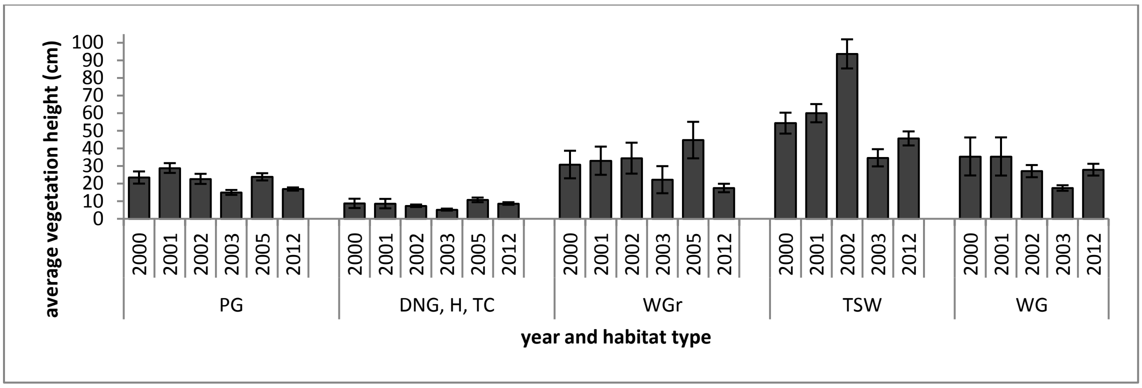
Appendix 3-25 Cover of litter (%) and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-26 Differences in cover of litter (%) per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df						
PP1	2.48 n.s.	1.66	4.97					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	5.08*	2.61	15.64	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP3	4.95*	3.7	11.11	post-hoc test achieved no result				
	F	df						
PP4	3.27 n.s.	1.76	5.28					
	F	df						
PP5	1.00 n.s.	2.27	6.82					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP6	9.91*	1.07	3.21	post-hoc test achieved no result				
	F	df						
PP7	2.20 n.s.	3.42	10.27					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP9	4.20*	5	15	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP10	6.89*	3	9	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP11	8.53*	2.88	5.77	post-hoc test achieved no result				
	F	df						
PP12	1.93 n.s.	1.94	5.82					
	F	df						
PP13	0.44 n.s.	1.12	3.37					
	F	df						
PP14	4.84 n.s.	1.22	3.65					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP15	101.99***	5	15	2000 - 2001	58.00	6.80	109.20	*
				2000 - 2005	54.50	1.83	107.17	*
	F	df		year	psihat	ci.upper	ci.lower	sig
PP16	4.57*	1.94	9.69	post-hoc test achieved no result				

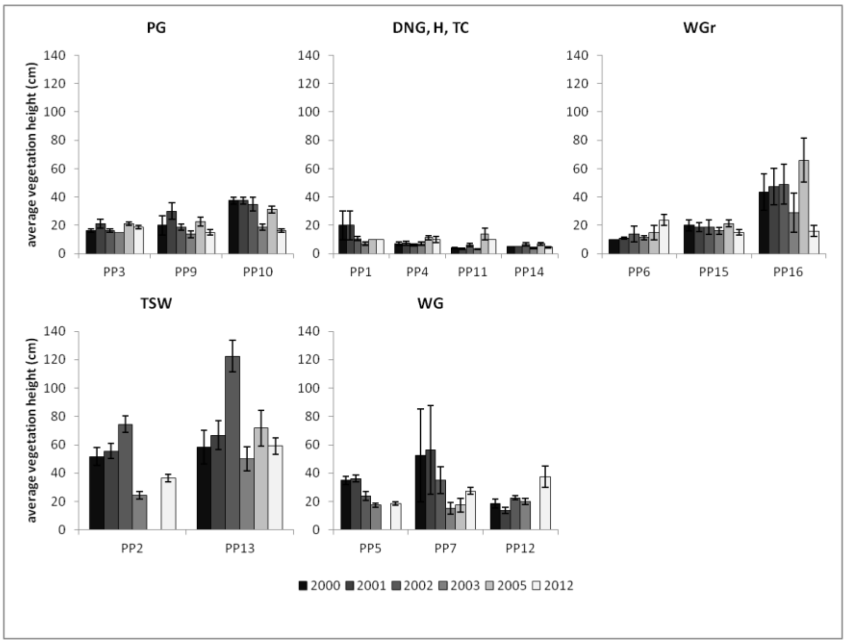
Appendix 3-27 Average vegetation height (cm) and standard error per habitat type in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-28 Differences in average vegetation height (cm) per habitat type between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each habitat type. Only significant results of post-hoc tests are shown. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant. DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.

Site	RM-Anova			Differences between the years				
	F	df		year	psihat	ci.upper	ci.lower	sig
PG	4.23*	2.65	21.2	2003 - 2005	-8.33	-13.16	-3.51	*
	F	df		year	psihat	ci.upper	ci.lower	sig
DNG, H, TC	10.35***	3.69	36.91	2003 - 2005	-4.55	-7.92	-1.17	*
	F	df		year	psihat	ci.upper	ci.lower	sig
HG	4.60**	3.2	35.19	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
TSW	11.48**	1.61	12.88	2000 - 2003	21.67	4.65	38.68	*
				2001 - 2003	25.00	7.04	42.96	*
				2002 - 2003	58.89	24.06	93.72	*
				2002 - 2012	47.78	29.11	66.44	*
				2003 - 2012	-14.44	-28.20	-0.69	*
	F	df						
WG	2.16 n.s.	1.61	11.27					

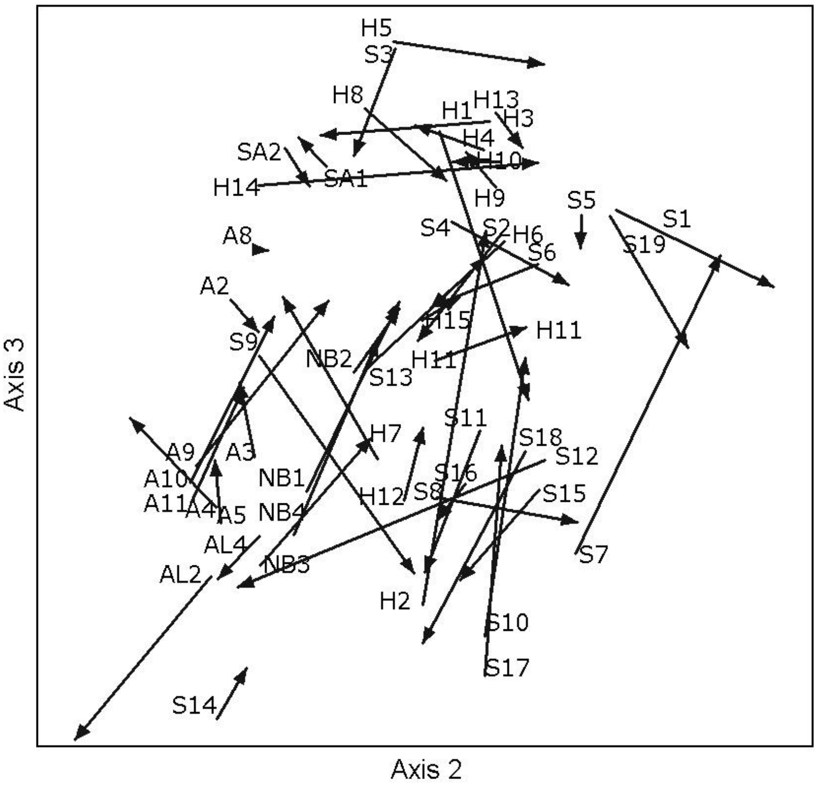
Appendix 3-29 Average vegetation height (cm) and standard error per permanent plot in the years 2000 to 2012. PG= poor grassland; DNG, H, TC= dry nutrient-poor grassland, heathland and trampling-communities; WGr= wet grassland; TSW= temporary small waters and shores; WG= woods and groves.



Appendix 3-30 Differences in average vegetation height (cm) per permanent plot between the years. Results of the robust Repeated Measures ANOVA (RM – ANOVA) and post-hoc test for each permanent plot. F= test statistic, df= degrees of freedom, ci= confidence interval, sig= significance; *= p<0.05, **= p<0.01, ***= p<0.001, n.s.= not significant.

Site	RM-Anova			Differences between the years				
	F	df						
PP1	1.31 n.s.	1.02	3.06					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP2	17.05**	1.56	9.37	2000 - 2003	27.857	7.97201	47.74228	*
				2001 - 2003	31.429	9.811153	53.04599	*
				2002 - 2003	52.86	12.14	93.57	*
	F	df						
PP3	4.86 n.s.	1.94	5.83					
	F	df						
PP4	2.87 n.s.	3.03	9.09					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP5	18.25***	4	12	2001 - 2003	18.75	3.22	34.28	*
	F	df						
PP6	2.28 n.s.	1.53	4.6					
	F	df						
PP7	1.33 n.s.	1.05	3.14					
	F	df						
PP9	3.72 n.s.	2.68	8.03					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP10	12.93**	2.75	8.26	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP11	26.13**	2.43	4.86	post-hoc test achieved no result				
	F	df		year	psihat	ci.upper	ci.lower	sig
PP12	5.74*	2	5.99	post-hoc test achieved no result				
	F	df						
PP13	2.87 n.s.	2	4					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP14	3.69*	5	15	post-hoc test achieved no result				
	F	df						
PP15	1.08 n.s.	2.47	7.41					
	F	df		year	psihat	ci.upper	ci.lower	sig
PP16	4.95**	3.89	19.45	2001 - 2003	15.00	0.42	29.58	*
				2003 - 2005	-35.83	-62.91	-8.76	*
				2005 - 2012	37.50	6.61	68.39	*

Appendix 4-1 Ordination diagram of Nonmetric Multidimensional Scaling (NMDS) of all traits and all sites. Attribute proportions per trait related to species abundances. The diagram was rotated in direction of the time gradient. Arrow base refers to the beginning of grazing and arrowhead refers to the last vegetation relevé. NMDS configuration: Euclidean distance, 3 dimensions, best solution of 500 runs, stability criterion = 0.0005, random starting configuration. Variance represented by Axis 2 = 26.3% and Axis 3 = 45.2%. A= Augsburg, Al= Allgäu, NB= Lower Bavaria, SA= Swabian Alb, S= Solling-Vogler, H= Höltigbaum.



Appendix 4-2 **Pearson Correlation coefficient between tested functional traits of all sites and first axis.** Correlation coefficients ≥ |0.5| printed in bold type.

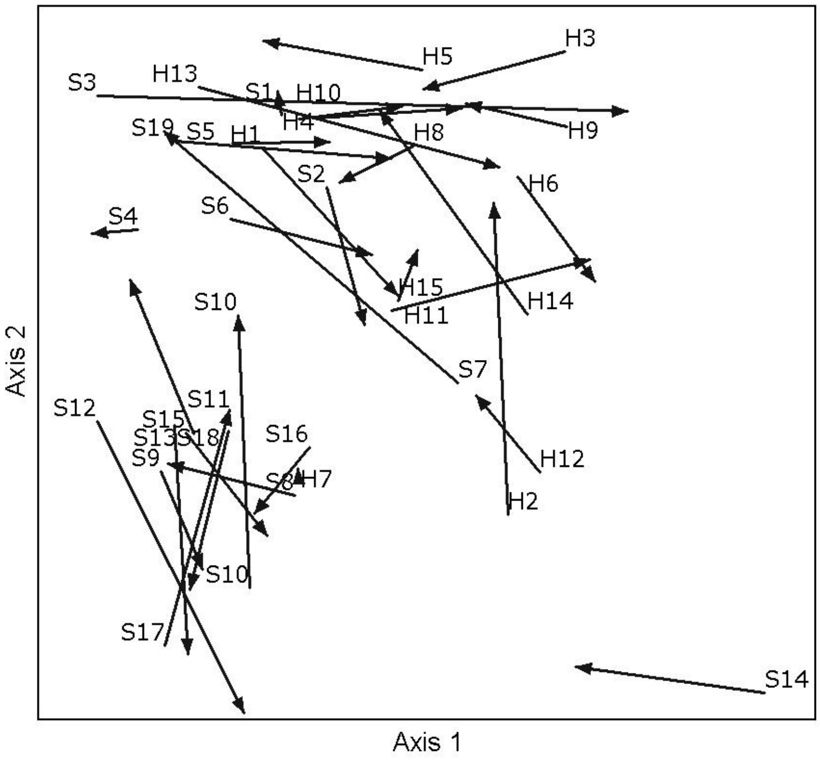
Trait	**Characteristic**	**Correlation coefficient with first axis**	**Correlation coefficient with second axis**
lifespan	lifesshort	**0,628**	0,016
	lifeslong	**-0,629**	-0,015
life form	chamaephyte	0,089	0,232
	geophyte	-0,017	**-0,501**
	hemicryptophyte	0,126	0,442
	hydrophyte	-0,281	-0,318
	nanophyte	-0,273	-0,401
	phanerophyte	-0,363	-0,147
	therophyte	0,397	-0,184
leaf distribution	regular	0,163	**-0,649**
	semirosette	0,049	**0,510**
	rosette	-0,340	0,194
canopy height in m	<0,3	0,161	**0,632**
	0,3-0,6	0,001	0,101
	>0,6	-0,161	**-0,676**
specific leaf area in mm^2/mg	<20	**-0,656**	-0,398
	20-25	-0,177	0,331
	>25	**0,805**	0,137
clonalgrowth	yes	**0,572**	**0,522**
	no	**-0,572**	**-0,522**
minimum budbank depth in cm	<-10	-0,095	-0,032
	-10-0	0,174	-0,427
	>10	-0,106	**-0,551**
seed bank	longterm	0,185	-0,030
	present	0,112	0,116
	shortterm	**0,856**	0,180
	transient	**-0,852**	-0,177
maximum seed shedding	spring	-0,302	-0,142
	summer	-0,371	-0,384
	autumn	**0,584**	0,276
	winter	-0,373	0,043
preference	eaten	0,199	**0,885**
	avoided	**-0,520**	**-0,545**
	poisonous	0,013	**-0,550**
	preferred	0,474	-0,223
grazing tolerance	intolerant	**-0,604**	**-0,780**
	moderately tolerant	0,262	**0,684**
	well tolerant	0,359	0,037
trampling tolerance	intolerant	-0,362	**-0,907**
	moderately tolerant	0,460	**0,814**
	well tolerant	-0,135	0,211

Appendix 4-3 Differences of Plant trait proportions on single grazed sites between first and last year of grazing. Results of Wilcoxon-signed-rank-Tests. A= Augsburg, Al= Allgäu, NB= Lower Bavaria, SA= Swabian Alb. ↑= Increase, ↓= Decrease, n.s.= not significant, *= p<0.05, **= p<0.01, ***= p<0.001.

Trait	Attribute	A2	A3	A4	A5	A8	A9	A10	A11
life form (-phyte)	chamae	↑n.s.	↑n.s.	-	↑n.s.	↓*	-	↓n.s.	↑n.s.
	hemicrypto	↓*	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↑*	↑*	↑*
	hydro	-	-	-	-	-	-	-	-
	nanophanero	↓n.s.	↑n.s.	↓*	↑n.s.	↓n.s.	↓*	↓*	↓*
	phanero	↓n.s.	↓*	↓*	↑*	↓n.s.	↓*	↓*	↓*
leaf distribution	regular	↑n.s.	↓n.s.	↓*	↓*	↑n.s.	↓n.s.	↓n.s.	↓*
canopy height in m	<0,3	↑n.s.	↑n.s.	↑*	↑*	↑n.s.	↑n.s.	↑n.s.	↑*
	>0,6	↓n.s.	↓*	↓*	↓*	↓*	↓*	↓*	↓*
specific leaf area in mm^2/mg	<20	↓*	↓n.s.	↓*	↓*	↓n.s.	↓n.s.	↓*	↓*
	20-25	↑*	↑n.s.	↑*	↑*	↑n.s.	↑n.s.	↑n.s.	↑*
clonalgrowth	yes	↑n.s.	↓n.s.	↑*	↑*	↑n.s.	↑*	↑*	↑*
	no	↓n.s.	↑n.s.	↓*	↓*	↓n.s.	↓*	↓*	↓*
minimum bud-bank depth in cm	1-10	↑n.s.	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.
	>10	↑n.s.	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↑*	↑n.s.
seed bank	shortterm	↑*	↓n.s.	↓*	↓n.s.	↓n.s.	↓n.s.	↓*	↑n.s.
maximum seed shedding	summer	↓n.s.	↑n.s.	↓*	↓n.s.	↓n.s.	↑*	↓n.s.	↑*
	autumn	↓*	↓n.s.	↓n.s.	↑n.s.	↑n.s.	↑*	↑n.s.	↑*
preference	eaten	↓n.s	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↑*	↑*	↑*
	avoided	↑n.s.	↓n.s.	↑*	↑*	↓n.s.	↓*	↓n.s.	↓*
	poisonous	↑n.s.	↓n.s.	↓*	↑*	↑n.s.	n.s.	↓*	↓*
grazing tolerance	intolerant	↑n.s.	↓n.s.	↓*	↑n.s.	↑n.s.	↓n.s.	↓*	↑n.s.
	moderately tolerant	↓*	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↑*	↑*	↑n.s.
	well tolerant	↑n.s.	↑n.s.	↑*	↑n.s.	↓n.s.	↓*	↓n.s.	↓n.s.
trampling tolerance	intolerant	↑*	↓n.s.	↑*	↓n.s.	↑n.s.	↑n.s.	↑n.s.	↑*
	moderately tolerant	↓*	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↑n.s.	↓*
	well tolerant	↑n.s.	↑n.s.	↓*	↑n.s.	↓n.s.	↓n.s.	↓*	↓n.s.

Trait	Attribute	Al2	Al4	NB1	NB2	NB3	NB4	SA1	SA2
life form (-phyte)	chamae	↑n.s.	↑**	↑n.s.	↑*	↓n.s.	↑n.s.	↓*	↓*
	hemicrypto	↑***	↑***	↑n.s.	↓*	↑n.s.	↑*	↑n.s.	↓*
	hydro	↑n.s.	↑n.s.	↑n.s.	-	↑n.s.	↓*	-	-
	nanophanero	↓n.s.	↓**	↓n.s.	-	↓n.s.	↓n.s.	↑n.s.	↓*
	phanero	-	↓n.s.	↓n.s.	↓n.s.	-	↑n.s.	↓n.s.	↓*
leaf distribution	regular	↓***	↓**	↓*	↑*	↓n.s.	↓**	↓*	↓*
canopy height in m	<0,3	↓***	↓***	↑**	↑*	↑**	↑*	↓*	↓*
	>0,6	↑n.s.	↑n.s.	↓**	↓n.s.	↓*	↓n.s.	↓*	↑*
specific leaf area in mm^2/mg	<20	↑*	↑n.s.	↓*	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↓*
	20-25	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.
clonalgrowth	yes	↓***	↓**	↑n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↑n.s.
	no	↑***	↑**	↓n.s.	↓n.s	↓n.s.	↑n.s.	↓n.s.	↓n.s.
minimum bud-bank depth in cm	1-10	↓***	↓***	↑n.s.	↑n.s.	↑*	↑n.s.	↑n.s.	↓n.s.
	>10	↑***	↑***	↓n.s.	↓n.s.	↓*	↓n.s.	↓n.s.	↑n.s.
seed bank	shortterm	↓n.s.	↓n.s.	↑**	↑*	↑**	↑n.s.	↓n.s.	↓n.s.
maximum seed shedding	summer	↑***	↑**	↓n.s.	↑*	↑n.s.	↓n.s.	↓*	↑*
	autumn	↓***	↓n.s.	↓*	↓n.s.	↑*	↑*	↓*	↑*
preference	eaten	↓*	↓**	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↑*	↑n.s.
	avoided	↑**	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↓*	↓*	↓*
	poisonous	↓n.s.	↑*	↑n.s.	↑*	↑n.s.	↓n.s.	↓n.s.	↓*
grazing tolerance	intolerant	↑***	↑***	↓**	↓n.s.	↓**	↓n.s.	↓*	↑*
	moderately tolerant	↓***	↓**	↑*	↑*	↑*	↑n.s.	↓n.s.	↓*
	well tolerant	↓*	↓n.s.	↑**	↑n.s.	↑**	↓n.s.	↑*	↑n.s.
trampling tolerance	intolerant	↑***	↑*	↓*	↓*	↓**	↓**	↓*	↑*
	moderately tolerant	↓***	↓*	↑*	↑n.s.	↑**	↑**	↑n.s.	↓n.s.
	well tolerant	↓**	↑n.s.	↑**	↑*	↑*	↑*	↓n.s.	↓*

Appendix 4-4 Ordination diagram of Nonmetric Multidimensional Scaling (NMDS) of all traits and mixed grazing sites. Attribute proportions per trait related to species abundances. The diagram was rotated in direction of the time gradient. Arrow base refers to the beginning of grazing and arrowhead refers to the last vegetation relevé. NMDS configuration: Euclidean distance, 3 dimensions, best solution of 500 runs, stability criterion = 0.0005, random starting configuration. Variance represented by Axis 1 = 18.8% and Axis 2 = 53.8%. S= Solling-Vogler, H= Höltigbaum.



Appendix 4-5 Pearson Correlation coefficient between tested functional traits of mixed grazed sites and first axis. Correlation coefficients ≥ |0.5| printed in bold type.

Trait	Characteristic	Correlation coefficient with first axis	Correlation coefficient with second axis
lifespan	lifesshort	0,085	-0,136
	lifeslong	-0,086	0,134
life form	chamaephyte	0,443	-0,052
	geophyte	0,107	**0,634**
	hemicryptophyte	-0,336	**-0,792**
	hydrophyte	-0,227	0,075
	nanophyte	0,096	**0,565**
	phanerophyte	0,193	0,289
	therophyte	0,006	0,183
leaf distribution	regular	0,468	**0,722**
	semirosette	-0,412	**-0,688**
	rosette	-0,228	-0,202
canopy height in m	<0,3	**0,549**	**-0,581**
	0,3-0,6	**-0,599**	-0,335
	>0,6	-0,018	**0,877**
specific leaf area in mm^2/mg	<20	-0,316	**0,522**
	20-25	-0,226	-0,480
	>25	**0,539**	-0,131
clonalgrowth	yes	0	**-0,504**
	no	0	**0,504**
minimum budbank depth in cm	<-10	0,128	0,180
	-10-0	-0,088	**0,573**
	>10	0,039	0,495
seed bank	longterm	-0,304	-0,063
	present	0,316	-0,123
	shortterm	**0,637**	-0,137
	transient	**-0,548**	0,186
maximum seed shedding	spring	0,022	-0,016
	summer	-0,048	0,333
	autumn	-0,098	-0,181
	winter	0,166	-0,137
preference	eaten	0,018	**-0,861**
	avoided	**-0,550**	0,330
	poisonous	0,280	**0,828**
	preferred	0,187	0,161
grazing tolerance	intolerant	-0,405	**0,734**
	moderately tolerant	0,463	**-0,502**
	well tolerant	-0,010	0,004
trampling tolerance	intolerant	-0,154	**0,880**
	moderately tolerant	0,166	**-0,743**
	well tolerant	0	-0,374

Appendix 4-6 Differences of Plant trait proportions on sites of Höltigbaum between first and last year of grazing. Results of Wilcoxon-signed-rank-Tests. H= Höltigbaum, ↑= Increase, ↓= Decrease, n.s.= not significant, *= p<0.05, **= p<0.01, ***= p<0.001.

Trait	**Attribute**	**H1**	**H2**	**H3**	**H4**	**H5**	**H6**	**H7**	**H8**
life form (-phyte)	hemicrypto	↓n.s.	↑**	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↓n.s.
	nanophanero	↓n.s.	↓n.s.	↓n.s.	-	↑n.s.	-	↓n.s.	-
leaf distribution	regular	↑n.s.	↓*	↑n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.	↑n.s.
	semirosette	↓n.s.	↑*	↓n.s.	↑n.s.	↓n.s.	↑n.s.	↑n.s.	↓n.s.
canopy height in m	<0,3	↓n.s.	↑*	↑n.s.	↑n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.
	0,3-0,6	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.
	>0,6	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.
clonalgrowth	no	↓n.s.	↓**	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↑n.s.	↑n.s.
minimum bud-bank depth in cm	<-10	↑n.s.	-	-	-	↑n.s.	-	↑n.s.	-
	-10-0	↑n.s.	↓**	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	-
	>10	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.
seed bank	longterm	↑n.s.	↓n.s.	↑n.s.	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↓n.s.
maximum seed shedding	summer	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↑n.s.
preference	eaten	↓n.s.	↑**	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↓n.s.	↑n.s.
	avoided	↑n.s.	↓**	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.
	poisonous	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.
grazing tolerance	intolerant	↑n.s.	↓**	-	↓n.s.	↓n.s.	↓n.s.	↑n.s.	-
	moderately tolerant	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↑n.s.	↑n.s.	↓n.s.
trampling tolerance	intolerant	↑n.s.	↓*	↑n.s.	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↓n.s.
	moderately tolerant	↓n.s.	↑**	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↑n.s.	↓n.s.

Trait	**Attribute**	**H9**	**H10**	**H11**	**H12**	**H13**	**H14**	**H15**
life form (-phyte)	hemicrypto	↑n.s.	↑*	↓n.s.	↑n.s.	↑n.s.	↑n.s.	↑n.s.
	nanophanero	-	-	↓n.s.	↑n.s.	-	-	↓n.s.
leaf distribution	regular	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.
	semirosette	↓n.s.	↑n.s.	↑n.s.	↑n.s.	↓n.s.	↓n.s.	↑n.s.
canopy height in m	<0,3	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↑n.s.	↑n.s.
	0,3-0,6	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↑n.s.	↑n.s.
	>0,6	↓n.s.	↓*	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↓*
clonalgrowth	no	↓n.s.	↓*	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.
minimum bud-bank depth in cm	<-10	-	-	↓n.s.	↓n.s.	↓n.s.	-	↑n.s.
	-10-0	↑n.s.	↓*	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.
	>10	↓n.s.	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓**
seed bank	longterm	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↑n.s.
maximum seed shedding	summer	↑n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↑n.s.
preference	eaten	↑*	↑n.s.	↑n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.
	avoided	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓*
	poisonous	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↑n.s.	↓n.s.
grazing tolerance	intolerant	↑n.s.	↑n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.	↓n.s.
	moderately tolerant	↓n.s.	↓*	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓*
trampling tolerance	intolerant	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↓n.s.	↑n.s.	↓n.s.
	moderately tolerant	↓n.s.	↓n.s.	↑n.s.	↑n.s.	↓n.s.	↑n.s.	↑n.s.

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    - ONB Niederbayern
    - Niedersächsische Landesforsten

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