Effects of different seasonal cutting regimes on the regrowth of black alder (*Alnus glutinosa* L.) and on plant species diversity

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Developing a strategy to eliminate alder trees that encroached into open calcareous fens of Upper Bavaria (Germany)

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Anne Braukmann (3702618)

MSc Programme Sustainable Development, track Global Changes and Ecosystems

E-mail: A.Braukmann@students.uu.nl

Address: Weidenfohr 15, 57223 Kreuztal, Germany

Supervisor: Prof. Dr. Martin J. Wassen, Utrecht University

Co-Supervisor: Prof. Dr. Gert Rosenthal, Kassel University

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Abstract

The commonly managed and extensively grazed pastures in Upper Bavaria have become a valuable remainder of a heterogeneous and diverse landscape, which exhibits an exceptionally high diversity of habitats for plant and animal species. Characteristic for this landscape is the spatial and temporal coexistence of different successional stages. However, in the wetland areas of these pastures open fen grasslands are at danger of disappearing, because they are rapidly colonised by black alder. This would result in a loss of typical fen plant communities (e.g. Caricion davallianae) adapted to this open habitat. As the current grazing regime is not suitable to keep the fens open, which have already been colonised by young alder trees, an alternative method has to be found. For this reason it was investigated in this thesis whether different seasonal cutting regimes can be an efficient measure to eliminate alder trees that have colonised mesotrophic calcareous fens. Additionally, it was studied what effect these cutting regimes have on the plant species composition after two and a half years of tree cut.

To compare the efficiency of a cutting regime in winter with a cutting regime in summer the number of shoots, the height and the crown area of alder trees was measured after repeated cutting. This could indicate whether the cutting resulted in a reduced regenerative ability of the trees. The impact on the vegetation was analysed by comparing vegetation relevés in the surrounding of alder trees that were repeatedly cut back and trees that were not cut back.

These investigations could demonstrate that repeatedly cutting back alder trees in summer leads to a much stronger weakening of alder trees than cutting them back in winter. After being cut back twice in summer about 40 % of the trees had died completely, while only 15 % had died when cut back in winter. Additionally, in the surrounding of the cut trees more plant species could be found, indicating that the cutting regime already had a positive effect on the fen vegetation. However, only a slight increase of light-demanding species could be observed, where alder trees had been cut.

Finally, options and possible challenges of managing these open fen grasslands in a sustainable way were discussed.

1 Background

1.1 The development of heterogeneous landscape mosaics

Diverse and dynamic landscapes which are characterised by mosaics of open land, shrubs and forested areas are disappearing rapidly all over Europe (e.g. Tscharntke et al. 2005; Luick 2008). In the natural landscape of the European continent, spatial and temporal coexistence of different successional stages was maintained by reoccurring abiotic perturbations like fire, erosion, windthrow or flooding on the one hand and by the impact of large herbivores, like deer, elk, aurochs, the European bison, wild horses or the impounding of rivers by beavers on the other hand (Sousa 1984; Vera 2000). In many cases abiotic and biotic factors were also connected. For instance increased grazing often occurred in areas that had been previously affected by fire or windthrow. This combination had a stabilising or even increasing effect on the proportion of open land (Beutler 1996).

With increasing human impact extensive forms of agriculture, which mostly consisted of low-input arable farming, extensive grazing by livestock at low stocking rates, haying and timber logging, became new dominant factors influencing the structure and appearance of the landscape (Pott 1998). Domesticated animals like cattle, horses, sheep, pigs or goats substituted their wild ancestors and were kept on large scale pastures which often consisted of a mosaic of grasslands and forests. They shaped the landscapes in a slow but persistent way (Bakker & Londo 1998). These human-induced impacts unintentionally resulted in an exceptionally high structural diversity of landscapes, which constituted habitats for many plants and animals that were adapted to highly differentiated conditions (Harding & Rose 1986; Farrell 1989). In particular many open landscapes with nutrient-poor soils, such as heathlands, were created due to the permanent depletion of nutrients and the lack of fertilisers (Webb 1999).

However, this extensive form of agriculture was very labour-intensive and as a consequence of the rapid growth of the human population, more efficient solutions had to be found. The result was a drastic intensification of agriculture, facilitated by new possibilities of transportation, the development of chemical fertilisers and new technologies that led to an automation of agricultural processes and an immense increase in productivity. On the downside of this development, the intensively managed areas generally exhibited a rapid decline in species diversity, due to the effects of eutrophication, pesticides and the focus on monocultures (Stoate et al. 2001). Accompanying this development, an abandonment of less profitable parts of the landscape, such as wetlands or nutrient-poor grasslands, occurred within the last 40-50 years. As nowadays also most of the disturbance factors that can initialise succession processes are successfully controlled by humans, in many regions an increase of forest cover and a decline of earlier successional stages can be observed (Reier et al. 2005).

1.2 Large-scale pastures of Upper Bavaria as an example for a diverse landscape

Today only few remainders are left of these historical landscapes, which strongly affected the identity of the particular regions (Sörlin 1999). One unique example of a relatively intact dynamic and heterogeneous landscape, representing traditional land use patterns, can be found in the prealpine regions of southern Bavaria (Germany). Characteristic for this area is the exceptionally long and continuous history of traditional use of common pastures (Lederbogen et al. 2004). Due to financial and practical constraints, local farmers used to keep their cattle on large-scale commonly managed pastures, so-called ‘Allmendweiden’ (20-150 ha in size). These pastures not only consisted of open grassland, but also of complete series of succession and different habitat types, ranging from dry to wet (Lederbogen et al. 2004). As a consequence of the limited amount of adequate fodder, the cattle was forced to graze in all parts of the pastures. In combination with timber activities and the mowing of grasslands by local farmers, this resulted in a park-like landscape of open grasslands interspersed with areas colonised by shrub and forests. In fens, which are a characteristic part of these common pastures, fen gasslands (Caricion davallianae, Caricion lasiocarpae) form habitat mosaics with alder-spruce-fen woods (Alnion glutinosae) and mountain pine forests (Sphagnion magellanici). As a consequence of this high structural diversity of the landscape, the β- and γ-diversity of these extensively grazed ecosystem mosaics is exceptionally high. The ‘Allmendweiden’ in Bavaria therefore provide habitats for many animal and plant species representing a large range of different habitat demands (Lederbogen et al. 2004; Wagner 2000).

1.3 Threats to biodiversity in the Bavarian ‘Allmendweiden’

However, major changes in agricultural policy and increasing competition lead to a continuing privatisation of the ‘Allmendweiden’ and many local farmers fear that this traditional form of cattle grazing is financially no longer feasible. A cessation of grazing has already occurred and it starts to show first effects on the habitat diversity. Open grasslands become increasingly rare and the formerly smooth transitions between forested and open parts (ecotones) disappeared. This is especially the case for mires, as they only provide low quality fodder for the animals and therefore are rarely grazed. This can be considered as a consequence of the current predominance of progressive succession over regressive succession. Unlike during the past centuries, regressive succession hardly influences the shape and composition of the landscape in this region anymore (Rosenthal et al. 2004). In addition, the need for timber woods has rapidly declined due to their replacement by fossil fuels. In particular calcareous fens are affected by the omission of regular tree and shrub cutting (‘Schwenden’, Bavarian idiom), meaning that there is no more limiting force of the rapidly progressing encroachment of black alder. From a nature conservation point of view this is problematic, because it means a loss of valuable species and species associations (Rosenthal 2010). Several parts of this region are protected under the fauna and flora habitat (FFH-) directive (e.g. LRT 7230: Caricion davallianae) and a number of red list species can be found in the research area and its surrounding. Some examples of threatened plant species are *Spiranthes spiralis, Parnassia palustris, Pedicularis palustris and Dactylorhiza traunsteineri* (Lederbogen et al. 2004).

1.4 Black alder as a keystone species for secondary succession

For the wetland areas of these landscapes black alder trees (*Alnus glutinosa* L.) act as keystone species. These light demanding and fast growing woody pioneers are well adapted to wet conditions and can establish in fens, where hardly any other tree seedlings would survive (McVean 1953). They can indeed tolerate the highest degree of soil moisture of all deciduous tree species of central Europe (Hacker & Pflug, 1998). Black alder is avoided by cattle and horses and even deer usually only harm it by rubbing against or debarking the stems. Once alder trees have reached the size of 2 m, they face no more risk of being harmed by herbivores and can develop into mature trees (Rosenthal et al. 2004). Their establishment in fens is even facilitated by trampling of large herbivores or other site disturbances which create optimal conditions for the germination of their seeds (Peringer 2008). Over time alder trees can form small homogenous alder-carr-forests, which are considered as the climax stage of the fen succession.

Their key role for progressive succession can be attributed to the fact that

(1) alder trees are able to enrich the nutrient poor soils of calcareous fens with nitrogen due their symbiosis with nitrogen-fixing actinomycetes, which are located in nodules of their roots, and mycorrhizal fungi (Hall et al. 1979).

(2) their growth causes a development of elevated hummocks, which constitutes a microhabitat for other plant species. The soil on these hummocks is dryer than the soil in the surrounding hollows of the fens. Additionally, alder trees produce litter which is decomposing quickly, enhancing the formation of a suitable soil. This allows for the colonisation of the area by other tree species like spruce (*Picea abies*), which are less tolerant of wet soil conditions (Falinska 1991). In the course of time spruce is likely to replace some of the alder trees because of their higher shade tolerance.

(3) crowns of the trees create unsuitable conditions for light demanding grassland plants of the understorey, but favourable conditions for forest species.

In the context of this research the remarkable colonising ability of in particular wet ecotones by black alder is of major importance. In the following, the main factors playing a role for the successful colonising strategy of alder trees are summarised (Hacker, 1995). Firstly, they exhibit biological characteristics typical for pioneer species, such as the development of numerous small seeds, which are dispersed by wind and water and the rapid growth of the seedlings and young trees, which generates an advantage in competition with other young trees. Alder trees have a strong root system with which they are able to penetrate deeply into dense soils and they exhibit a flexible growth of the shoots. Of particular importance for this project is their high regenerative ability. When damaged, for instance by intensive browsing by herbivores, or cut back they rapidly develop several new shoots in the next growth period. Due to this way of regrowth after disturbance they often resemble spherical bushes rather than trees (Figure 1). Their morphological and ecological flexibility enhances their competitive strength and therefore often a development of stable dominant stands can be observed (Peringer & Rosenthal 2009).

Figure 1: Mature alder trees (background) and spherical alder bushes (front row) that were cut back in winter 2009.

1.5 Challenges and options for slowing down encroachment of black alder into open fens

As described above grazing by cattle or horses is not a very efficient measure to slow down or stop encroachment of black alder into open fens. If the particular flora and fauna of calcareous fens with its comparatively high percentage of endangered species is to be protected, other methods need to be found. One option is to mechanically damage or remove young black alder trees that have penetrated the open parts of the fens. However, completely removing the trees including their extensive roots system is by far too work-intensive and constitutes an intolerable damage of the ecosystem.

In the course of a four year intensive research project on ‘Allmendweiden’ in south Bavaria, funded by the German Federal Ministry for Education and Research, this particular issue turned out to be a critical point for the conservation of the heterogeneity of the landscape (Lederbogen et al. 2004). Therefore, a short-term experiment was conducted within this project to compare the efficiency of different methods to combat the encroachment by black alder (Strohwasser et al. 2004). In the following table the different treatments applied and their effects in fens and half-bogs are summarised.

Table 1: Results of the comparison of the six different treatments applied to combat black alder trees that were growing on formerly open wet meadows (adapted from Strohwasser et al. 2004)

Method	Effect
Treatment 1: Ringing to 2/3 of the circumference of the stem in 1 m height at full foliar stage in May and December 2001	In summer 2002 foliage was less dense than for undamaged trees. Long-term effect cannot be judged, yet.
Treatment 2: Cutting off of alder trees in January 2000, three times cutting back of regrown shoots in summer 2000, 2001 and 2002	Shoots of alder trees that were completely cut off only showed signs of decreasing vitality after being cut back twice.
Treatment 3: Ripping whole trees including roots out of the soil with a rope winch in January 2000	Roots that were ripped out (and part of them turned upside-down) were still in contact with the soil. Alder trees could therefore generate new shoots.
Treatment 4: Complete ringing of bark in summer 2000	Underneath the ringing new vital shoots appeared that could replace the dying apical shoot.

This comparison could demonstrate that when black alder was growing in a suitable habitat, such as a fen, most of the treatments were not efficient. Under every treatment the trees could regenerate and develop new shoots. Only for treatment 2 a considerable decrease in vitality could be observed after the trees were repeatedly cut. For this reason and because this treatment is the most common practice in this area, the research project described here focusses on a repeated cutting regime instead of ringing the trees or ripping out whole trees including their roots.

Furthermore, it became clear that mature seed-producing trees are a major problem. Regarding this aspect Peringer and Rosenthal (2009) investigated the successional patterns and colonisation strategy of black alder by means of dendrochronological methods and life trait analysis. They could show that open reed vegetation on the lee side of fruiting alder trees is particularly threatened by encroachment. As a long-term management option to slow down encroachment, they propose to only fell mother trees west of the shrubs and leave the remaining part of the alder forest unaffected.

If the first successional stages of open fens with their characteristic composition of light demanding, often highly specialised species are lost this will lead to a significant reduction of plant species diversity. It was calculated by Rosenthal (2010) that if only later successional stages of the alder forests were left, 71 plant species of the calcareous fen succession series (= 29 % of the total number of species) would disappear, because they only occur in the open vegetation of calcareous fens. In this light the importance and urgency of the presented topic becomes clear.

2 Problem definition

In the prealpine region of Bavaria extensive grazing by cattle has been used for centuries as a cost efficient method to keep the landscape open by limiting shrub or tree encroachment. There is a decreasing tendency of cattle grazing nowadays, because often farmers fear that it is not profitable enough anymore. Next to this the nutrient enrichment and drainage of some areas has led to an attraction of the cattle to productive meadows and an avoidance of wet, less productive sites. As a consequence there has been increased encroachment by black alder into the open fens and bogs.

This development is associated with a loss of threatened, light demanding species as a consequence of the homogenisation of the landscape (Lederbogen et al. 2004).

In order to ensure the persistence of the dynamic and diverse landscape it became apparent that in open fens alternative measures to extensive grazing needed to be found to at least partially limit encroachment by alder trees. This is also important to ensure that extensive grazing can still be practiced in the fens, because these parts of the pastures become even more unattractive for cattle of horses if they are not kept open.

Traditionally, the local farmers used to cut back the trees during winter. However, this measure is carried out much less nowadays. Additionally, a winter cut seems to be relatively ineffective for suppressing the regrowth of alder trees. For this reason the effects of cutting back black alder in winter will be compared to cutting back the trees in summer, during the vegetative period.

3 Aims of the proposed research

The first part of the proposed research is aimed at investigating how alder trees that have established in the formerly open calcareous fen can be eliminated without causing too much perturbation of the soil and the present plant communities. A promising option that resulted from the insights of previous investigations is to compare the effects of different seasonal cutting regimes on young encroached alder trees with control plots on which only one initial cutting of trees has been carried out.

In the second part of this research the focus will be on analysing to what extent different cutting regimes affect the plant species composition of the area under investigation. Comparing vegetation relevés should reveal whether a repeated cutting regime can help to achieve the nature conservational goal of restoring the species diversity of open fen grasslands.

In conclusion, recommendations will be made on how the most successful cutting regime could be implemented in the future to ensure the preservation of a dynamic landscape with different successional stages and the associated plant species communities. Furthermore, it will be discussed whether there are possibilities to make use of the harvested alder material in order to ensure the sustainability and efficiency of this proposed method.

4 Research question and hypotheses

The main research question can be formulated as follows:

Is repeatedly cutting back alder trees in summer significantly more effective for reducing their vitality than a cutting regime in winter and how do the repeated seasonal cuttings affect the plant species composition in the surrounding of the cut trees?

The following hypotheses are the main guidelines for this research:

1. Repeatedly cutting back alder trees in summer is expected to be more efficient than cutting them back in winter, because it will probably cause more damage to the regrown trees when they are at the peak of the development of their foliage and metabolic activity. Cutting back the trees in winter might not lead to a sufficient reduction in vitality and regrowth potential, because they are in a dormant phase at this time of the year.

2. The diversity of plant species is expected to be higher in the surrounding of the cut alder trees, because more light is available due to the reduced shading by the trees. The repeated cutting regime will allow for a higher occurrence of species typical for open fens, which are missing when the crown cover by alder trees is high.

5 Methodology

5.1 Research area

The research area is located close to the village Prem in the south-west of Bavaria in Germany (Figure 2). It is situated in a prealpine young moraine landscape that is characterised by its undulating relief, with heights of 750 – 900 m a.s.l, resulting from the Würm glacial stage. The soil is formed by tertiary layers of molasses and carbonate-containing moraines. In depressions also water impenetrable layers of lacustrine clay and calcareous mud originating from former lake grounds can be found (Bayerisch-es Geologisches Landesamt 1996).

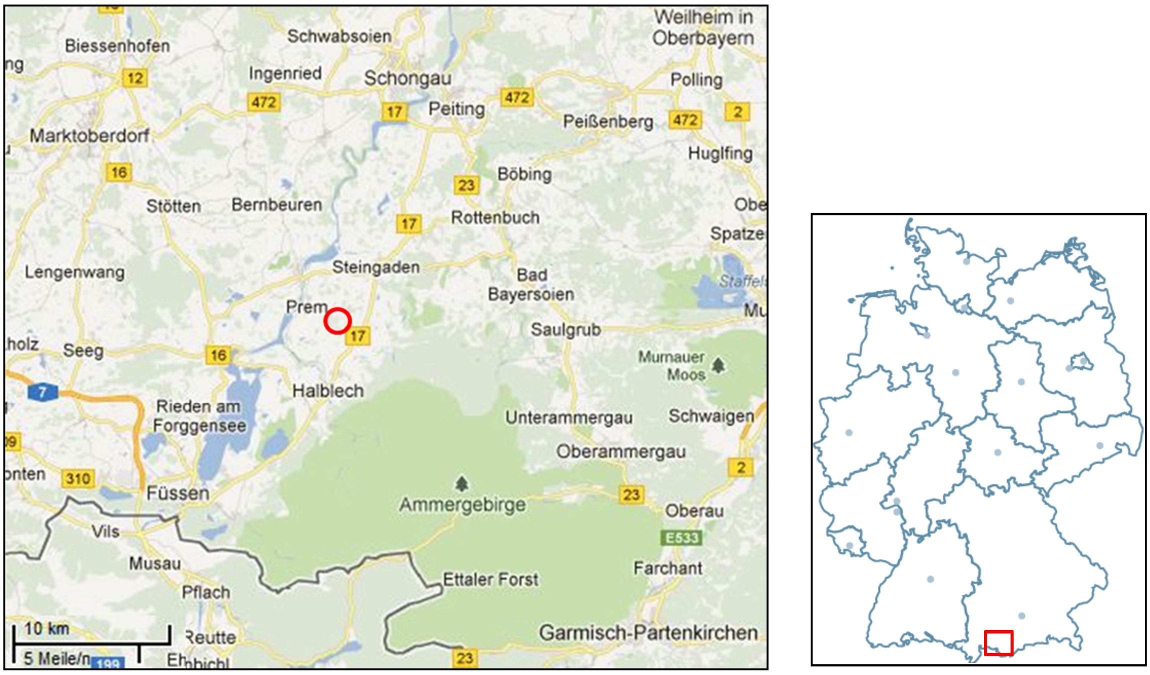

Figure 2: Research area. The red circle marks the location of the research area in the south of Bavaria (left). It is situated in the prealpine region of Germany (right).

Besides these geomorphological conditions, the moist and cool climate characteristic for the north-ern edge of the Alps is the main reason for the existence of numerous fens and bogs in this area. Yearly precipitation ranges from 1200 to 1500 mm and temperature from 6 to 7 °C. The latter is rela-tively low for the southern part of Germany.

Due to the hilly landscape a differentiated range of climate and soil conditions could develop and persist. Therefore a transition from mineral soils on hill tops via transitional bogs to calcareous fens in depressions can be found. In some of the depressions also intermediate and raised (rainwater-fed) bogs have formed (Lederbogen et al. 2004).

The research project is conducted within the 'Holzer Viehweide', a pasture established hundreds of years ago but repeatedly reduced in size. Today it is owned by four farms located nearby, of which three are still actively using the land. Only the drier habitats of this pasture (Cynosurion communi-ties) are fertilised, whereas the fens and transitional bogs of the present experimental area do not receive any fertilisers and are only extensively grazed by cattle and horses. This could be achieved by the financial support of a Bavarian programme for nature conservation (Strohwasser & Lederbogen 2004). Traditionally, the farmers mainly use young cattle ('Braunvieh') on the wide-ranging pastures, with a low stocking capacity of 0.5 to 2 young cattle per ha (Waldherr 2000). The 'Holzer Viehweide' has a high percentage of wet areas. It mainly consists of calcareous fens and different successional stages of alder forests. However, also transitional bogs with small-scale mountain pine populations constitute smaller parts of it.

The experimental plots for this research are located in a semi-open calcareous fen, which is slowly but steadily colonised by black alder from the surrounding forest and shrubs. The soil of the fen consists of alkaline, mesotrophic gley or peat. It is constantly saturated with water and the water level is very stable over the year. This is a precondition for the occurrence of the characteristic plant community of Caricion davallianae with a proportionally high number of endangered sedge species (e.g. *Carex davalliana, C. flava and C. hostiana)* and herbaceous helophytes such as *Epipactis palustris, Pinguicula vulgaris* and *Primula farinosa* (Lederbogen et al. 2004). The grazing that has occurred in this area for centuries induced complexes of hollows and hummocks, which also contribute to the diversity of plant species by providing different microclimates. However, increasing encroachment by alder trees leads to a progressive succession of this plant community towards alder pioneer forests.

The experimental plots were set up on a location where young alder trees had already colonised the open fen. These trees had reached the stage of a young pioneer forest with an average tree height of 4 m, an average diameter at breast height of 3 cm and an average age of 11 years (Kuisle 2009).

5.2 Measurements in the field

In the selected experimental site on the 'Holzer Viehweide' the alder trees that had grown into the open fen were cut back to trunks of about 10 to 20 cm in winter 2008/2009 (Figure 5). In the following year, in April 2010, the experimental plots for this research project were established in the fen where those trees were cut.

The following three different treatments were compared in order to investigate the effect of the cutting on the regrowth of black alder trees:

1. Plots on which alder trees were cut annually in winter (W)

2. Plots on which the trees were cut annually in summer (S)

3. Plots on which alder trees were only cut in winter 2008/2009 and then left undisturbed (control plots, C)

One plot was 5x5 m large and contained 6 to 21 alder trees of a comparable age and height. There were four replicates of every treatment, which were located close enough to each other to ensure comparability but far away enough of each other to avoid edge effects. Thus, in total there were 12 plots in the research area. The replicates of the *W* plots and those of the *S* plots were arranged alternately in a block design. In contrast the four control plots were located next to each other in a square of 10x10 m close by but outside the block design of the *S* and *W* plots (Figure 3). This solution had to be found due to the limited amount of space in the research area and because taller growing alder trees within the control plots could have affected the growth of the trees in the seasonally cut plots by shading and increased litter production.

After the cut in summer 2010 all plots were fenced off, because deer had strongly damaged some of the regrown shoots, which lead to an undesired and uncontrollable effect on the results.

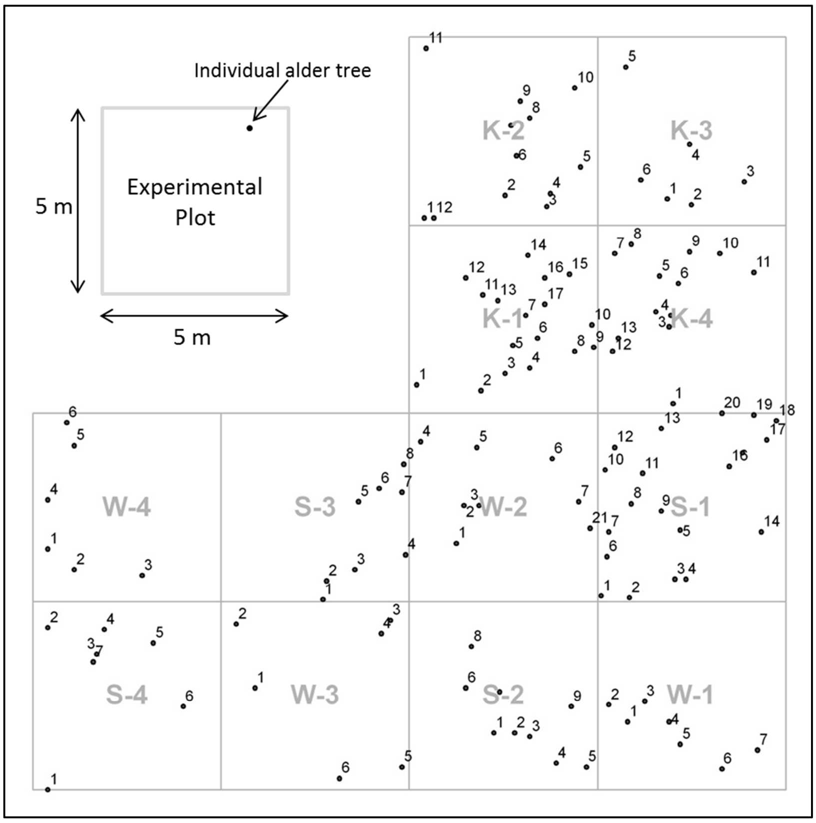

Figure 3: Experimental design. S1-4: plots with alder trees cut in summer; W1-4: plots with alder trees cut in winter; K1-4: control plots. The black dots mark the position of the individual alder trees in the plots.

5.2.1 Measurement of the regrowth parameters

From winter 2010 on regrowth parameters of the alder trees were measured twice a year in winter and summer, prior to the respective seasonal cutting. For each alder tree the total number of basal shoots, the number of damaged and dead shoots and the length of the five longest shoots was determined. For the five longest shoots the average length was calculated as well as the maximum, which can also be used as an approximate indicator for the height of the measured tree. In some cases shoots were broken or damaged but their length could still be estimated. Additionally, the diameter (a) of the crown at its largest width and the diameter (b) perpendicular to this were measured. With these two values the largest crown area (A) of each tree could be calculated to get an estimate of the crown coverage of the herbs layer by the alder trees: $A = \frac{1}{4}\pi * a * b$ (Figure 4).

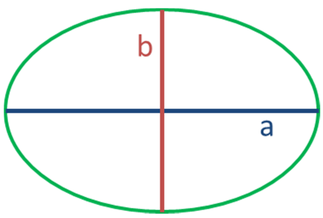

Figure 4: The crown area of each alder tree was calculated using the formula $A = \frac{1}{4}\pi * a * b$, in which a represents the horizontal diameter of the crown at its largest width and b the horizontal diameter perpendicular to a.

As a supplementary variable the volume of each alder tree was calculated by multiplying the crown area with the maximum height of the trees. In this context it has to be noted that the assumption that the volume of an alder trees equals that of a cylinder, is only a rough approximation of the actual volume.

Finally, it was recorded how many trees had completely died off in the different plots.

For the control plots also the initial diameter of the trunk was determined in winter 2010. This was done because different sizes of trunk diameters could have an influence on the regrowth of the alder trees.

These parameters were determined to describe and compare the regenerative ability of the alder trees in the three treatments (S, W and C) at different points in time.

Figure 5: Different stages of cut back alder trees. Left: Alder tree cut back and regrown. It exhibits the typical shperical form of damaged and regrown alders. Right: Trunk of an alder tree just cut back. Most of the shoots are dead already.

5.2.2 Assessment of plant species diversity

In summer 2012 in each of the three treatments ten quadrats of 50x50 cm were randomly located to assess the plant species diversity. While complying with a random distribution of the relevés, attention was paid to having at least one relevé in every plot.

At first the influence of the surrounding alder trees and the percentage of vegetation cover were determined for the relevés. In this context the percentage crown cover by black alder over the herbal layer, the height of the covering alder tree, the height of the herbal layer, the coverage of the herbal layer and the coverage of mosses were determined. Subsequently, all species (except for mosses due to the limited amount of time) within the quadrat were determined and their abundances estimated using an extended version of the Braun-Blanquet method (Reichelt & Wilmanns 1973).

This assessment of the plant species could give an indication whether different treatments already had an effect on plant species composition and diversity.

As a further option to assess to influence of the presence of alder trees on the composition of the vegetation, the location of the trees and of the vegetation relevés was exactly determined and transferred to a digital map of the plot design (Figure 6). This map is also used as a visualisation tool and for interpreting the results.

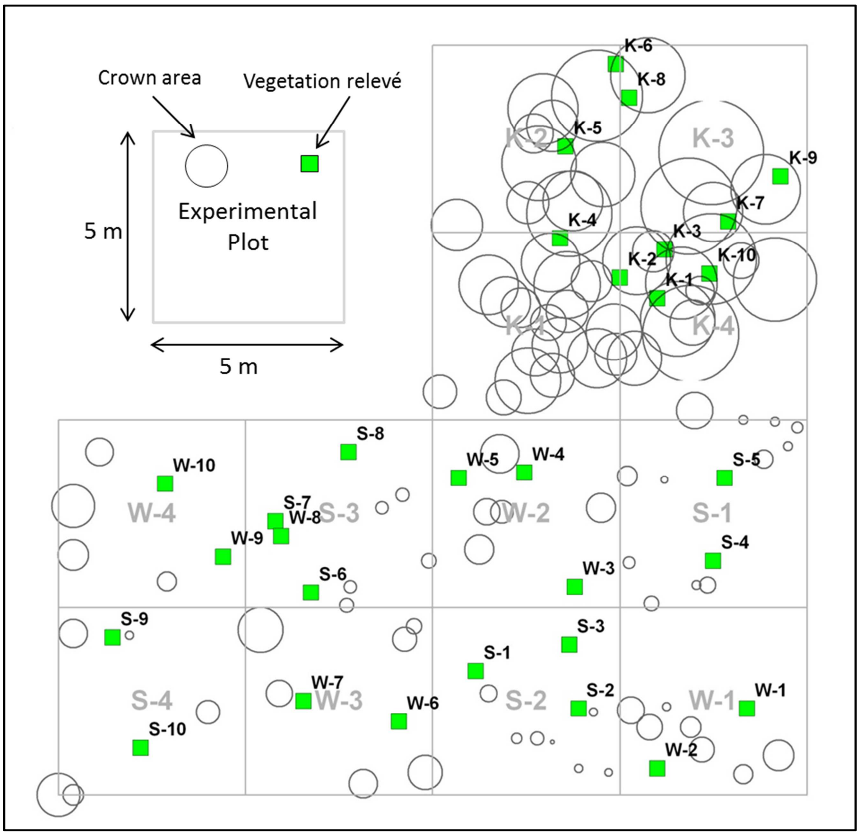

Figure 6: Experimental design. S1-4: plots in which trees were cut in summer; W1-4: plots in which trees were cut in winter; K1-4: control plots . The circles represent the size of crown areas of the individual trees in summer 2012 and the green squares mark the locations (and size) of the vegetation relevés.

5.3 Statistical Analysis

The data obtained from the field work were first preselected and subsequently analysed in SPSS 20 (IBM Corp. 2011) for the measurements of the trees and in CANOCO 4.5 (ter Braak & Smilauer 2002) for the vegetation assessments. A decision was made to focus on the measurements of winter 2010 (initial state of the trees without any effect of the treatments) and the three summers 2010, 2011 and 2012 for the statistical analysis (Figure 7). The reason for this selection was that in winter 2011 and 2012 hardly any regrowth was observed or measured and that it is more convenient to compare the regenerative ability in the summer period. However, the data gathered in winter can play a role for the discussion and interpretation of the results. Additionally, individual trees that were strongly damaged or that exhibited other clearly flawed features were left out of the analysis.

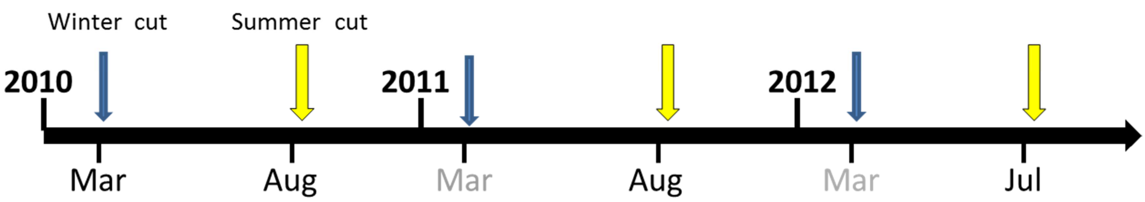

Figure 7: Measurement and cutting dates during the three years of the experiment. Blue arrows represent winter cuttings, yellow arrows represent summer cuttings. The two dates which are left out of the statistical analysis (March 2011 and March 2012) are light grey.

To get a first overview of the effects of the different treatments in connection to the point in time of a particular cutting, the change of the measured parameters was plotted for the time span of 30 months over which the experiment was carried out.

Subsequently it was tested whether there was a significant difference between the four replicate plots of one treatment. As this was not the case, the four plots of each treatment could be pooled for further analysis. This means that for the statistical tests the measured variables of all individual trees in the control plots (n = 49) were compared to those of all trees in the S plots (n = 44) and all trees in the W plots (n = 26).

As most of the data was neither normally distributed nor homogenous in variance, a Median test was conducted to investigate whether there were significant differences between the three different treatments (C, S and W) for each of the four selected points in time (winter 2010, summer 2010, 2011 and 2012). It was followed up by the respective post hoc tests (cross tabulation analysis) to find out where the actual differences were located. These tests were carried out for the outcome variables crown area, mean height of the five longest shoots and number of shoots.

To find out whether there were significantly more dead trees in the S plots than in the W or the control plots a Chi²-test was conducted. This test was only done for summer 2011 and 2012, because in the first year no clear effect of the cutting regimes was expected, yet.

To assess whether there was a significant influence of the initial trunk diameter on the number of shoots or the volume of the trees, a linear regression analysis was done. As the original data was not normally distributed a square root transformation was applied. This analysis could only be done for the trees in the control plots, because the initial trunk diameter was not measured in the S and W plots.

In order to analyse the vegetation relevés, first the estimated values for cover of each species were transformed to cover percentages. Then the list of species was reduced to a subset of 20 species by omitting rare species with less than 3 occurrences. Subsequently, a Principal Component Analysis (PCA) was conducted to reveal connections between plant species occurrence and treatments and further estimated variables (e.g. crown coverage by alder trees etc.). A PCA was chosen as the most appropriate ordination method, because it focuses on analysing short and linear behaviours of plants along floristic gradients (indirect gradient analysis). A DCA (Detrended Correspondence Analysis) indeed revealed a short floristic gradient of the first axis, with a multivariate standard deviation of only 2.167, which is an indication for linear instead of unimodal response curves (ter Braak & Smilauer 2002). Additional vegetation data were treated as supplementary variables and added post hoc by regressing their data onto the existing ordination axes, which had been previously calculated. For this analysis the data was standardised (rescaling of the variables with a mean of zero and a variance of one) and centred.

Additionally, the number of species per plot was compared between the three treatments using a one-way independent ANOVA. To assess the similarity of species compositions in the relevés between the three treatments a percentage similarity coefficient (Bray and Curtis 1957) was used. This coefficient can be calculated using the formula: $S = 2W/(A+B)$, in which S is the similarity coefficient, W is the sum of the lesser scores of species occurring in both quadrats which are compared, A is the sum of the scores of the first quadrat and B is the sum of the scores of the second quadrat.

Finally, the alpha-diversity of the three treatments was compared using the species richness (number of species) and the Shannon-Wiener Index.

The statistical tests used and the corresponding working hypotheses are summarised in Table 4 in Appendix A.

6 Results

6.1 Comparison of the seasonal cutting regimes

The development of the number of shoots, the mean height of the trees, the crown area (and the approximate volume) of the alder trees was plotted for the time period during which the experiment was carried out. Subsequently it was tested whether these variables were significantly different for the three treatments (C, S and W).

The average number of shoots of the trees in the control plots continuously decreased, except for the last measurement, where there was a slight increase again (Figure 8). For the number of shoots in the S plots first a strong decrease can be discerned and subsequently the number of shoots is fluctuating depending on the cutting regime. In the winter measurements very few or even no regrown shoots could be found for the S plots. In the W plots only after the first cut a strong reduction of the number of shoots can be found. In the following measurements the number of shoots either increased or stayed approximately the same as before. Notably in every treatment an increase of the number of shoots can be observed for the last measurement after 27 months.

When the number of shoots was compared between the three treatments, for the first year (winter and summer 2010) there was no significant difference between the treatments (Figure 9). In contrast to this in summer 2011 and 2012 the number of shoots in the W plots was significantly higher than the number of shoots in the control plots, but not significantly higher than in the S plots. The number of shoots for the control plots and the S plots was still similar and therefore not significantly different.

The mean height of the trees was constantly increasing for in the control plots over time. In the first season (from winter 2010 to summer 2010) the trees showed the strongest growth (Figure 10). In general, the height of the trees increased when they were not cut back and decreased when they were. It is striking that the first summer cut induced a strong response of the trees in the S treatment, which can be seen in the weak regrowth in winter 2011 (only 4 cm after 11 months). Subsequently the height of the trees was much lower even in the summer periods. The mean height of the trees in the W plots also slightly decreased first, but then stayed at a very similar level of about 60 cm, despite the cuttings in the winter.

When the alder trees were measured for the first time in winter 2010, the height of the trees in the control plots and the S plots was similar, but in the W plots it was significantly higher than in the control plots (Figure 11). There was no significant difference between S and W plots. In summer 2010, after the first winter cut the height of the trees in the control plots and the S plots was significantly higher than in the W plots. However, in summer 2011 and 2012 the height of the S plots was significantly lower than in the control plots and W plots. Furthermore, there was no more significant difference between the control plots and W plots compared to winter and summer 2010.

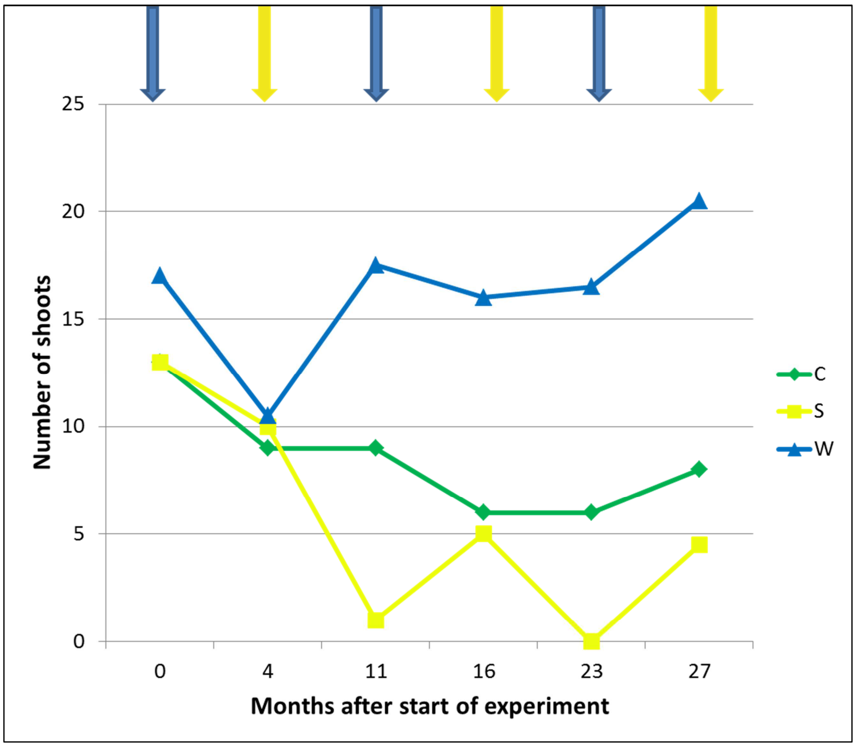

Figure 8: Temporal development of the average number of shoots (median) in the different treatments. S: summer; W: winter; C: control plots. Green line: development of the number of shoots of individual trees in the control plots (n = 49); yellow line: development in the plots with trees cut back in summer (n = 44); blue line: development in the plots with trees cut back in winter (n = 26). Blue arrows at the top of the graph indicate the winter cut, yellow arrows the summer cut.

For the crown area of the trees a similar change in the average values per treatment can be observed as for the mean height (Figure 12). In the control plots the crown area is constantly increasing, while it is rapidly decreasing for the S plots after the first cut. After this the average crown area does not exceed 1000 cm² anymore. Depending on the winter cut the crown area of the trees in the W plot fluctuates around 3000 cm².

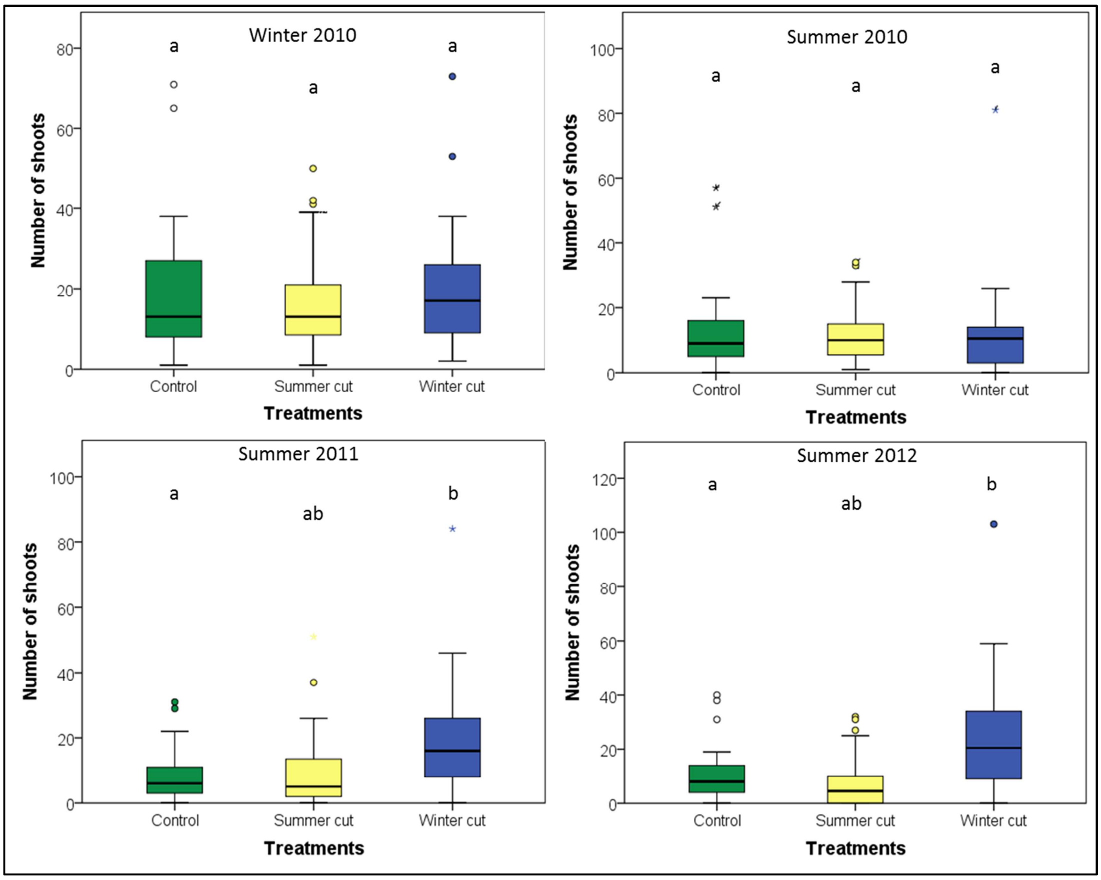

Figure 9: Comparison of the number of shoots per trunk of the alder trees in the control plots (n = 49). S plots (summer) (n = 44) and W plot (winter) (n = 26). Boxplots show the median for each treatment and the interquartile range of the data, which is represented by the box length. The whiskers show up to 1.5 times the interquartile range of the data. Outliers: circles, stars: extreme values. Different letters represent significant differences (p<0.05) between treatments.

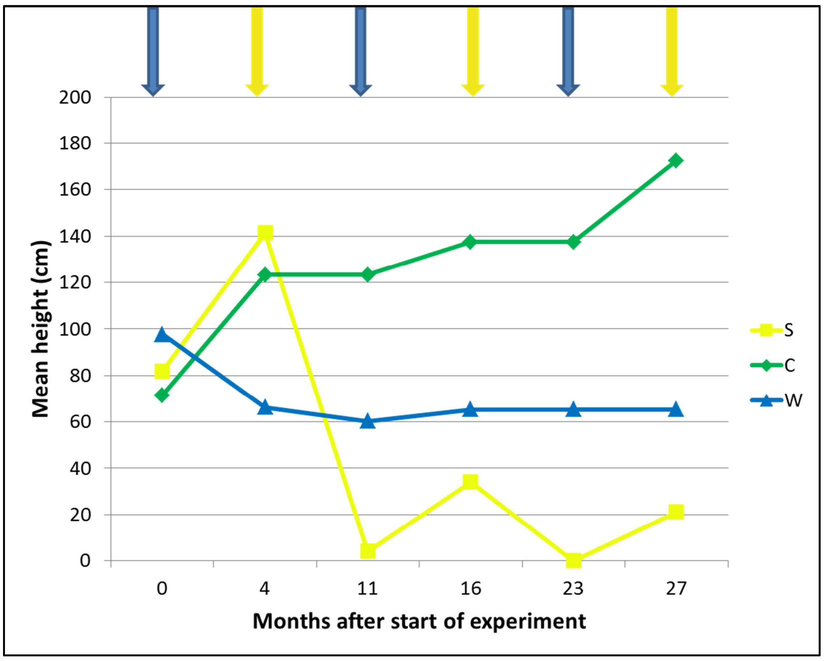

Figure 10: Temporal development of the mean height of the trees in the different treatments. For more information about the figure see Figure 8.

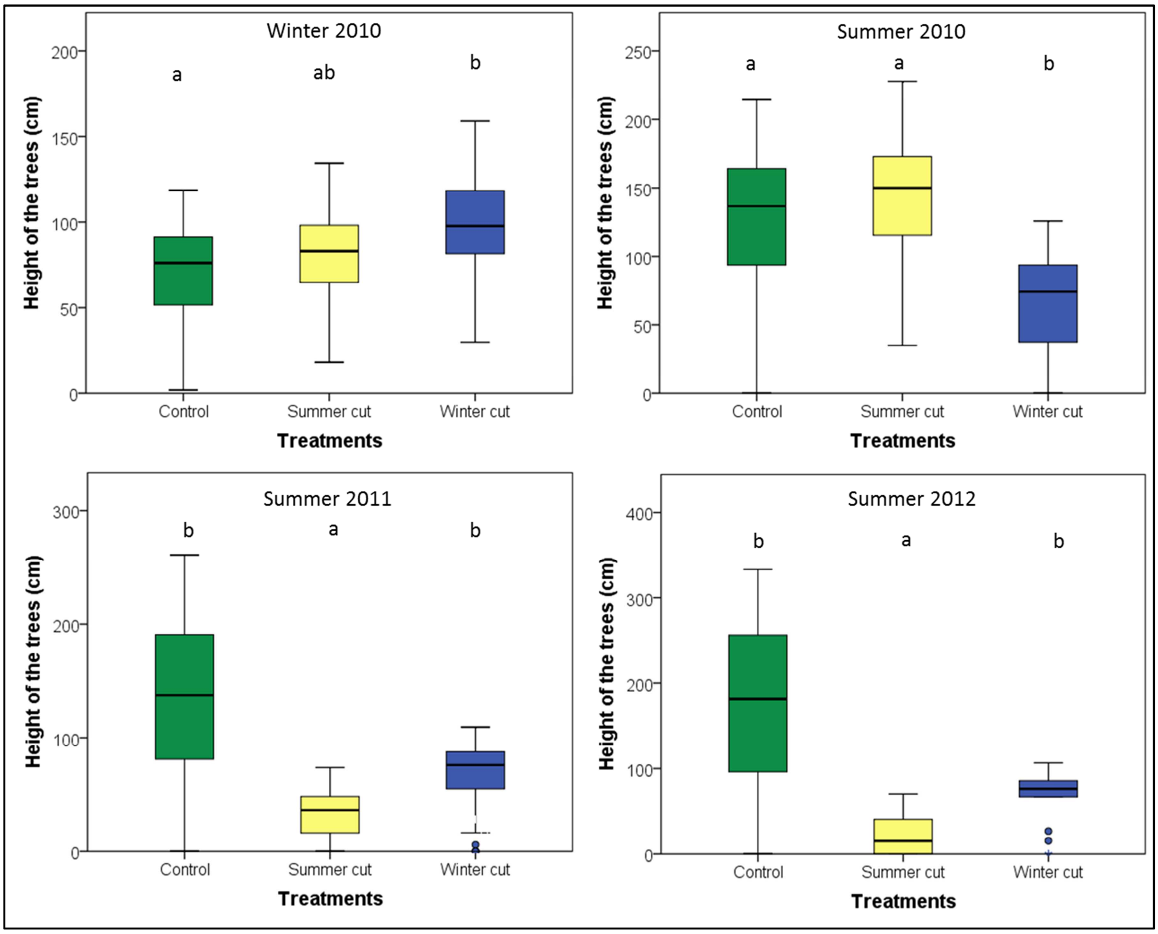

Figure 11: Comparison of the heights of the alder trees in the control plots (n = 49), the S plots (n = 44) and the W plot (n = 26) for the initial winter measurement and the three measurement dates in summer. For more information about the boxplots see Figure 9.

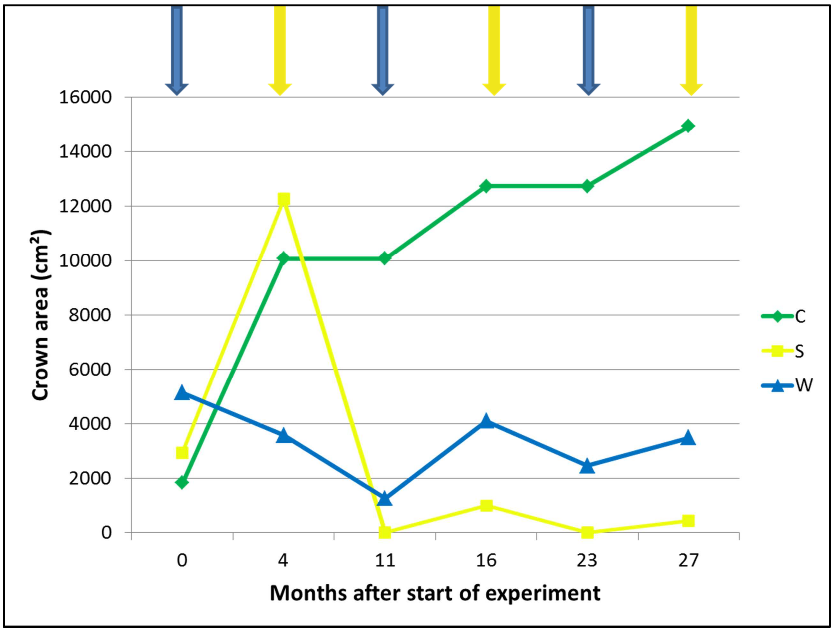

Figure 12: Temporal development of the crown area of the trees in the different treatments. For more information about the figure see Figure 8

When comparing the crown areas of the alder trees between treatments, pronounced differences can be found (Figure 13). Only in winter 2010 no significant difference can be found between the control plots and the S plots and between the S and the W plots. In the following three summers all treatments show significant differences in crow areas. While the crown areas of the trees in the S plots are still the highest in summer 2010, they become the lowest in in summer 2011 and 2012.

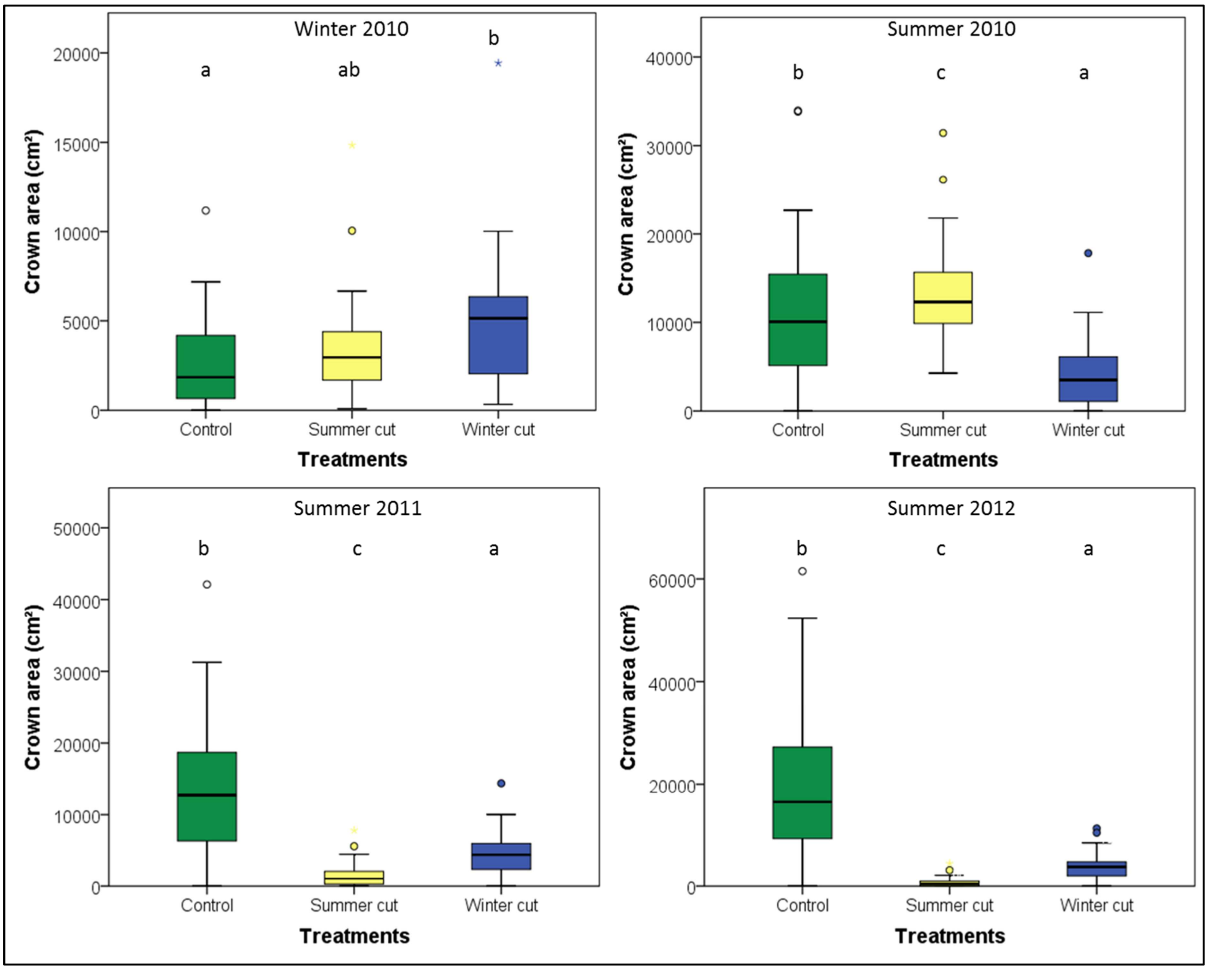

Figure 13: Comparison of the crown areas of the alder trees in the control plots (n = 49), the S plots (n = 44) and the W plot (n = 26) for the initial winter measurement and the three measurement dates in summer. For more information about the boxplots see Figure 9.

For summer 2011 and 2012 also the percentage of dead trees was compared between the different treatments (Figure 14). This comparison revealed that in summer 2011 there was no significant difference between the three treatments, yet. However, in summer 2012 about 40 % of the alder trees had died on average in the S plots, which was significantly more than in the control plots (only 10 %). The proportion of dead trees was also considerably higher in than in the W plots, but there was no statistically significant difference.

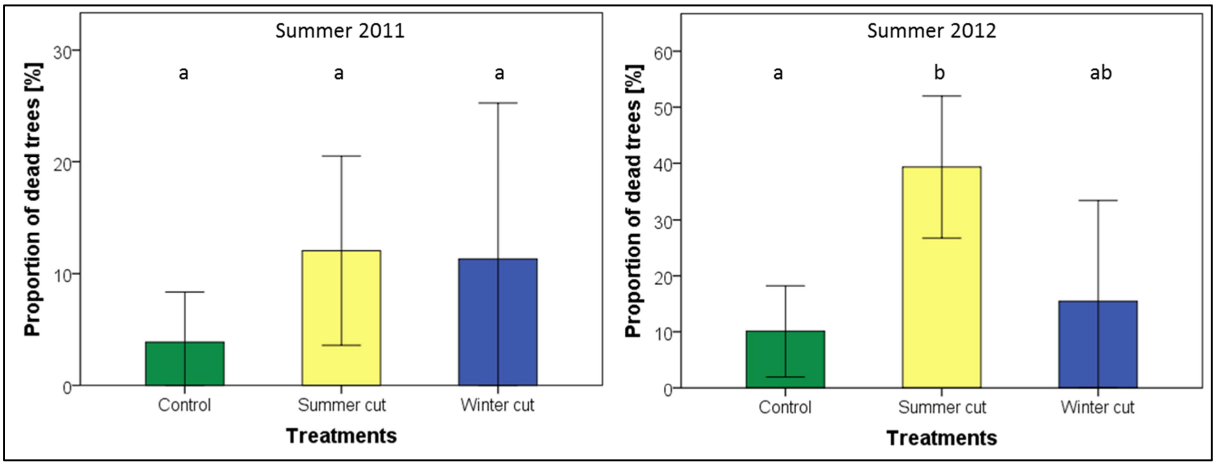

Figure 14: Comparison of the percentage of dead alder trees in the control plots, the S plots and the W plots (n = 4) for summer 2011 and 2012. The bar plots show the mean for each treatment ± standard deviation. Different letters represent significant differences (p<0.05) between treatments.

As it was expected that the regrowth potential of the trees that were cut back also depends on their initial size, a linear regression analysis was conducted to investigate the influence of the initial trunk diameter of the trees in the control plots on the number of regrown shoots and the approximated volume of the alder trees in winter 2010. This regression analysis revealed that for there was a significant correlation between the initial trunk diameter and the number of shoots ($p<0.001$) as well as the volume of the trees ($p<0.001$). However, the correlation only had a medium strength of R = 0.575 for the number of shoots and R = 0.494 for the volume of the trees (Figure 15).

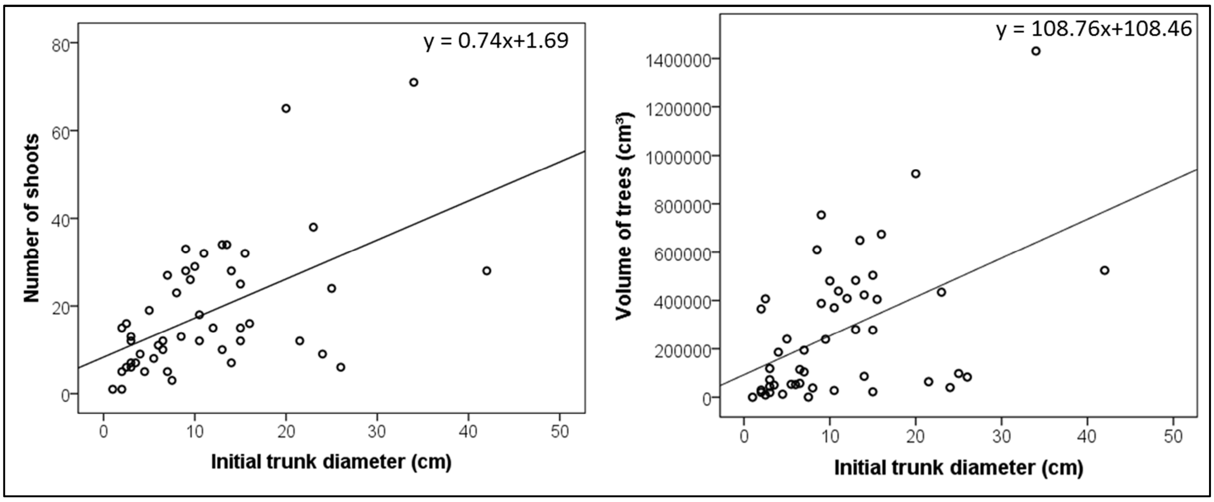

Figure 15: Results of the regression analysis on the influence of the initial trunk diameter on the number of regrown shoots (left side: R = 0.575; R^2 = 0.33) and the volume of the alder trees (right side: R = 0.494; R^2 = 0.24). In the figures the regression line and the corresponding equation (top right of each figure) are shown. The regression analysis was done for the trees in the control plots (n = 49) and the measurements of winter 2010.

6.2 Effects of the cutting regimes on the vegetation

The flora of the experimental plots represents the characteristic vascular plant species of small sedge communities of the Caricion davallianae in low productive calcareous fens. Mosses were not considered in the context of this thesis. A specific feature of these plants is that they are light demanding, small growing and propagate vegetatively by means of rhizomes. They form dense grass-moss-carpets of a rather low productivity (20-40 dt/ha). In the control plots *Carex elata* was clearly the most dominant species. This sedge was growing in high and dense swards underneath the alder trees, interspersed with *Carex davalliana*, *Cardamine amara* and *Myosotis pallustris* in much lower abundances. In contrast to this, in the S and W plots the herbal layer was lower and the species composition was more diverse and similar to the surrounding fen vegetation, which had not been colonised by alder trees so far.

Table 2 lists frequencies and mean cover percentages of all 30 vascular plant species found in the 30 relevés. *Carex elata*, *Myosotis palustris* and *Cardamine amara* (group 2) have their highest frequencies and abundances in the control treatments (core area), where alder trees strongly shade the herbal vegetation. Grassland species such as *Holcus lanatus, Agrostis stolonifera, Ranunculus acris* and *Juncus inflexus* on the other hand prefer plots, in which alder trees were cut either in summer or in winter. The vegetation of plots cut in winter or summer does not differ much, because there are only a few infrequent species which occur in either of the treatments (groups 5 and 6).

Table 2: Mean values per treatment of the estimated vegetation parameters and the plant species found in the 50x50 cm vegetation relevés (n = 10). The species are grouped based on their occurrences in the different treatments. For each individual species the frequency in the relevés and the mean cover values per treatment are listed.

	Control		Winter cutting		Summer cutting	
No. of relevees	10		10		10	
	Mean		Mean		Mean	
Crown_coverage_%	76.0		0.0		0.0	
Height_alder_trees_cm	248.0		0.0		0.0	
Height_herbal_layer_cm	50.0		42.5		42.5	
Coverage_herbal_layer_%	80.0		82.0		85.5	
Coverage_moss_layer_%	5.2		22.9		27.5	
No_plant_species	4.9		9.5		9.4	
Plant species	Freq. % of n=10	Cover Mean %	Freq. % of n=10	Cover Mean %	Freq. % of n=10	Cover Mean %
Group 1: only Control						
Leontodon_hispidus	10	1				
Group 2: Core area Control						
Carex_elata	100	65	100	48	100	44
Myosotis_palustris	40	7	20	2	10	2
Carex_davalliana	50	11	40	8	30	4
Cardamine_amara	40	2	40	2	10	2
Group 3: Core area Winter/Summer cutting						
Ajuga_reptans	30	14	60	7	20	6
Epilobium_palustre	90	4	100	13	100	16
Molinia_caerulea	10	10	40	2	50	2
Carex_rostrata	20	1	60	6	50	2
Cirsium_palustre	30	2	90	4	80	7
Epilobium_parviflorum	20	2	70	4	70	4
Galium_palustre	20	1	50	2	50	2
Poa_trivialis	20	1	80	3	90	4
Valeriana_dioica	10	4			50	12
Group 4: only Winter/Summer cutting						
Mentha_longifolia			50	14	10	1
Juncus_inflexus			20	10	10	10
Hypericum_tetrapterum			10	10	20	10
Potentilla_erecta			10	1	20	2
Ranunculus_acris			10	2	20	1
Agrostis_stolonifera			10	2	30	2
Holcus_lanatus			30	2	60	2
Eriophorum_latifolium			10	2	10	2
Group 5: only Winter cutting						
Eleocharis_uniglumis			10	1		
Equisetum_palustre			10	1		
Galium_uliginosum			20	2		
Mentha_aquatica			10	2		
Group 6: only Summer cutting						
Carex_hostiana					10	1
Carex_panicea					20	6
Juncus_articulatus					10	1
Veronica_beccabunga					10	1

For the Principle Component Analysis (PCA) the ordination of the plant species and the ordination of the treatments and additional vegetation data are displayed in two separate graphs (Figure 16). However, both graphs are based on the ordination of the plant species (the treatments and the vegetation data were added post-hoc) and the graphs were only separated for reasons of clarity. The eigenvalues were 0.814 for the first axis and 0.078 for the second axis. This resulted in a cumulative explanation of 89.3 %, meaning that almost 90 % of the variation in the original data matrix is explained by the two axes.

Furthermore, the PCA showed contrasting species responses: species particularly occurring in summer and winter cut plots, such as *Epilobium parviflorum, E. palustre, Juncus inflexus, Carex rostrata* and *Holcus lanatus* (groups 3 and 4, Table 2) have the highest positive loadings on axis 1. Species mainly occurring in the control plots, such as *Carex elata* and *Cardamine amara* (group 2, Table 2) have the highest negative loadings on axis 1 and on axis 2. Groups 3 and 4 coincided with a high species number per plot and high moss cover but a low herb and tree cover, as it is realised in the treatments, in which alder trees were cut. The opposite is true for species of group 2 (among others represented by *C. elata* and *C. amara*), which showed high abundances in the control plots.

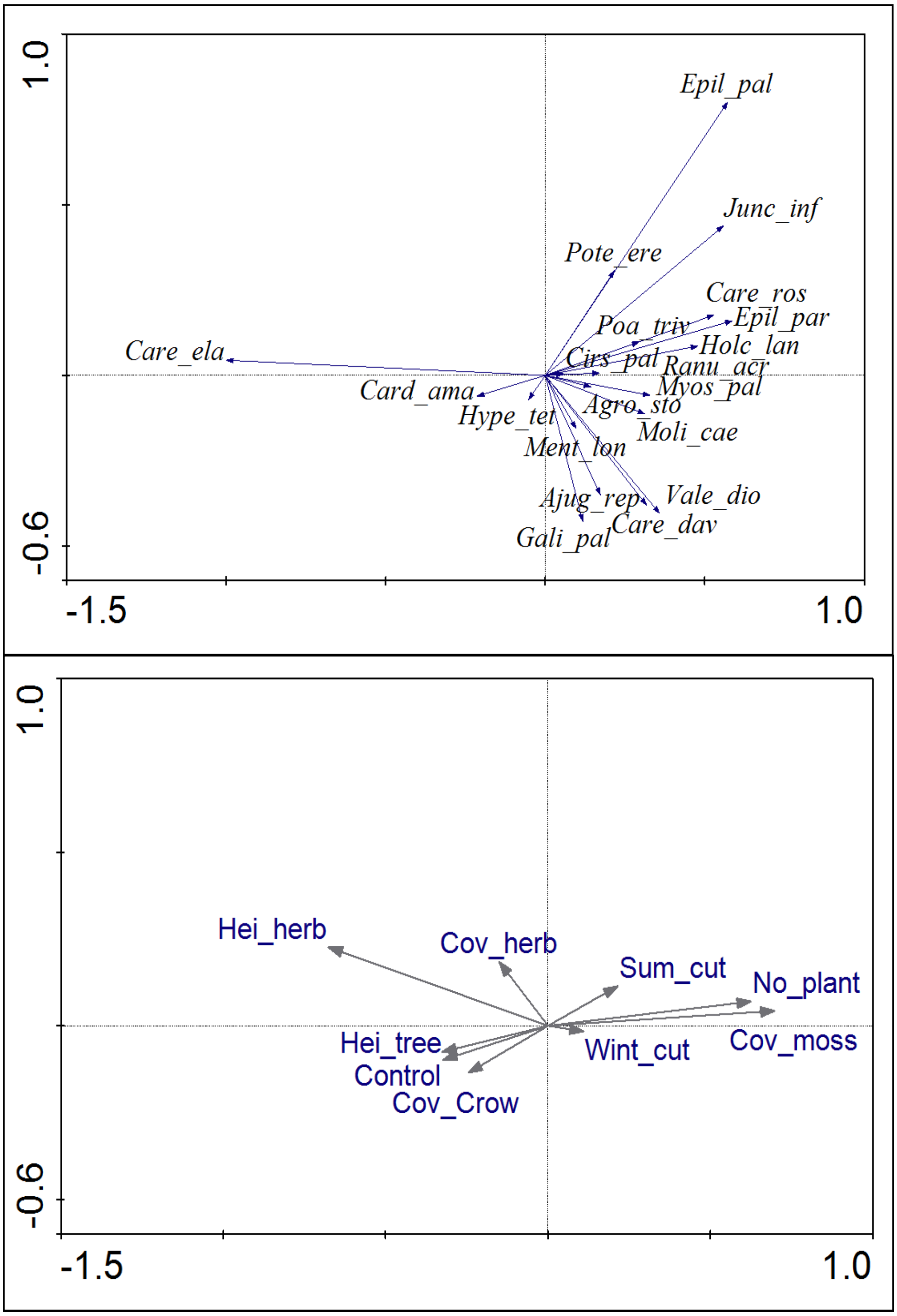

Figure 16: Top: Ordination diagram of the PCA with a reduced subset of 20 species and 30 samples (10 samples per treatment). Bottom: Additional vegetation data, the number of plant species per sample and the treatments were treated as supplementary variables and added post-hoc by regressing their data onto the existing ordination axes. The angles and the length of the arrows indicate the loading of each variable/species, which reflects the respective correlation coefficients. Abbreviations: Hei herb: Height of herb layer, Cov herb: Cover of herb layer, Cov moss: Cover of moss layer, Hei tree: Height of the surrounding alder trees, Cov crow: crown cover of the alder trees, No plant: number of plant species; Sum cut: Summer cutting treatment, Wint cut: Winter cutting treatment; Agro_sto: *Agrostis stolonifera*, Ajug_rep: *Ajuga reptans*, Card_ama: *Cardamine amara*, Care_dav: *Carex davalliana*, Care_ela: *Carex elata*, Care_ros: *Carex rostrata*, Cirs_pal: *Cirsium palustre*, Eleo_uni: *Eleocharis uniglumis*, Epil_pal: *Epilobium palustre*, Epil_par: *Epilobium parviflorum*, Gali_pal: *Galium palustre*, Holc_lan: *Holcus lanatus*, Hype_tet: *Hypericum tetrapterum*, Junc_inf: *Juncus inflexus*, Ment_lon: *Mentha longifolia*, Moli_cae: *Molinia caerulea*, Myos_pal: *Myosotis palustris*, Poa_tri: *Poa trivialis*, Pote_ere: *Potentilla erecta*, Ranu_acr: *Ranunculus acris*, Vale_dio: *Valeriana dioica*.

The similarity of relevés in the different treatments was assessed using the similarity coefficient according to Bray and Curtis (1957) (Table 3). This showed that the relevés in the S plots and the W plots had a relatively high similarity of 79 %. The similarity between the relevés in the control plots and the S plots was only 55 %. Also the similarity between the relevés in the control plots and the W plots was lower (58 %).

Table 3: Similarity coefficients (Bray & Curtis 1957) of the three treamtents.

	Control	**Summer cut**	**Winter cut**
Control	1	0.55	0.58
Summer cut		1	0.79
Winter cut			1

For each vegetation relevé the total number of species was calculated and subsequently these values were compared between the three treatments (Figure 17). The analysis revealed that there was no significant difference between the relevés in the summer cut and the winter cut, in which nine species were present on average. However, in the relevés of the control only five species on average were found, which was a significantly lower number than in both the S and the W plots.

In addition the Shannon-Wiener index for each relevé was calculated to also take into account the relative abundance of the plant species. The comparison of the Shannon-Wiener indices between the different treatments gave very similar results to the comparison of the number of plant species (Figure 17). In the control plots the Shannon-Wiener index was significantly lower than in the S and the W plots, while there was no significant difference between S and W plots.

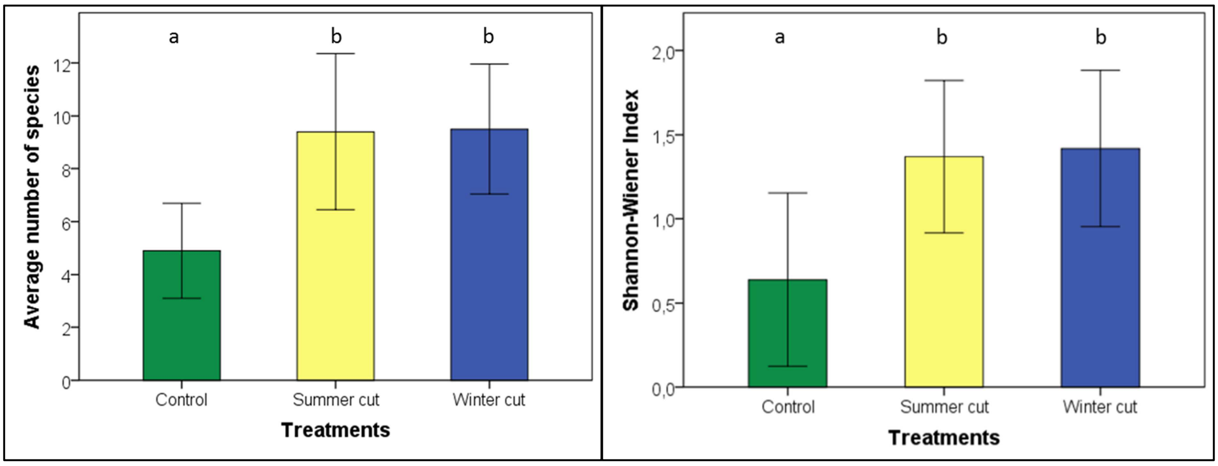

Figure 17: Left: Comparison of the number of species per treatment; Right: Shannon-Wiener indices of different treatments. The bars represent the mean number of species per treatment ± standard deviation. Different letters represent significant differences ($p<0.05$) between treatments.

7 Discussion

7.1 Comparison of the seasonal cutting regimes

Concerning the comparison of the effect of different seasonal cutting regimes on alder trees, the hypothesis formulated prior to the experiment could not be falsified. Repeatedly cutting back the alder trees in summer indeed turned out to be more efficient to weaken or even eliminate alder trees than cutting them back in winter. Regarding the effect of the cutting regime on the surrounding vegetation it could be shown that the number of plant species and the biodiversity increased where the trees had repeatedly been cut back. However, it could not be observed yet that there were considerably more light demanding species in the surrounding of the cut back trees.

The regrowth potential of the trees, represented by their crown area and the mean height of their shoots, was similar for all treatments in the first winter 2010, when the trees in each treatment had been cut back to the trunk one year before the experiment started. Only the height and crown area in the W plots was slightly higher, but this might be influenced by several comparatively large trees in these plots. In the W plots there were only 26 trees (compared to 49 trees in the control and 45 trees in the S plots), which could be a possible explanation of why the individual trees were bigger in these plots. This can also be seen in the visualisation of the crown areas of winter 2010 in Appendix B, Figure 18. In summer 2011 and summer 2012, when the trees in the S and the W plots had been cut back, clear differences could be seen between the different treatments. Already in 2011 the regenerative ability of the trees cut back in summer was considerably lower than that of the trees cut back in winter, despite the fact that in summer 2011 the trees in the W plots had already been cut back twice, while only once in the S plots. This difference could also be observed in summer 2012, which clearly showed that even though the trees in the W plots had been cut back more often, they had a better regenerative ability than the trees in the S plots. This finding is also confirmed by the comparison of the percentages of dead trees per treatment. In summer 2011 there were already comparatively more dead trees in the S plots than in the control or W plots. However, in summer 2012 already 40 % of the trees had died in the S plot, which was more than twice as much as in the W plots and the control plots. Even though there was no statistically significant difference, this clearly indicates that cutting back the trees in summer is more efficient to eliminate them than cutting them back in winter.

The number of shoots per tree was still relatively similar in every treatment in winter and summer 2010. In contrast to this, in summer 2011 and 2012 the number of shoots decreased in the control plots and increased in the W plots. This can be explained by the relatively high competition between alder trees in the control plots. In the visualisation of the trees of summer 2012 (Figure 6), it can be seen that the alder trees in the control plots grow at a high density. When they grow bigger only the strongest shoots survive and the smaller ones die off. (Eschenbach 2005) As black alder is a very light demanding species, weaker and smaller trees may even die off completely when there is strong competition for light between the trees. This can also be seen in Figure 14, which shows that in summer 2012 about 10 % of the alder trees in the control plots had died. The number of shoots per tree in the S plots was lower than in the control and the W plots from the summer first cut on. The reason why the trees that were repeatedly cut back in summer, did not develop more shoots than the trees in the control plots probably is that they were so strongly weakened by the cutting regime that they could not produce many new shoots after the winter anymore.

Another aspect that is worth mentioning in this context is that in summer 2010 in all treatments (even in the W plots in which the trees had been cut back and new shoots had regrown) the number of shoots was reduced compared to winter 2010 (Figure 9). This reduction was visibly caused by cattle or deer browsing or damaging the shoots by trampling or rubbing against them. For the experiment this effect was not desired, therefore the plots were fenced off in summer 2010. However, for the success of an elimination of alder trees it is interesting to note that the damage caused by deer could actually be helpful, as it further weakens the trees after they have been cut back.

There are several possible explanations for these findings which are connected to the physiology of the alder trees. Firstly, cutting back alder trees in summer stops the transportation of assimilates from leaves and other photosynthetically active tissues to the roots. This will inhibit the growth of the roots and metabolic processes connected to this, which are still at full activity in summer. Dilly et al. (2000), for instance, reported that up to 60 % of the assimilates are invested into belowground tissues. Therefore, a removal of the aboveground biomass has a drastic impact on the root system of alder trees. Secondly, this also means that less energy for the next growing season can be stored in belowground tissues, which results in a strongly decreased regenerative ability of the alder trees which were cut back in summer. In winter this effect probably is much smaller, because during this dormant phase the photosynthesis rate is lowered and in general much less energy is needed for the processes taking place in the roots. Thirdly, it is known that for a sufficient aeration of the alder roots under the waterlogged conditions of the soil, oxygen needs to be transported to roots, for instances deriving from photosynthesis in the stem (Armstrong and Armstrong 2005). Hence, when alder trees are cut in summer, also the oxygen supply to the roots is suppressed. This means that alder trees might be literally ‘drowning’ when the aboveground biomass is removed. Again this is probably less problematic in the winter season, when the demand for oxygen in the roots is decreased.

Concerning the hypothesis that the initial trunk diameter, which indicates the initial size and roughly the age of the trees, also influences the regenerative ability of the alder trees, only a first indication was possible. As only the initial trunk diameters in the control plots were measured in winter 2010, but not those of the trees in the S and W plots, only these values could be used for the analysis. The regression analysis of the influence of the initial trunk diameter on the number of shoots and the volume of the trees revealed that larger initial trunk diameters do to a certain extent increase the regenerative ability of alder trees. This could actually mean that trees with a larger initial trunk diameter might need to be cut back more often than trees with a smaller diameter. However, these results should be confirmed with more data, especially including data from the S and W plots.

7.2 Effects of the cutting regimes on the vegetation

Concerning the interpretation of the Principal Component Analysis (PCA) in Figure 16 it should be considered that it is mainly a method for ordering species and environmental variables. If the cumulative explanation of the principal components is low, it does not necessarily mean that species/variables that are at a similar position in the ordination diagram are strongly correlated. However, in the PCA presented here the cumulative explanation was almost 90 %. Additionally, the results of the PCA are generally confirmed by the grouping of the species according to treatments in Table 2. It is therefore possible to discuss and interpret associations between certain species and treatments or other environmental variables. The PCA and Table 2 showed that most of the plant species either occurred in the control treatment, which was associated with a high crown cover by alder trees and a high and dense layer of herbs, or in the plots in which alder trees were cut in winter or summer, which were associated with a higher cover of mosses and higher numbers of plant species per relevé. Some of the species also occurred in all treatments, but showed higher abundances in the control or S or W plots. *Carex elata* for instance was present in every treatment, but was particularly dominant in the control plots. Species that were only present in the S or W plots were for example *Mentha longifilia, Juncus inflexus* and *Holcus lanatus*.

The original hypothesis was that in the control plots there would be more shade tolerant species due to the denser crown cover of the alder trees, while in the S and W plots also species that are more light-demanding could be found. When comparing the Ellenberg indicator values for light for the species in the different groups, it becomes clear that this hypothesis can be falsified. The L values for the species mainly found in the control plots range between 7 and 9, while the L values for the species found in the S and W plots range between 6 and 8. This can probably be explained by the fact that the cutting regime had only been carried out for two and a half years when the vegetation assessment was done. It is not surprising that during this short period of time no considerable increase of light demanding species was found for the S and W plots.

That many species occurred both in the S and W plots and had similar abundances in these treatments was also confirmed by the comparison of the Bray-Curtis-similarity coefficients. This indicates that the summer cut and the winter cut had similar effects on the plant species composition. In the control plots the stronger shading by the dense crown cover of the alder trees probably had a major effect on the plant species composition, which resulted in a lower similarity of the control to the S and W plots.

The hypothesis that the number of plant species and the biodiversity in the S and W plots is higher than of the control plots could not be falsified. Indeed the number of plant species and the alpha-diversity was higher in the plots in which alder trees were cut back repeatedly than in the control plots (Figure 17). Noticeable is that the biodiversity calculated with the Shannon-Wiener index (which also takes the relative abundance of the plant species into account) hardly gave a different result than solely the average number of plant species. Therefore, the number of plant species already seems to be a good indicator of the alpha-diversity in the context of this research. The results indicate that the cutting regimes already positively influenced the diversity of the plant species in the S and W plots. This can be attributed to the strong changes in abiotic conditions caused by the cutting back of alder trees in these plots, which means that the ground vegetation layer is exposed to more light and higher temperatures.

However, two important points need to be considered in this context. Firstly, the number of plant species is not only influenced by the crown cover of the alder trees, but also by the height and the density of the herbs layer. In the control plots especially *Carex elata* was growing in high and dense swards, which probably had an additional impact on the comparatively lower number of species in these plots. Secondly, only vascular plants were determined in the vegetation assessments, omitting mosses, which also are important indicator species in this calcareous fen ecosystem. In Table 2 it can be seen that the cover of mosses was much higher in the S and the W plots than in the control plots. Therefore, it seems worthwhile to determine moss species and their individual cover, in case another vegetation assessment will be carried out in the plots.

When comparing the list of plant species from the vegetation assessments presented here to species found in a previous study about succession series in calcareous fens, which ranged from open fen grassland to alder-carr stages (Rosenthal 2010), it can be seen that all species found here, except for *Cardamine armara,* are more or less strongly associated with the first successional stage of open fen grasslands (see Table 5 in Appendix C). *C. armara* and several other species (e.g. *Carex elata, Mentha aquatica, Molinia caerulaea* or *Carex davalliana*) occur in the stage of a pioneer alder forest or in the final successional stage of the alder-carr-forest. Typical species of the climax alder-carr-forest stage (such as *Oxalis acetosella, Carex remota* or *Paris quadrifolia*) were not present in this vegetation assessment. However, some obligatory open fen species like *Eriophorum angustifolium* or *Menyanthes trifoliata* were missing in the vegetation assessments as well. The S and W plots can therefore be classified as being at a transition between open fen grassland and a pioneer alder forest, while in the control plots a pioneer alder forest stage is present.

In the S and W plots there were a few more occurrences of light demanding species (such as *Eriophorum latifolium*), but after only two and a half years of repeated cutting of the alder trees and when taking the small size of the experiment into account, it cannot be expected that most species characteristic for an open fen can be found there.

7.3 Practical application and recommendations

Concerning the practical application of these results for the conservation of mesotrophic calcareous fens in the upper Bavarian 'Allmendweiden', it can be recommended to cut back alder trees that have encroached into open fens in summer instead of in winter. This experiment could demonstrate that a winter cut only has a very weak impact on the regenerative ability of black alder. In contrast to this, cutting the trees back in summer already showed a strong weakening of the trees after the first cut and on average 40 % of the trees had died after the second cut.

The vegetation assessments carried out in this experiment give a first indication that the number of species will increase when alder trees are cut back and even though this could not yet be observed here, it is likely that the number of light demanding species will increase as well. However, if alder trees that have grown into a fen have already reached the stage of a pioneer forest, this development will evidently take some time.

Despite the encouraging results of this study, it should be pointed out that on a large scale even a cutting regime in summer will be quite work-intensive. As could be shown here, the trees will have to be cut back repeatedly, at least two or three times to eliminate a sufficient number of trees. Therefore, it is important to carefully select the areas in which such a cutting measure shall be conducted. The criteria for the selection of the area should be based on its value for nature conservation, but also on the option of using cattle to continuously keep the fen open. The cutting of alder trees should only be used as an initial measure to allow for grazing in the fens. However, this can only be achieved by grazing during the whole year using robust cattle breeds or by fencing in cattle on the less attractive wetland parts of the pastures (Rosenthal 2012). It is therefore also important to support and strengthen the system of the 'Allmendweiden', because it represents a sustainable way of managing the grassland and at the same time preserving the landscape diversity (Lederbogen et al. 2004).

Furthermore, it needs to be noted that only cutting back encroached alder trees will not be a sufficient solution for reducing or in some parts even stopping the progressive succession of alder trees. This measure needs to be combined with a limitation of the dispersal of alder trees through seeds. As mentioned before, Peringer and Rosenthal (2009) proposed to fell mature mother trees west of the sites that are at a risk of being colonised by alder trees. Eliminating already encroached alder trees by repeatedly cutting them back in summer and preventing new encroachment by removing seed-producing trees in the described way seems to be a promising way of protecting open calcareous fens in this area.

In order to realise these measures, it is possible to apply for financial support at the Bavarian agri-environmental schemes, for instance for the management of litter meadows.

Concerning the possibility to use the woody material gained from the cutting as a renewable energy resource, for instance for biofuel or in general for heating, several important points should be mentioned. On a larger scale it can make sense to collect and use the alder wood for energetic purposes.

This has been done in this area for centuries and it can contribute to a sustainable management of the area (Lederbogen et al. 2004). As prices for fire wood are increasing, it might even be financially beneficial. However, it probably only makes sense to use the yield from the initial cut. The subsequent cuts will only yield small amounts of wood. Hence, it is not very efficient to collect and use this wood from the repeated cutting.

Finally, it can be added that next to the biological relevance of the research presented here, preserving a high diversity of the landscape with different successional stages also offers recreational benefits to humans and appeals from an aesthetic point of view.

8 Conclusion

The research presented here could prove that repeatedly cutting back alder trees in summer is a more efficient measure for eliminating alder trees that have colonised open fen grasslands than a repeated cutting regime in winter. Therefore, a summer cutting regime can be a useful tool for protecting the plant species diversity of calcareous fens which constitute the habitat of light demanding species characteristic for the Caricion davallianae plant community. In combination with a selective removal of mature alder trees for preventing the establishment of new trees and with a form of extensive grazing to keep the fens open in the long run, this can allow for a sustainable coexistence of the different successional stages of calcareous fens in the 'Allmendweiden' of Upper Bavaria.

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Appendix A

Table 4: Overview of the working hypotheses, the data used for the statistical analysis and the statistical methods that were used to falsify the respective hypotheses.

Number	Hypotheses	Data used	Statistical Method
1	- In the initial phase of the experiment no significant differences in re-growth parameters (height of the shoots and crown area) are expected between the control plots and the plots on which alder trees are cut in winter or summer. - In the second year the regrowth variables of the control are significantly higher than those of the trees that were cut. However, there is no significant difference between cutting in winter and summer, yet. - In the third year the regrowth variables of the control are significantly higher than those of the trees that were cut and the values of the trees that were cut in winter are significantly higher than those of trees cut in summer.	- Mean heights of the shoots of all trees in the control plots (n = 49), in the S plots (n = 44) and in the W plots (n = 26) for winter 2010 and summer 2010, 2011 and 2012 - Crown areas of the alder trees in the control plots (n = 49), in the S plots (n = 44) and in the W plots (n = 26) for winter 2010 and summer 2010, 2011 and 2012	- Median tests - Cross tabulation analysis for post-hoc testing between the different treatments
2	Concerning the number of shoots per tree, the expectation is that in the first winter there will be no significant differences between treatments. In the course of time, the number of shoots will decrease for the alder trees in the control plots, but stay similar of even increase for the S and W plots. The reason for this hypothesis is that when the trees are not cut back anymore, such as in the control plots, only the strongest shoots will survive and the other ones will die off.	- Number of shoots of each tree in the control plots (n = 49), in the S plots (n = 44) and in the W plots (n = 26) for winter 2010 and summer 2010, 2011 and 2012	- Median tests - Cross tabulation analysis for post-hoc testing between the different treatments
3	In the third year there are significantly more dead trees in the plots that were cut in summer than in the control or in the plots cut in winter, while this is not clear for the first or the second year.	- Dead or alive trees in the control plots (n = 49), in the S plots (n = 44) and in the W plots (n = 26) for summer 2011 and 2012	- Chi²-Test - Cross tabulation analysis for post-hoc testing between the different treatments
4	Individual trees also have different starting conditions which influence their regrowth potential. Species with a higher initial trunk diameter develop more and healthier shoots and therefore have a better regeneration potential.	- Initial trunk diameter of trees in control plot (n = 49) as independent variable - Number of shoots and volume of trees in control plot for winter 2010	- Linear regression

5	- The number of species and the biodiversity in the plots cut in summer and winter is significantly higher than in the control plots. - The similarity between the S and W plots is higher than between control and S plots or control and W plots.	- Number of plant species in the relevés and Shannon-Wiener index for the control plots, the S plots and the W plots (n = 10) - Mean cover percentages of species in the relevés in the control plots, the S plots and the W plots (n = 10)	- ANOVA and Tukey Test (as post-hoc) - Percentage similarity coefficient (Bray and Curtis 1957)
6	It is possible to associate certain species with a particular treatment and the corresponding biotic variables.	- Number of plant species in the relevés in the control plots, the S plots and the W plots (n = 10) - Mean cover percentages of species in the relevés in the control plots, the S plots and the W plots (n = 10) - Table with groupings of species	- PCA

Appendix B

Statistical results

1. **Number of shoots**

a) *Winter 2010* (Kruskal-Wallis test)

(I) Treatments	(J) Treatments	Pearson Chi²	F	Significance
C	S	1,279	,295	,745
S	W	1,279	,295	,745
W	C	1,279	,295	,745

b) *Summer 2010* (Kruskal-Wallis test)

(I) Treatments	(J) Treatments	Pearson Chi²	F	Significance
C	S	,311	,121	,886
S	W	,311	,121	,886
W	C	,311	,121	,886

c) *Summer 2011* (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	0,44	,022	,834
S	W	6,787	,311	,009
W	C	7,996	,327	,005

d) *Summer 2012* (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	3,511	-,194 and ,194	,061
S	W	13,310	,436	,000
W	C	4,749	,252	,029

2. **Mean heights**

a) *Winter 2010* (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	1,664	,134	,197
S	W	1,568	,150	,158
W	C	5,602	,273	,018

b) Summer 2010

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	2,328	,158	,127
S	W	29,218	-,646 and ,646	,000
W	C	19,075	-,504 and ,504	,000

c) Summer 2011 (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	46,354	-,706 and ,706	,000
S	W	22,028	,561	,000
W	C	2,831	-,194 and ,194	,092

d) Summer 2012 (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	59,231	-,798 and ,798	,000
S	W	37,051	,728	,000
W	C	1,490	-,141 and ,141	,222

3. Crown area

a) Winter 2010 (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	1,185	,113	,276
S	W	2,468	,188	,116
W	C	6,303	,290	,012

b) Summer 2010 (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	4,604	,223	,032
S	W	27,672	-,629 and ,629	,000
W	C	13,841	-,430 and ,430	,000

c) Summer 2011 (Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance

C	S	51,636	-,745 and ,745	,000
S	W	17,137	,495	,000
W	C	7,728	-,321 and ,321	,005

d) Summer 2012(Median test)

(I) Treatments	(J) Treatments	Pearson Chi²	Phi and Cramer's V	Significance
C	S	74,395	-,894 and ,894	,000
S	W	23,267	,577	,000
W	C	16,962	-,476 and ,476	,000

4. Vitality of the trees

a) Summer 2011

Vitality_summer11 * Treatment_number Crosstabulation

Count

		Treatment_number			Total
		1	2	3	
Vitality_summer11	0	3	6	3	12
	1	46	38	23	107
Total		49	44	26	119

(dead = 0, alive = 1; Treatment 1=C, 2=S, 3=W)

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1,521[a]	2	,467
Likelihood Ratio	1,589	2	,452
Linear-by-Linear Association	,834	1	,361
N of Valid Cases	119		

a. 3 cells (50,0%) have expected count less than 5. The minimum expected count is 2,62.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	,113	,467
	Cramer's V	,113	,467
N of Valid Cases		119	

b) Summer 2012

c) **Vitality_summer12 * Treatment_number Crosstabulation**

Count

	Treatment_number	Total

		1	2	3	
Vitality_summer12	0	4	18	4	26
	1	45	26	22	93
Total		49	44	26	119

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15,373[a]	2	,000
Likelihood Ratio	15,379	2	,000
Linear-by-Linear Association	2,079	1	,149
N of Valid Cases	119		

a. 0 cells (0,0%) have expected count less than 5. The minimum expected count is 5,68.

Symmetric Measures

		Value	Approx. Sig.
Nominal by Nominal	Phi	,359	,000
	Cramer's V	,359	,000
N of Valid Cases		119	

a. Not assuming the null hypothesis.

5. **Regression analysis initial trunk diameter**

a) Number of shoots

➔ Data was transformed using square root function

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,575[a]	,331	,317	1,30903

a. Predictors: (Constant), sqrt_itd

b. Dependent Variable: sqrt_nos

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	39,858	1	39,858	23,260	,000[b]
	Residual	80,537	47	1,714		
	Total	120,396	48			

a. Dependent Variable: sqrt_nos

b. Predictors: (Constant), sqrt_itd

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1,693	,508		3,331	,002	,670	2,715
	sqrt_itd	,735	,152	,575	4,823	,000	,428	1,042

a. Dependent Variable: sqrt_nos

b) Volume of the trees

➔ Data was transformed using square root function

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	,494[a]	,244	,228	239,88735

a. Predictors: (Constant), sqrt_itd

b. Dependent Variable: sqrt_vol

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	872615,458	1	872615,458	15,164	,000[b]
	Residual	2704659,292	47	57545,942		
	Total	3577274,750	48			

a. Dependent Variable: sqrt_vol

b. Predictors: (Constant), sqrt_itd

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95,0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	108,460	93,104		1,165	,250	-78,840	295,761
	sqrt_itd	108,760	27,930	,494	3,894	,000	52,573	164,947

a. Dependent Variable: sqrt_vol

6. Number of plant species

7. **ANOVA**

Number_species

	Sum of Squares	df	Mean Square	F	Sig.

Between Groups	138,067	2	69,033	11,520	,000
Within Groups	161,800	27	5,993		
Total	299,867	29			

Multiple Comparisons

Dependent Variable: Number_species

Tukey HSD

(I) Treat-ments_code	(J) Treat-ments_code	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-4,500*	1,095	,001	-7,21	-1,79
	3	-4,600*	1,095	,001	-7,31	-1,89
2	1	4,500*	1,095	,001	1,79	7,21
	3	-,100	1,095	,995	-2,81	2,61
3	1	4,600*	1,095	,001	1,89	7,31
	2	,100	1,095	,995	-2,61	2,81

*. The mean difference is significant at the 0.05 level.

8. Shannon-Wiener index

ANOVA

SWI

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3,817	2	1,909	8,343	,002
Within Groups	6,177	27	,229		
Total	9,994	29			

Multiple Comparisons

Dependent Variable: SWI

Tukey HSD

(I) Treatments	(J) Treatments	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1,00	2,00	-,73100*	,21391	,006	-1,2614	-,2006
	3,00	-,78000*	,21391	,003	-1,3104	-,2496
2,00	1,00	,73100*	,21391	,006	,2006	1,2614
	3,00	-,04900	,21391	,972	-,5794	,4814
3,00	1,00	,78000*	,21391	,003	,2496	1,3104
	2,00	,04900	,21391	,972	-,4814	,5794

*. The mean difference is significant at the 0.05 level.

Appendix C

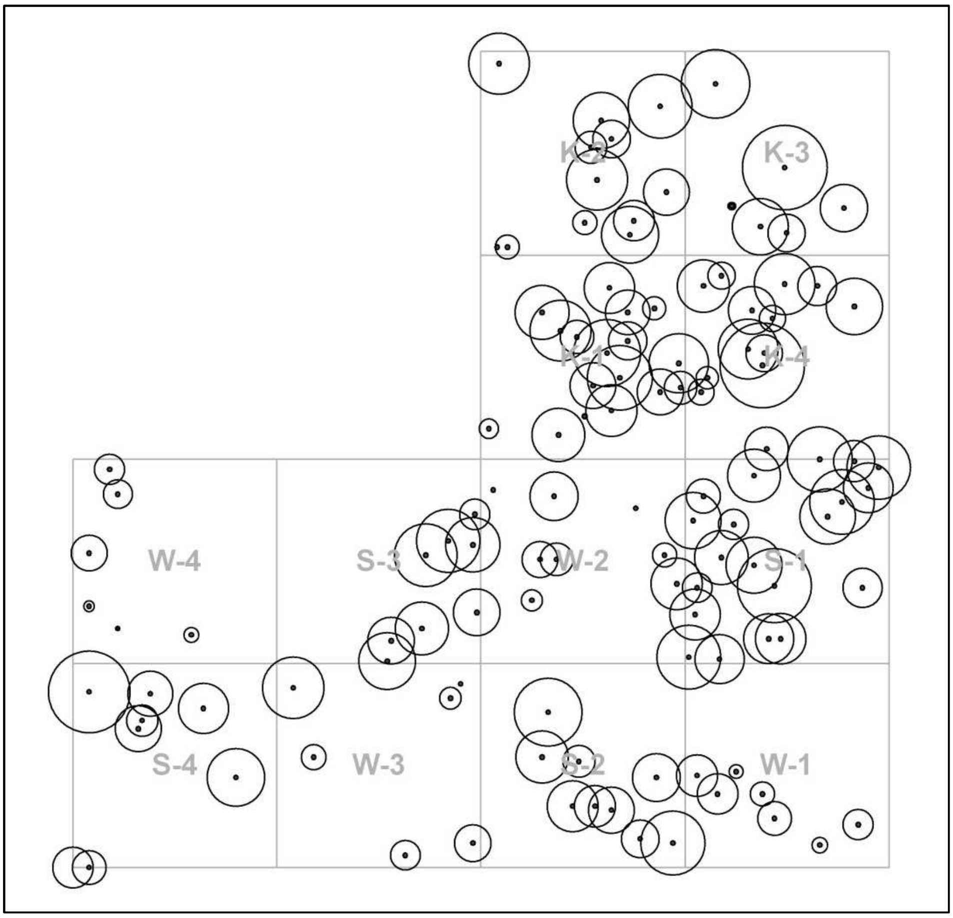

Figure 18: Initial crown areas of the alder trees in the plots of the different treatments (K = control plots, S = summer cutting plots and W = winter cutting plots) in winter 2010.

Appendix D

Table 5: Species occurring in different successional stages of mesotrophic calcareous fens in Upper Bavaria. Frequency classes (Roman numerals) and plant cover (mean values in %) for three succession stages (I to III) are given. Only species with at least frequency class III in at least one of the stages were included in the table. B indicates species which exclusively grew on alder hummocks in more than 50 % of the cases (from Rosenthal 2010).

	Sukzessionsstadium	I		II		III		Bultbesiedler	
	Aufnahmezahl		10		6		7		
	Mittlere Flächengröße (m²)		15,2		28,0		40,8		
	Mittlere Artenzahl		43,3		46,3		63,4		
	Höhe Gehölze (m)		0,7		6,7		11,3		
	Feldschicht (FS) Deckung (%)		56		52		43		
	Moosschicht Deckung (%)		61		29		28		
waldbildende Gehölzarten		Stet	Do	Stet	Do	Stet	Do		Soziologisches Verhalten
BS 1	Alnus glutinosa	.		.		III	43		Alnetalia glutinosae
(>10m)	Picea abies	.		.		I	2		Piceetalia abietis
BS 2	Alnus glutinosa	.		IV	47	V	26		Alnetalia glutinosae
(5-10m)	Picea abies	.		.		III	5		Piceetalia abietis
SS	Alnus glutinosa	III	8	V	40	V	11		Alnetalia glutinosae
(0,5-5m)	Picea abies	.		I	4	V	27	B	Piceetalia abietis
FS	Alnus glutinosa	III	4	V	2	IV	1		Alnetalia glutinosae
(<0,5m)	Picea abies	II	+	V	1	V	3	B	Piceetalia abietis
	Eriophorum latifolium	V	4	.		.			Tofieldietalia
	Leontodon hispidus	IV	8	.		.			Magerrasen
	Eriophorum angustifolium	IV	5	.		.			Scheuchzerio-Caricetea
	Carex lepidocarpa	IV	1	.		.			Tofieldietalia
	Linum catharticum	IV	+	.		.			Molinietalia
	Galium uliginosum	IV	+	.		.			Molinietalia
	Trifolium repens	III	8	.		.			Arrhenatheretalia
	Drepanocladus revolvens	V	45	I	+	.			Utricularietalia
	Carex hostiana	V	4	I	+	.			Tofieldietalia
	Eleocharis uniglumis	V	2	III	2	.			Phragmitetalia
	Briza media	IV	2	I	+	.			Magerrasen
	Parnassia palustris	IV	+	I	+	.			Scheuchzerio-Caricetea
	Menyanthes trifoliata	III	12	III	4	.			Scheuchzerio-Caricetea
	Mentha aquatica	V	5	II	2	III	+		Phragmitetalia
	Carex rostrata	V	7	III	28	III	13		Phragmitetalia
	Molinia caerulea	V	4	IV	5	III	+		x
	Carex davalliana	V	7	IV	3	IV	4		Tofieldietalia
	Calliergonella cuspidata	V	21	V	13	V	14		k.A.
	Campylium stellatum	V	10	V	2	V	2		Utricularietalia
	Potentilla erecta	V	5	V	+	V	+	B	Nardo-Callunetea
	Valeriana dioica	V	5	V	5	V	4		Molinietalia
	Plagiomnium elatum	V	4	V	15	V	13		k.A.
	Carex elata	IV	37	V	16	IV	21		Phragmitetalia
	Caltha palustris	III	3	V	6	V	5		Molinietalia
	Cardamine amara	.		V	4	IV	6		Montio-Cardaminetea
	Polytrichum formosum	.		IV	+	V	3	B	k.A.
	Deschampsia cespitosa	.		III	1	III	+	B	x
	Solanum dulcamara	.		III	+	IV	+		x
	Galium mollugo agg.	.		III	+	IV	+	B	Arrhenatheretalia
	Plagiothecium ruthei	.		II	2	III	1	B	k.A.
	Plagiomnium undulatum	.		II	+	III	1	B	Fagetalia
	Taraxacum sect. ruderalia	.		II	+	IV	+	B	x
	Dryopteris carthusiana	.		II	+	IV	+	B	x
	Rhizomnium punctatum	.		II	+	IV	2	B	k.A.
	Sorbus aucuparia	.		II	+	V	+	B	x
	Oxalis acetosella	.		I	3	III	6	B	x
	Thuidium delicatulum	.		I	+	III	7	B	k.A.
	Carex remota	.		I	3	III	14		Fagetalia
	Quercus robur	.		I	+	IV	+	B	Querco-Fagetea
	Primula elatior	.		I	+	IV	+	B	x
	Hypnum cupressiforme	.		I	+	V	7	B	k.A.
	Paris quadrifolia	.		.		III	+	B	Fagetalia
	Dicranodontium denudatum	.		.		IV	1	B	k.A.
	Berberis vulgaris	.		.		IV	+	B	Prunetalia spinosae
	Fragaria vesca	.		.		IV	+	B	Epilobietea