

Natural regeneration of *Abies densa* and *Tsuga dumosa* and its herbaceous competition in a forest management unit in Western Bhutan

Diploma Thesis
Ulrich Schreiber

1 Acknowledgements

This study was conducted as partial fulfilment of the degree of Diplom Ingenieur at the University of Applied Life Sciences Vienna. It was done in the framework of the CORET (Conifer Research and Training Partnership) project – a development cooperation between the Austrian and the Bhutanese government.

I want to thank my scientific advisor AO Univ. Prof. DI Dr. Georg Gratzner for his precious support in preparation, execution and analysis of the study. He not only gave me the opportunity to visit the beautiful country of Bhutan, but has also shown incredible patience and did not give up hope that the work would be finished.

DI Andras Darabant was also a valuable consultant in all matters concerning a foreign country and scientific work, a friend and generous landlord in Bhutan.

I want to thank Mr. Lobzang Dorji, Divisional Forest Officer, Thimphu Division and Mr. Tandin Wangchuk, Divisional Manager, Forest Development Corporation, Thimphu for the logistic support in carrying out the field work in Bhutan.

Special thanks go to Mr. Phento Tshering my cograduand for much of the organisation of the field work and giving me an introduction to the Bhutanese way of life. The same can be said about some very special Bhutanese friends, who have shown incredible warm hospitality towards me and made a foreign country a warm and friendly place. They have shown me Bhutanese life from the inside, took me to their homes and let me be part of their life. These special friends were Mr. P.B. Rai, Mr. Kinley Tenzin, and especially Mr. D.B. Chetrij, who even invited me to live with his family for some days.

The field team did great work under very wet conditions and still kept up a good mood at all times. They provided me even with Bhutanese kitchen secrets. These people were Mr. Sonam Tashi, Mr. Ugen Wangchuk, Mr. Sherub Thinley, Mr. Ram Bhadur Ghallay, Mr. Sangay Wangdi, Mr. Karman Subba, Mrs. Ghalley, Mr. Arun Rai, Mr. J.B. Mongar, Mr. Bhopal Rai, Mr. Nima Chojay, Ms. Dorji Wangmo, Mr. Dawa, Mr. Dorji and Mr. Dorji.

In my current occupation at the Austrian national forests I was kindly supported by my superior DI Dr. Norbert Putzgruber, my colleagues DI Laurenz Aschauer and especially DI Heinz Wallentin. They were helping me and were relentless reminders to finalise this study. For the last phase of the work I am especially grateful to Ms. Elisabeth Lehner for taking on the hard work of giving the last necessary motivation to a very long term student and gently pushing me to the finish line.

Last but not least I want to thank my family, my late mother Hildegund Schreiber for allowing me to study, believing in her children and passing on her love for nature to her

children, my siblings Vinzenz Schreiber and Maria Schreiber for their kind support in all matters of life and providing me with a safe haven and my loving partner and friend Frauke Lejeune for the home and support she gives me.



Figure 1: The field survey team

2 Abstract

2.1 English

The mixed conifer forests of Bhutan are an important natural and economical resource of the country. To manage these forests on a sustainable basis an understanding of the regeneration ecology of trees is necessary. This study examined the herbaceous competition for the regeneration of the economically most important and most dominant tree species in the study area of two forest management units. In these areas, the data collection was conducted in cable lines operated with the group selection system. The examined tree species were *Abies densa*, *Tsuga dumosa*, *Picea spinulosa*, *Pinus wallichiana*, *Acer campbellii* and *Betula utilis*. As main competitors in the herbaceous layer *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.*, *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua* and *Yushania microphylla* were identified. To gain more insight in the tree regeneration management and to separate regeneration types for the tree species, the light requirements of the competitors were also examined. The light levels were positively correlated with the biomass in the observation plots, which was mainly consisting of the selected competitor species. For *Abies densa*, one of the most abundant tree species, negative correlations with the light levels and biomass were found and positive ones with all tree species. For *Tsuga dumosa*, the second species of high abundance, tree regeneration showed positive correlations with all other tree species with the exception of *Picea spinulosa*. All tree seedlings pooled together were negatively correlated with the opening size of the gaps. The competing herbaceous species were positively correlated with opening size and accordingly the light levels. This reiterates that bigger openings with higher levels of light are more favourable for the herbaceous competitors than for the tree regeneration. *Artemisia moorcroftiana*, *Salvia sp.*, *Sambucus adnata* and *Yushania microphylla* are the most influential competing herbaceous competitors, although the findings in the two survey areas were not matching in all correlations. Regeneration types have been recognised for the two main tree species *Abies densa* and *Tsuga dumosa*. As these are tree species are shade tolerant small openings are necessary to keep the herbaceous competitors in check, while the light levels would be sufficient for the tree regeneration. If the currently used gap selection system does not yield the desired regeneration results, the use of a shelterwood cutting system could probably successfully used in areas, where it is technically possible.

2.2 German

Die Nadelmischwälder in Bhutan sind sowohl wirtschaftlich wie ökologisch von großer Bedeutung. Da die forstwirtschaftliche Nutzung zunimmt, wird es immer wichtiger für eine nachhaltige Nutzung auch die Verjüngungsmechanismen zu verstehen. Diese Studie hat die Konkurrenz in der Krautschicht für die Verjüngung der wirtschaftlich wichtigsten, bestandesbildenden Baumarten in zwei Bewirtschaftungseinheiten untersucht. Das Aufnahmegebiet waren Femellöcher, die mit Seilkränen geerntet worden waren. Als Hauptbaumarten für die Untersuchung wurden *Abies densa*, *Tsuga dumosa*, *Picea spinulosa*, *Pinus wallichiana*, *Acer campbellii* und *Betula utilis* ausgewählt. Als Hauptarten in der krautigen Konkurrenzvegetation wurden *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.*, *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua* und *Yushania microphylla* ausgewählt. Für diese Arten wurden auch die Lichtbedürfnisse untersucht, um die Baumverjüngung besser steuern zu können und Verjüngungstypen ausscheiden zu können. Die Lichtintensität war positiv korreliert mit der Biomasse. Diese wurde hauptsächlich von der krautigen Vegetation gebildet. Für eine der beiden zahlreichsten Baumarten in der Verjüngungsschicht – *Abies densa* – wurden negative Korrelationen mit der Lichtintensität und der Biomasse, positive mit der übrigen Baumverjüngung festgestellt. Die andere sehr zahlreiche Baumart *Tsuga dumosa* hatte positive Korrelationen mit allen anderen Baumarten, ausgenommen *Picea spinulosa*. Die gesamte Baumverjüngung war negativ korreliert mit der Größe der Femellöcher bzw. mit der Lichtintensität. Auch waren alle Baumarten miteinander positiv korreliert. Für die krautige Konkurrenzvegetation wurden positive Einflüsse der Größe der Femellöcher bzw. der Lichtintensität ermittelt. Das unterstützt die Annahme, dass größere Verjüngungslücken sich besser auf das Wachstum der Konkurrenzvegetation, als das der Baumverjüngung auswirken. *Artemisia moorcroftiana*, *Salvia sp.*, *Sambucus adnata* und *Yushania microphylla* scheinen die Konkurrenzarten mit dem größten Einfluss auf die Baumverjüngung zu sein, obwohl die Ergebnisse für die zwei Aufnahmegebiete nicht in allen Punkten übereinstimmen. Für die zwei häufigsten Baumarten *Abies densa* und *Tsuga dumosa* wurden Verjüngungstypen ausgeschieden. Da diese beiden Arten relativ schattentolerant sind und die Konkurrenzvegetation mit Zunahme der Lückengröße dominiert, sollten die Öffnungen möglichst klein gehalten werden. Wenn das Femelschlagsystem nicht zum gewünschten Verjüngungserfolg führt, könnte in Gebieten wo das technisch machbar ist ein Schirmschlagsystem zum Erfolg führen.

3 Contents

3.1 Chapters

1 Acknowledgements	2
2 Abstract	4
2.1 English	4
2.2 German	5
3 Contents	6
3.1 Chapters	6
3.2 Figures	8
3.3 Tables	8
3.4 Tables Annex	8
3.5 Figures Annex	9
4 Introduction	10
4.1 Natural Regeneration	10
4.2 Driving Factors for Regeneration	12
4.2.1 Competition and Succession	12
4.2.1.1 General Concepts	12
4.2.1.2 Disturbances and Gap Formation	12
4.2.1.3 Resource Availability and Demands	15
4.2.2 Competition between Tree Regeneration and Herbaceous Plants	17
4.2.3 Microsites	18
4.2.4 Light Regime	20
4.2.5 Seeds	22
4.2.6 Mortality	24
4.2.6.1 Herbivory and Seed Predation	24
5 Objectives	26
6 Materials and Methods	28
6.1 Study Area	28
6.1.1 Bhutan	28
6.1.1.1 Blue Pine (<i>Pinus wallichiana</i>) Forests	29
6.1.1.2 Spruce (<i>Picea spinulosa</i>) Forests	29
6.1.1.3 Hemlock (<i>Tsuga dumosa</i>) Forests	30
6.1.1.4 Fir (<i>Abies densa</i>) Forests	30
6.1.1.5 Alpine Scrub	30
6.1.2 Forestry in Bhutan	30
6.1.3 Gidakom FMU	32
6.1.3.1 Main Forest Types in the FMU	33
6.1.3.1.1 Blue Pine (<i>Pinus wallichiana</i>)	33
6.1.3.1.2 Mixed Conifer	33
6.1.3.1.3 Broad Leaf	34
6.1.3.1.4 Fir (<i>Abies densa</i>)	34
6.1.3.2 Grazing and Browsing	34
6.1.3.3 Management	34

6.2	Data Collection	36
6.2.1	Site Selection	36
6.2.2	Plot Design	36
6.2.3	Measurements of Tree Regeneration	37
6.2.4	Sampling and Measurements of Herbaceous Plants	38
6.2.5	Hemispherical Photography	38
6.2.6	Inventory Data	39
6.3	Data Analysis	40
6.3.1	Hemispherical Photographs	40
6.3.2	GSF Value	40
6.3.3	Plant Sample Data	41
6.3.4	SPSS Analysis	41
6.3.4.1	Descriptive Statistics	41
6.3.4.2	Correlation Analysis	41
6.3.4.3	Factor Analysis	41
6.3.4.4	Cluster Analysis	43
6.3.4.5	Discriminant Analysis	43
7	Results	44
7.1	The Strongest Herbaceous Competitors for the Tree Regeneration	44
7.1.1	Inventory Data	44
7.1.2	Plot Data	48
7.1.3	Aggregation	53
7.2	The Differences in Site Demands of the Herbaceous Competitors and the Regeneration	53
7.2.1	Inventory Data	53
7.2.2	Plot Data	59
7.2.3	Aggregation to Plot Level	64
7.3	Influence of Light on the Herbaceous Competitor Species	65
7.4	Regeneration Types Based on Herbaceous Competitors and Site Factors	66
7.4.1	Cluster Analysis Inventory Data	66
7.4.2	Discriminant Analysis Inventory Data	67
7.4.3	Cluster Analysis Plot Data	69
7.4.4	Discriminant Analysis Plot Data	70
8	Discussion	72
8.1	The Strongest Herbaceous Competitors for the Tree Regeneration	72
8.1.1	Impact of Herbivory on the Tree Regeneration	76
8.1.2	Plant Size and Location in the Gap	77
8.2	The Differences in Site Demands of the Herbaceous Competitors and the Regeneration	80
8.3	Influence of Light on the Herbaceous Competitor Species	84
8.3.1	Light Levels and Tree Regeneration	85
8.3.2	Light Levels and Herbaceous Competitors	86
8.3.3	Shade Tolerance/Mortality of Tree Species	87
8.4	Regeneration Types Based on Herbaceous Competitors and Site Factors	89
8.5	Management Implications	92
8.5.1	Field Guide	94
9	Conclusions	95
10	References	96
11	Annex	100

3.2 Figures

Figure 1: The field survey team	3
Figure 2: Map of Bhutan - google. earth 30.11.2009	29
Figure 3: Plotdesign	37
Figure 4: Example of a hemispherical photograph	39
Figure 5: Screeplot - Factor Analysis Inventory Data	58
Figure 6: Screeplot - Factor Analysis Plot Data	63
Figure 7: Canonical Discriminant Functions Overview - Cluster Analysis Inventory Data	68
Figure 8: Canonical Discriminant Functions Overview - Cluster Analysis Plot Data	71

3.3 Tables

Table 1: Correlations Herbs / Tree Species - Inventory Data	45
Table 2: Correlations Herbs – Inventory Data	46
Table 3: Correlations Tree Species – Inventory Data	47
Table 4: Correlations Herbs- Plot Data	49
Table 5: Correlations Tree Species - Plot Data	49
Table 6: Correlations Site Factors / Herbs - Plot Data	51
Table 7: Correlation Site Factors / Tree Species - Plot Data	52
Table 8: Correlation Site Factors / Tree Species – Inventory Data	54
Table 9: Correlations Site Factors / Herbs– Inventory Data	55
Table 10: KMO and Bartlett´s Test - Factor Analysis Inventory Data	57
Table 11: Communalities - Factor Analysis Inventory Data	58
Table 12: Rotated Factor Matrix - Factor Analysis Inventory Data	59
Table 13: Correlations Herbs / Trees Species - Plot Data	61
Table 14: KMO and Bartlett´s Test - Factor Analysis Plot Data	62
Table 15: Communalities - Factor Analysis Plot Data	62
Table 16: Rotated Factor Matrix - Factor Analysis Plot Data	64
Table 17: Case Processing Summary – Cluster Analysis Inventory Data	66
Table 18: Case Summaries - Clusteranalysis Inventory Data	67
Table 19: Test Results (a) - Discriminant Analysis Inventory Data	67
Table 20: Case Processing Summary - Cluster Analysis Plot Data	69
Table 21: Case Summaries - Cluster Analysis Plot Data	70
Table 22: Abundance of Species According to Gap Position	79
Table 23: Regeneration Types	91

3.4 Tables Annex

Annex 1: Descriptive Statistics Selected Competing Herbs – Inventory Data	100
Annex 2: Descriptive Statistics Selected Regeneration – Inventory Data	100
Annex 3: Descriptive Statistics Selected Competing Herbs – Plot Data	101
Annex 4: Descriptive Statistics Selected Regeneration – Plot Data	101
Annex 5: Correlations – Inventory Data	102
Annex 6: Correlations – Plot Data	103
Annex 7: Total Variance Explained - Factor Analysis Inventory Data	104
Annex 8: Factor Analysis, Anti Image Covariance and Anti Image Correlation – Inventory Data	105
Annex 9: Total Variance Explained - Factor Analysis Plot Data	106
Annex 10: Factor Analysis, Anti Image Covariance and Anti Image Correlation – Inventory Data	107
Annex 11: Test of Equality of Group Means - Discriminant Analysis Inventory Data	108
Annex 12: Eigenvalues - Discriminant Analysis Inventory Data	108
Annex 13: Wilk´s Lambda Test - Discriminant Analysis Inventory Data	108
Annex 14: Structure Matrix - Discriminant Analysis Inventory Data	109
Annex 15: Classification Function Coefficients - Discriminant Analysis Inventory Data	110
Annex 16: Classification Results (a) - Discriminant Analysis Inventory Data	111
Annex 17: Overview Important Variables - Clusteranalysis/Discriminant Analysis Inventory Data	112
Annex 18: Test of Equality of Group Means - Discriminant Analysis Plot Data	113
Annex 19: Eigenvalues - Discriminant Analysis Plot Data	113
Annex 20: Wilk´s Lambda Test - Discriminant Analysis Plot Data	114

<i>Annex 21: Classification Results (a) - Discriminant Analysis Plot Data</i>	<i>114</i>
<i>Annex 22: Structure Matrix - Discriminant Analysis Plot Data</i>	<i>115</i>
<i>Annex 23: Classification Function Coefficients - Discriminant Analysis Plot Data</i>	<i>116</i>
<i>Annex 24: Overview Important Variables - Clusteranalysis/Discriminant Analysis Plot Data</i>	<i>117</i>
<i>Annex 25: Site Information for Hemiphot Analysis</i>	<i>118</i>
<i>Annex 26: Recorded Parameters – Inventory Data</i>	<i>118</i>
<i>Annex 27: Recorded Parameters – Plot Data</i>	<i>119</i>

3.5 Figures Annex

<i>Figure Annex 1: Dendrogramm – Cluster Analysis Inventory Data</i>	<i>123</i>
<i>Figure Annex 2: Territorial Map - Cluster Analysis Inventory Data</i>	<i>124</i>
<i>Figure Annex 3: Dendrogram - Cluster Analysis Plot Data</i>	<i>125</i>
<i>Figure Annex 4: Territorial Map - Cluster Analysis Plot Data</i>	<i>126</i>

4 Introduction

4.1 Natural Regeneration

Regeneration is a term describing the process of reproduction of tree species. This process includes seed production and dispersal, as well as germination of the seeds and transition from seedling into sapling stages. There is also the possibility of asexual or vegetative reproduction of tree parts, even if the above ground parts of the tree are already dead or harvested.

For the production of seeds of a tree some autecological factors like minimum age, fertility, vitality, mast years etc. are important. To a similar degree external environmental conditions like weather conditions, inter- or intraspecific competition, predation, resource availability etc. play a role. These factors can be pronounced, e.g. if a species needs a forest fire to open its seed cones and is therefore dependent on specific disturbances.

Natural regeneration is regeneration by means of natural processes, while in artificial regeneration the germination and first stages of growth are controlled by humans in forest nurseries. The resulting seedlings or saplings are planted afterwards in the respective areas. By means of artificial regeneration the possibility of altering the natural genetic diversity and or species composition is given.

In the past forestry has used artificial regeneration, to increase its profits by planting tree species with higher economical value. This practice of altering the percentages of tree species or even introducing foreign species, has led to higher profits, but also brought with it a set of problems.

The new stands, resulting from artificial regeneration, in many cases have a lower stability LARSEN (1995). One reason for this is the mostly monospecific composition of these stands. The new species may not be as adapted to the environment of its sites, which could become a growing problem in times of climate change. Some foreign trees introduced new species of harmful insects or diseases to the region, or the increased frequency and size of monocultures led to gradations in the local bark-beetle population. Nowadays these developments are taken more into account in silvicultural management practices. If artificial regeneration is used, the tree species shall be suited for the new sites. Using natural regeneration of trees as the basis for the future stand has the advantage over artificial regeneration, that the tree species have been adapted in a long evolutionary process to the local environment, provided that the parent stands are adapted and not the result of artificial regeneration with unsuitable plant material.

Current climate change demands further thinking about the suitable tree species, with much uncertainty included in the selection process. The estimated changes of temperature and humidity have to be taken into account. Overall, foresters must try to get more stable and therefore more diverse stands, with a suitable species composition. These are strong arguments for natural regeneration. Natural regeneration makes the species composition ecologically feasible and the economical costs remain in a better relation to the expected earnings. Natural regeneration is a way to use the species, which are adapted to the environment of the sites.

Forestry also tries to manage the naturally regenerated tree species, so that the economically most desired species are facilitated. For the diverse species composition more tree species have to be facilitated in the later stages of forest management and the goal of monospecific stands for better economical profits has to be rated behind the goal of stability.

By natural regeneration the tree stands are able to rejuvenate and the migration of successful species in the landscape is possible. This takes of course much time. Nowadays species are often introduced to a region by artificial regeneration or accidentally imported by human activities (e.g. out of gardens or parks).

Through natural regeneration also a selection of the fittest or best suited organisms is taking place. In artificial regeneration the selection pressure is lower, as the seedlings are brought up in forestry nurseries in a protected environment.

The regeneration of trees has been an issue in forestry since men began using timber in greater amounts for firewood and construction. With ongoing technological progress and a rising demand for timber the regeneration of the harvested forests became more important.

In Europe the commercialised forestry often uses artificial regeneration. This practice can result in a set of problems and extra costs. Sometimes the planting itself had produced unstable stands, because the roots of the trees had been damaged or deformed during the planting process. With new planting techniques and more diligence these problems should become less.

Herbivores especially ungulates feed on the young trees and destroy them or hinder a fast enough development, which puts extra costs of care and protection measures on the plantations. Also the young trees have to be protected from competing herbaceous and tree species.

All these protection and facilitation measures, together with the upbringing of the plants cost a lot of money. One can imagine that natural regeneration is even cheaper than artificial regeneration and should in most cases be preferred.

4.2 Driving Factors for Regeneration

4.2.1 Competition and Succession

4.2.1.1 General Concepts

The concept of competition is closely linked to successional dynamics in plant ecology as succession is partly regulated by competition mechanisms. The competition by herbs for the regeneration in this study is also happening as part of the gap succession dynamics in the observed forest.

To clarify the term of succession GLENN-LEWIN & VAN DER MAAREL (1992) define fluctuations as changes over a short period of time, which appear in a mosaic and sometimes in cycles. The average of species remains more or less constant. The distinction between fluctuations and succession is mainly one of scale. The same holds true for long term change (secular succession).

The classic definition of succession with a discrete starting point, a clear directional trajectory and an unambiguous end has been too narrow a definition for some successional processes. In most cases succession is not starting from a clean slate. Nearly always a legacy of former vegetation is present. Also structures and a reproductive potential is left by the former dominant community PICKETT and CADENASSO (2005).

To improve the fuzzy and too narrow classic definition new theories and separations were developed. Important differentiations make GLENN-LEWIN & VAN DER MAAREL (1992), who separate between primary and secondary succession. Primary succession is vegetation development on newly formed or exposed substrate, on raw soil material rather than modified soil. No biological legacy (seed bank, previous vegetation) exists on the primary succession sites.

Secondary succession happens after disturbances, which have disrupted the existing vegetation. In these cases most times a biological legacy exists in the form of a seed or sapling bank. This is the kind of succession, by which old growth forest stands are mostly regenerated.

A further distinction is made between autogenic succession, which is vegetation change due to biotic interactions of the environment (e.g. competition, shade, soil modification by plants,...) and allogenic succession, which happens due to a change of overall environmental conditions (e.g. climate change,...).

4.2.1.2 Disturbances and Gap Formation

Secondary succession can only happen, if a disturbance occurs. Disturbances are mechanisms causing partial or total plant biomass destruction. This leads to conditions which

interfere with the normal functioning of a biological system and a change in the availability of resources. Important attributes of disturbances are its spatial extent, the time scale between iterations of the disturbance and its magnitude – the intensity level of destruction (GLENN-LEWIN & VAN DER MAAREL 1992, CRAWLEY 1997a). The disturbance leads to a species composition change, with the need of species to regenerate to remain present in the future set of species in the habitat. If the environmental conditions in a habitat are uniform and the species have similar resource demands, periodic disturbances create spatial and temporal heterogeneity. The dominant competitor species are removed and other species get a chance to establish it selves – this is the concept of the regeneration niche (VEBLEN 1992). Recruitment in an already existing plant community is much more difficult, due to less available resources.

If it is a small scale disturbance in an old growth forest, where windthrows, pathogens, insects or other reasons lead to the death of trees in the canopy layer, this procedure is also described as gap formation. Here we get to the in itself vast field of gap dynamics and the mechanisms important for the regeneration success in this study.

For a successful establishment of seeds a safe site is necessary – this is created by the removal of environmental or vegetation barriers. This window of opportunity may be temporal as in gaps (GLENN-LEWIN & VAN DER MAAREL 1992). For characterising a species' regeneration niche it is necessary to describe its regeneration mode (behaviour in relation to disturbance). Three types of regeneration mode are described: catastrophic regeneration mode with a stand devastating disturbance, large patches (> 1ha), a sudden release of resources, an even aged population and often shade intolerant species; gap phase regeneration mode with small to intermediate patches (e.g. tree fall from age), a mosaic of different age patches, it occurs mostly in old growth stands or in stands near the compositional equilibrium; continuous regeneration mode with an absence of disturbance, not too dense canopy, shade tolerant species and a continuous resource availability (VEBLEN 1992).

In communities like old growth forests a disturbance is often necessary for the creation of a regeneration window (REES 1997). In these old growth stands, pioneer species can only regenerate in forest gaps and these must have the appropriate size. CARSWELL et al. (2007) came to the conclusion, that without major disturbances or gaps, in mixed forests shade tolerant (mostly deciduous) species will dominate the seedling stage and over time also the canopy layer. In bigger gaps regeneration niches can be found, according to higher amounts of light and temperature, as well as different microsites (soil conditions). So in the bigger gaps different species are able to regenerate according to their preferred regeneration conditions.

In all cases of disturbance in forests or pioneer growth after agricultural land use the final development stage, if no further disturbance occurs, of the area is forest. This is true no matter, which herbaceous or tree species are taking part in the competition process (BAZZAZ 1996). In the long term trees have advantages in competition over the herbaceous plants. CRAWLEY (1997a) reckons that the shoots of perennial herbaceous plants in difference to trees die back every year. The advantage for the herbs is that they are not as vulnerable to drought, cold or damage by herbivores and pathogens in the unfavourable season. The disadvantage is that they have to fight for their place in the canopy every year again, but they also do not have to invest resources in production or maintenance of a supporting woody structure. Over time the long term strategy of trees overcomes the herbs either by superior growth on the spot or by ingrowth from the edges of the plots.

GLENN-LEWIN & VAN DER MAAREL (1992) call the process that sites in a habitat become more similar with time convergence. Recognition of convergence is dependent upon spatial scales of observation. It is facilitated by low diversity, a low immigration pool of species and a strong dominance by few species. VEBLEN (1992) introduces the concept of compositional equilibrium for forest stands. By this a state of vegetation communities is described, in which the overall percentages of the main vegetation species stay the same and all represented species are regenerating and remain in the community for time spans greater than the turnover of the population. In these stable stands in a climax phase the frequency distribution over age or size classes is balanced. Many individuals in the smaller diameter and age classes are reduced over time to few individuals in the older and bigger classes. A quantitative equilibrium cannot be expected, as small disturbances are occurring and small scale succession happens. Here the spatial scale of observance is also important for the description of the community. The recognition of a stand in compositional equilibrium is possible by varying methods. Long term observation of forest stands is a good method, but has limitations due to the long life spans of trees. The differences in mortality rates and recruitment of species observed in relative short time periods are assumed to remain so for longer periods, which is problematic as change is likely (due to climatic change, change due to stand development, selective disturbances, disease, insect attacks, ...). It seems to be a principle that mortality rates get lower with growing age of the trees (VEBLEN 1992). A second method is to derive successional trends from forest stand structure analysis. Here it is also assumed that recruitment and mortality rates and the age structure stay constant on the population level. The input due to varying seed production, weather conditions, etc varies with the consequence that mortality rates for trees should not be inferred from static age structures. Size corresponds not always with age, especially if species can survive for a

long time in a waiting sapling stage under a closed canopy. Autoecological aspects of the species should be incorporated in the stand structure analysis.

The stands in a compositional equilibrium reach at some point in time the gap phase. In this phase successional mechanisms and species change happens in gaps and a mosaic structure is developed. For communities near or in the compositional equilibrium the percentage of gaps and early successional species stays more or less the same in the whole community. In gaps and clearcuts patterns of succession can be recognized. Most of the successional species stem from neighbouring plant communities. Near the edges the density of regeneration is bigger and it is also mostly closely related. Further from the edge more species diversity exists and less related individuals occur in these more open and receptive spots (BAZZAZ 1996). Most seeds are deposited only a short distance from the parent plant (VAN DER VALK 1992). In general there is thought to be much more variance in light and other resources like moisture or nutrients in gaps, than under forest canopies. General predictions for the precise succession in gaps are difficult, because of the great environmental heterogeneity, especially in high diversity habitats (BAZZAZ 1996).

4.2.1.3 Resource Availability and Demands

VEBLEN (1992) reckons that in gaps three mechanisms change the availability of resources: the decreased use of resources by loss of biomass, increased decay and mineralization of nutrients (temperature) and exposure of bare soil. The vegetational response to gaps has two general patterns. The reorganization pattern is the accelerated growth of already established individuals. The new establishment pattern is the colonization of the gap by immigrants, the germination of dormant seeds and growth of propagules of the neighbouring plant community. Gap size, shape and orientation influence the species composition by microclimate and edge effects. The time of gap creation respectively the magnitude of destruction and the gap turnover rate have also an impact on the species composition. The species composition of the canopy trees influences the succession by alteration of the understorey vegetation, its litter, regulation of soil moisture and light levels, by providing microsites and by harbouring a specific set of pathogens and predators (VEBLEN 1992).

There are gradients in the different resources and as no supergeneralists exist, which excel along all gradients, the species partition the gap environment. One of the most common separations is made by shade tolerant and light demanding species. In this classification are included some other plant traits. Most light demanding species have for example small seeds, are wind dispersed, have an early seed production and have high photosynthetic growth rates (BAZZAZ 1996).

TILMAN (1997) defines the interspecific competition as interaction between species, where the increase of population density or biomass of one species leads to a decrease in population growth rate, population density or biomass of another. All plants compete for the same set of resources (light, water and nutrients) – the growth rate in a habitat is often limited by the availability of one resource, the limiting resource for the species.

How can the competitive strength of a species be classified? TILMAN (1997) uses a variable called R^* . This is the minimum resource capacity for a specific species of a single limiting resource needed to balance its various losses with its growth rate. If the resource capacity in the habitat is less than R^* the species becomes locally extinct. If several species compete for the resource, the one with the lowest R^* should displace all other species from the habitat, because this species can increase its abundance and reduce the resource concentration to R^* . As many different resources can be limiting in different levels for different species a complex system of superior and inferior competitors for different resources is created.

ANTOS et al. (2005) rate shade tolerant trees, which survive under canopy cover for long periods of time, as stress tolerators. They describe the environment as malign, due to short and cool growing season, low light and nutrient level, although the sites carried a lot of biomass in the canopy tree layer. This rating adverts to the C-S-R triangle classification of competitors (C), ruderals (R) and stress tolerators (S) by GRIME (1979). ANTOS et al. (2005) examined a tree seedling bank in a late successional conifer montane forest. They found that the growth and survival rates of the examined species were consistent with their shade tolerance rating. The saplings had very low growth rates – below 3mm a year – and were very old, some over 100 years. The seedling bank has an important function for the regeneration of the forest, as most canopy trees seem to have experienced very low growth in its youth as well, before experiencing a change in resources and growing into the canopy layer. This flexibility in growth suggests a classification as facultative stress tolerators and hints at a great phenotypic plasticity. The biotic stress may therefore be equal to abiotic stress in influencing the evolution of stress tolerance. This stress tolerance may be necessary for species forming a seedling bank.

For spatially immobile plants, the site of germination is of utmost importance. Plants compete strongly only with the six or so individuals in their immediate vicinity (CRAWLEY 1997a). Seedling selective recruitment preferences remain the same through sapling stage, which indicates the importance of microsites for the species establishment (CHRISTIE & ARMESTO 2003). COATES (2002) writes in contradiction that in his study the regeneration niches were discordant. This means that the best places for seedling recruitment are not the same as for growth and survival of the sapling. On the north sides of the gaps, the

regeneration conditions are worse (in the northern hemisphere), but the survival chances, for the established seedlings, are better, in spite of a less favourable regeneration environment (COATES 2002). Similar results were observed by RESCO DE DIOS et al. (2005). In gap centres seedling density was lower, but seedling mortality and also the growth rates were higher. The best conditions for germination are not always the best conditions for long term survival and regeneration of the species.

COATES (2002) also puts more weight on the successful development of the saplings, than on the early regeneration success when he says, that the survival and growth niches for the saplings seem to be more important for stand structure, species diversity and species abundance. Nonetheless without early regeneration no saplings will exist.

Species preferring a mineral soil seed bed have the advantage, that no competing herbaceous species have a head start over the regeneration. These species are mostly pioneer species, which, after major disturbances, restart the process of forest growth. There are several stages in the development of a forest, with the pioneer phase being the first one. This phase is called the stand initiation or regeneration stage after OLIVER & LARSON (1996), followed by a thinning or stem exclusion stage. Then comes a transition or understorey regeneration stage and finally the climax stage is reached. This is also called steady state or old growth state. Each of the different phases has its own species composition. Forest management tries to keep the forest in a phase, in which the economically desired species have the biggest percentage. To reach this goal different silvicultural systems and practices are used.

4.2.2 Competition between Tree Regeneration and Herbaceous Plants

The process of gap formation, its size and the patterns of regeneration in the gaps are sometimes overlaid by other factors. ABE et al. (2002) found, that the influence of a major dieback in the competing vegetation (in this case a dense bamboo layer), had more influence on the regeneration of the respective tree species, than the formation of the gaps itself. The more important influence on the regeneration, concerning the availability of light and other resources, was the competing bamboo layer and not the canopy layer of the tree stand. GRATZER et al. (1999) found in a study in Bhutan on regeneration of *Abies densa* and competition by Bamboo, that the seedling density decreased with density and height of the Bamboo. The crown density of *Abies densa* old growth was of less influence.

DARABANT et al. (2007) found that for the regeneration success in their study the burial of the seedlings by litter and the competition of herbs were of more influence than the distribution and type of microsites and microtopology. In a sowing experiment of herbaceous

plants by ESKELINEN (2005), it was found that the number of sown seedlings and the species richness were lower with a high level of biomass of competing vascular plants.

Regeneration is a process with multiple influences and may vary very much from one site to the other, but the competition for resources, especially light, plays always a major role. Here the competition by herbaceous plants is something that may have a big influence on the tree regeneration, in particular in the early stages of development. In the Bhutanese deciduous forest GYELTSHEN (2008) did a research concerning the competition between the tree regeneration and shrub competitors. In the study area of mixed conifer forests and framework of the project, of which this study is a part, there has been done already some research concerning the regeneration of the tree species. WANGCHUK (2007) did a more general survey of the regeneration situation and forest ecology of the mixed conifer forests. He also found that herbaceous competition, besides the grazing impact, which was further looked into by TSHERING (2005), plays a major role for tree regeneration. The competition by herbaceous plants, its light demands and a possible regeneration type classification are eligible to complement these studies.

4.2.3 Microsites

As mentioned above, the site and microsite conditions are an important factor for a successful regeneration. To look at the conditions in the required scale, the site of regeneration is downscaled to microsites. Microsites are the environmental and habitat surroundings on a one seedling or germinant scale. Published microsite preferences normally reflect survivorship probabilities on different microsites. This differential survivorship on different microsites can also be connected with seed size (CHRISTIE & ARMESTO 2003). The preferences of the species for certain microsites play a major role from germination through to seedling stages and underline the importance of the selection and availability of suitable microsites. The resource configuration at the site of establishment is crucial for the fitness of the plants. The relevant scale of these sites increases with growth of the plants from a few square centimetres to a few hundreds of square metres for adult plants.

GODER (1961) found that Hemlock regenerates best on logs, stumps or mounds in a pit and mound structure after windthrow. The microsite conditions are often still reflected in adult trees indicating that microsites play a decisive role in the whole establishment process and are not masked by later processes like competition.

A reflection of this is the shallow soil refugia hypothesis: On shallow soils *Pinus strobus* is able to outcompete other tree species and grow into older development stages or even into the canopy layer. The soil depth had no effect on the overall density of overstory trees, but the different species had preferences for different soil depths. For the sapling stages it

seems, that extremely shallow soils cannot maintain the seedlings in later stages, without regard for the species. The soil depth measurements for adult trees and saplings could not be compared, because of different measurement techniques. Although *Pinus strobus* had competition advantages on shallow soils, the extremely shallow soils proved to be a difficult habitat even for this species. Moisture and physical space requirements seem to be the limiting factors, rather than the competition by other species (DOVCIK et al. 2003).

SYDES & GRIME (1981a) examined in a study in deciduous woodland the influence of tree leaf litter on the growth of herbaceous vegetation. The results show that topography even in small variations has a big influence on the litter accumulation. Another factor is the present vegetation influencing the air flow on the soil. Herbaceous vegetation was less in the accumulation spots of litter. There were also specieswise differences, because the species have different strategies and abilities to penetrate the litter with their shoots.

In follow up experiments it was found that the physical aspects of litter as size, thickness and time of decomposition are probably more important than the chemical allelopathic effects. Grasses are more impeded by litter coverage than other herbs; this has an influence on the species composition. In thick litter coverage herbaceous plants have difficulties to reproduce. This may facilitate tree regeneration, especially of shade tolerant species, which has often bigger seeds and a better ability to penetrate the litter layer (SYDES & GRIME 1981b). Dead tree logs have often been found to play a major role for regeneration, especially in old growth forests or under special environmental conditions. In Boreal forests, the snow cover and topographical features are important for germination processes. In these areas fallen logs or a higher elevation often offer protection, which facilitates germination through lower snow coverage and a higher amount of radiation. BAIER et al. (2007) found in a study of *Picea abies* regeneration in Alpine regions, that the radiation was not the limiting factor. Regeneration was facilitated by snow obstacles, like old stumps or logs and better in areas with less competing vegetation. In moist conditions the logs provide also favourable drier microsites and vice versa in dry conditions with strongly decomposed logs showing a higher water holding capacity than mineral soil.

Moss microsites often facilitate the early germination, but if the roots cannot penetrate the moss layer there is the danger of desiccation. The nutrient supply is also not ideal on moss microsites.

The species growing on a certain spot also alter the environment there. The ground vegetation, the amount of light in the ground layer, humus layer with decay rates of the foliage, pH-value and allelopathic substances - all contribute to the change. Sometimes this changing of soil chemistry degrades the site and it is one of the objectives of forest

management to keep that in check. The species composition should be steered in a way to at least conserve the productivity and condition of the site if not improve it.

CHRISTIE & ARMESTO (2003) also state that the density of seedlings of shade intolerant species was higher on logs under closed canopy, than in gaps on soil sites. The seedling density of shade intolerant species was influenced by canopy opening, substrate and forest type, while the shade tolerant species was only proven to be influenced by forest type (old growth or mid-successional). The assumption is that seed size plays an important role – together with the distribution of microsites – for species distribution and coexistence.

If not buried too deeply, burial of seeds by litter improves the chance of germination and survival (predation, desiccation ...). The maximum depth of burial where recruitment is still possible is directly proportional to the seed mass (VAN DER VALK 1992).

NARUKAWA & YAMAMOTO (2002) found in their study of *Abies mariesii*, *Picea jezoensis* and *Tsuga diversifolia* seedlings in competition with dwarf bamboo (*Sasa sp.*) in a sub alpine forest, that the different microsites had great influence on recruitment. *Abies mariesii* has the possibility to regenerate on soil as well as on fallen logs, due to its bigger seed size and the possibility to penetrate the litter layer with its roots. *Picea jezoensis* and *Tsuga diversifolia* have smaller seeds and are therefore restricted to regeneration on logs. The presence of *Sasa* decreased the density of *Abies mariesii* seedlings on soil to a large degree. Fresh seedlings died to a large amount in all species in the first season, therefore the study concentrated mainly on the already established seedlings.

CHRISTY & MACK (1984) also tested the survival of seedlings of *Tsuga heterophylla*. One question was the loss to predation by rodents. Still predation seemed not to be the main mortality agent. The best germination results in his study were on mineral soil. The best seedling survival was on decaying logs with a cryptogam cover. They also say that the seed rain of conifers is distributed over some month in the year, and the germination date is important for survival (also depending on the specific climate situation in the year).

4.2.4 Light Regime

Microsites are not only characterized by the substrate and soil cover. Light is also a resource of major importance. TSHERING (2005), who used the same data as in this study for his analysis, found that the highest density of tree seedlings was observed in the south position of the gaps, the lowest in the centre. The herbaceous competitors had the highest densities in the gap centres (especially *Artemisia moorcroftiana*) and in the western positions. The different competitors had different prevalence's for the gap positions, according to their site demands and the interspecific competition between the herbaceous species.

This is congruent with the findings of RESCO DE DIOS (2005). In his study the seedling density was generally higher at the edges of the gap. As an explanation he offers the higher light and therefore temperature level in the centre, although mortality was not sufficiently examined. COATES (2002) comes to the same conclusions for the declining numbers of regeneration in open conditions in his recruitment study.

In the northern hemisphere the southern edges of the gaps are more protected from direct radiation, than the centre or northern edges. It seems natural that the freshly germinated trees are more susceptible to drought and sunburn effects, as they have only a very shallow root system and vulnerable shoots.

YORK et al. (2003) discovered in contradiction in their survey the highest trees north of the centre of the gaps along a south to north transect, the smallest on the southern edges. Light availability was measured with hemispherical photography and on average the southern edge received 60%, the northern edge 80% of the centres light intensity. The lower light intensity on the south edge with the resulting less root growth and therefore less access to soil moisture seems to more than compensate the higher competition of roots by canopy trees (also more light) and higher vapour pressure deficits on the north side. In the following development the former unfavourable sites become better places for rapid growth, as more light is available – a phenomenon called a discordant regeneration niche by COATES (2002).

COATES (2000) also had detected that middle position had the best performance in the gaps, even better than on the north edge. This hints at edge effects, maybe root competition by the surrounding canopy trees. The seedlings of all species performed poorly on the gap edges, regardless of the orientation. In medium sized (300 – 1000 m²) gaps the differences between edge and middle positions were the biggest. In contrast to growth early mortality rates increased with decreasing shade tolerance, especially in the low light forest understorey environment. The same was true for the shady areas of medium gaps.

The deduction is that gap partitioning seems to function more through differential early survivorship and long term survival under low light conditions, than through different growth in early gap phases.

KOZLOWSKI (2002) found that the major resources needed in the right amounts for germination are moisture, light and temperature. Temperature is also influenced to a great deal by the amount of light or length of photo period. If it is too wet this may also hinder germination. On logged sites, the water content of the soil often rises dramatically, because the pumping function of the standing trees – induced by evaporation via the foliage – is missing. This may cause problems for regeneration. If already an understorey existed the young trees keep the effect to a lower level.

The length of photo period and temperature level is responsible to a high amount for the time of germination. The quality (red to far red ratios) and amount of light have also a crucial role in the following development of the young trees. This makes it obvious that the canopy density and existence of gaps is critical. Not only has the amount of diffuse radiation, but also sun flecks, created by the canopy, a big influence on the species and amount of regeneration. In the openings or gaps the amount of radiation can be 10 to 100 times higher than in the shade under the canopy (BOTKIN 1992). The amount of radiation reaching a certain spot is not only influenced by the time of the year (photo period), but also by slope, aspect, local topographical features and of course the vegetation. Especially in the early stages of development the competition by herbaceous plants is a major factor for the regeneration. The fight for a place in the light is a matter of life or death for the little plants.

4.2.5 Seeds

Germination is a complex process. The physical adaptations which determine the moment of germination shall ensure good environmental conditions, so called germination syndromes, and chances of survival. Seeds may get dormant until by environmental conditions germination is triggered. These dormant seeds are called a seed bank and can remain inactive many years – sometimes they even survive the vegetative active part of its species. These seed and seedling banks are genetic reservoirs. In the seed bank dormant seeds of plants survive in the soil. The process of germination is triggered by a change in environmental conditions. This may be temperature, humidity or nitrate content in the soil. The seed banks are often spatially heterogeneous. The seed bank is important in the time a gap forms to allow species with less competitive ability to regain their place in the habitat. The seeds that do not germinate in the season following their production are not lost. If they are not eaten or destroyed by other means, they enter the seed bank and stay dormant (VAN DER VALK 1993). REES (1997) says two species can coexist under varying environmental conditions even if one is competitive superior if a seed banks exist. The inferior species uses the periods of favourable environment for its species for reproduction and the long term survival is secured. The species in a seed or seedling bank have a head start over the other species (REES 1997). Shade tolerant species often persist several years under the nearly closed or closed canopy in a seedling stage, thus forming a seedling bank (ANTOS et al. 2005). Under better light conditions, these seedlings in a waiting position can use their advantage over the freshly germinated plants. The seedlings grow over time into sapling stage. This strategy is only available for shade tolerant species, which often dominate the old growth forests. This procedure is fundamental in many old growth forests. In forests in a more or less steady state, most of the trees in the canopy layer are grown in

from the seedling bank (VEBLEN 1992). For scientists it's a question of great importance how forests develop after disturbances. Here the existence and development of a seedling bank has a big influence. The growth patterns of seedlings differ considerably from those of germinants (COATES 2002).

During disturbances some of the species always vanish from the area. This may be because the environmental conditions or competition changes or just because all seeds or mother-plants have been removed. That is the reason that a seed bank never represents the full amount of species, which occurred in the respective area before the disturbance. The event of the disturbance also provides a chance for new species to appear in the formerly occupied area. Here the seed dispersal patterns and required regeneration niches of the different species play a major role.

In gap colonization species with longer survival in shady conditions are better colonizers than species with a higher growth rate in low light levels – the better competitors in the traditional view – because they have greater numbers with a head start when the gap is formed. That is the reason, that these species dominate late successional forests (PACALA 1997). This classification contradicts the traditional view, that late successional species are poor colonizers. With increasing gap size early successional species get more advantages – more space, resources and numbers.

Seed densities of different species vary considerably on different sites. The differences in recruitment of the individual species in the gaps most likely represent the abundance of parent trees and specific modes of regeneration (COATES 2002). Not only are the seeds limited by the abundance of mother plants in former times but also is the physiology of the seeds not always suited to stay dormant for long times. Species with large seeds have less dormant seeds and species with very efficient seed dispersal in space have also less dormant seeds, because of higher fat content in the seeds (REES 1997), this shows also that the distribution of species is limited.

Also without available seeds germination on favourable sites is of course impossible. DOVCIK et al. (2003) tested if the seed rain limitation hypothesis, which says that seed rain determines the number of germinants, or safe site limitation hypothesis, which constitutes that the distribution of germinants and seedlings are more dependent on microsite and habitat availability than on seed rain, was more important in a study for *Pinus strobus* regeneration. No clear preference could be found. The initial germinant density was positively related to the seed rain density and the density of decaying wood. Also the basal area of living trees influenced the seedling density positively – probably partly via the density of seed rain. Moss coverage had a positive influence on seedling density, explaining the

same amount of variance as seed rain density. Both factors – seed and microsite availability had an effect.

A plant must accept certain trade offs in its regeneration strategy. Shade tolerant species have often bigger seeds, which make them more competitive in the beginning, but the dispersal distances are shorter than for the often wind dispersed, shade intolerant pioneer species CRAWLEY (1997a).

Predation on seeds by rodents, birds and insects consumes a high percentage of the possible germinants. This predation as well as the mosaic of favourable microsites and the dispersal pattern of the seeds often lead to a patchy distribution of regeneration. This offers other tree species and herbs the possibility to use the bare patches.

If the desired species, from an economical point of view, are light demanding species, the silvicultural methods must be adapted accordingly. By adequate measures the light demanding species are also able to be part of the main canopy. The forest stand is therefore kept in the development phase, which suits the ecological needs of the desired species best. In these situations clear cuts combined with soil scarification are often the silvicultural system of choice.

4.2.6 Mortality

For a successful regeneration several factors must convene. There have to be enough vital seeds. The environmental conditions like microsites and weather have to be favourable. The competition of herbs or other tree species has to be overcome and predation or destruction by animals or other harmful agents has to be survived or omitted. Then the tree has to grow into the main canopy.

The mortality of seedlings is much higher in the first life stages. CHRISTY & MACK (1984) found that after two years the mortality rate drops significantly. In their study desiccation and predation by rodents were probably responsible for most of the dead seedlings. Herbaceous competition and light availability could nonetheless also be important factors for seedling mortality.

4.2.6.1 Herbivory and Seed Predation

AMMER (1996) notes in his study, on the impact of ungulates on regeneration in a mountain forest, that the plant species composition changes considerably under the influence of browsing. Some species are clearly preferred as fodder by the ungulates. Also are the species vulnerable to browsing to different degrees – the conifer species are more sensible. The total plant density is, although a also function of the light regime, managed by

silvicultural practices to facilitate the desired tree species. Otherwise superior competitors fall behind, because they are victims to repeated browsing damage.

VAN DER VALK (1992) supposes the establishment of species happens in two main forms, by vegetative propagules or by seeds. Effectiveness of seed regeneration depends on quality and quantity of seed production, the vector of seed transport, the timing of seed release, the necessary distance of dispersal and the general fate of seeds (predation, germination success ...). Seed predation is one of the most important factors and regeneration success is not only dependent on the amount of seeds (which is more important) but also on the density of predators.

5 Objectives

This study is part of a bigger project of the Institute for Forest Ecology at the University of Natural Resources and Applied Life Sciences in Vienna Austria and the forestry research sector of the department of forestry in the Ministry of Agriculture of Bhutan. In this project, the Conifer Research and Training partnership (CORET) and, in its third phase, FORED (Forest research for development partnership), research on regeneration of tree species in the Bhutanese conifer forests is carried out. One question to be answered was the lack of regeneration in certain areas of the conifer belt in Bhutan.

This study is embedded into the larger framework of the project. In addition to the already examined light demands of the main regeneration tree species (DARABANT et al. 2001), the goal is to explore the demands and the competing role of herbaceous species. The idea is that certain herbaceous species compete with the conifer regeneration for nutrients, water and light resources. But how big are those influences? Which are the species with the biggest effect on regeneration, and how can the forest be managed to facilitate the establishment of the desired regeneration, but not the biggest competitors?

For answering these questions, two sets of data were used. One was the data gathered during an inventory in Chamgang and Gidakom forest management units (FMU), on a broader scale and in more plots, than the data collection on the plots of this study. The other one was the plot data collected by the field team of this study in the Gidakom FMU, which was more detailed and had recorded more parameters, including the biomass of competing species.

One question to be answered was, if there is any correlation between the site conditions recorded and the abundance of tree regeneration as well as correlation with the abundance of competing herbs. Also the relation between the number or the cover percentage of herbs – here the species with the most likeliness to have an influence were selected – and the number of tree regeneration was examined. Of the tree species, *Abies densa*, *Tsuga dumosa* and *Picea spinulosa* were selected as the main target species for tree regeneration based on their economic role as well as their abundance in the area.

For the plot data also the connection between the global site factor (GSF) value, as a measure for the light regime, and the occurrence of tree regeneration and the main competing herbs was investigated. As main competing herb species the following species were chosen: *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.*, *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua* and *Yushania microphylla*. The selection was based on size and abundance of these species and their hypothesized influence on successful tree

regeneration. A possible difference in the abundance of tree regeneration and competing herbs, concerning the spatial position of the subplots, was also investigated. The subplots were located at the edge of the logging gaps in different orientations. This was also examined in the study of DORJI (2004) in different areas.

Another target of the study was to find a grouping algorithm for the plots. The idea was to generate a tree regeneration index, by which the likelihood for natural tree regeneration can be determined from stand, site and competition factors. For this purpose groups were formed out of the subplots, with the amount of the competing herbs species, tree regeneration species and the site factors as variables.

Grazing and browsing have a negative influence on the tree regeneration, if the tree seedlings are subject to the damage. It may also be the case, that by reduction of the competing herbs grazing and browsing are facilitating the regeneration of the tree species. TSHERING (2005) examined this issue in his studies, in the same area and during the same time.

The objectives for this study were to:

1. Examine which are the most important herbaceous competitors for the regeneration of *Abies densa*, *Tsuga dumosa* and *Picea spinulosa* in the group selection cuttings of Gidakom FMU and Chamgang FMU.

2. Characterise differences in the site requirements of the competitors: *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.* *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua* and *Yushania microphylla*, as well as of the tree regeneration of *Abies densa*, *Tsuga dumosa* and *Picea spinulosa* regeneration.

3. Characterise the influence of the light regime on the growth of *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.* *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua* and *Yushania microphylla*.

4. Form regeneration types for *Abies densa*, *Tsuga dumosa* and *Picea spinulosa* on the basis of the influence of *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.* *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua*, *Yushania microphylla* and the site factors.

6 Materials and Methods

6.1 Study Area

6.1.1 Bhutan

Bhutan is a relatively small – about 40076 km² – landlocked country in the eastern Himalayas between 88° 45 ' and 92° 10 ' longitude east and 26°40 ' and 28°15 ' latitude north. The terrain is very rugged, with many valleys and altitudes ranging from 97 masl in the south to 7553 masl in the north, where the Himalayan range is the dominant topographic feature.

The valleys are mostly north-south orientated and have, together with the big differences in altitude, a big influence on the climate. The dominant influence for the climate is the Monsoon, which usually lasts from June to September with a decrease in rain fall from south to north. This general situation is overlaid by the strong influence of the local topography, which can also be noticed in sometimes very dry valley bottoms, due to valley wind systems (OSHAWA 1995) and Troll effect (SCHWEINFURTH 1984).

Forestry is not only an important economical factor in the countryside of Bhutan; it also has to fulfil an ecological role. The preservation of water resources, the protection against erosion and the habitat function for plants and animals are even more important conservation functions than the economical one. Some of Bhutan's most profitable and seminal resources – like the production of hydroelectric power and tourism – are strongly connected to a well working and ecological forestry. Bhutan belongs to one of the 10 UN hotspots for biodiversity in the world, because of its richness in plant and animal species. The government has therefore adopted a policy to keep 60% of the land under forest cover at all times.

There have been different proposals to divide Bhutan in vegetation zones – depending on the altitude, the climate and the dominant vegetation types. The following zones are a part of the classification by GRIERSON & LONG (1983).



Figure 2: Map of Bhutan - google. earth 30.11.2009

6.1.1.1 Blue Pine (*Pinus wallichiana*) Forests

The altitude ranges from 2100 – 3000 masl. Annual precipitation is 700 – 1200mm/year most falling in monsoon period. Dry mountain valleys are dominated by the Blue pine forests, the temperate counterparts to Chir Pine (*Pinus roxburghii*) forests. They are located in western and central regions of the country and occur in usually monospecific stands. The pine stands are highly susceptible to fire. In disturbed areas of lower altitude there is a transition to mixed conifer forests – there pioneer species (early successional stadium) have competitive advantages to original species. Bumthang region is one such area. Areas are especially prone to the development of Blue pine forests after the abandonment of agricultural use.

6.1.1.2 Spruce (*Picea spinulosa*) Forests

Picea spinulosa is located higher in altitudes of 2700 – 3200 masl. These are drier versions of montane cloud forests. With an annual precipitation of 700 – 1200mm/year, precipitation is considerably lower. With increased moisture these forests give way to *Tsuga dumosa* forests, which are located in roughly the same altitude. The dominating species is *Picea spinulosa* – in eastern and central Bhutan it is often mixed with *Pinus brachytyla*, *Larix*

griffithiana, *Acer pectinatum*, *Acer cappadocicum*, *Betula utilis* and in transition to hemlock forests with *Tsuga dumosa*.

6.1.1.3 Hemlock (*Tsuga dumosa*) Forests

As already mentioned the altitudinal range of 2800 – 3300 masl is similar to the *Picea spinulosa* forests. With an annual precipitation of 1300 – 2000mm/year, these are moister sites. Normally a well-developed understorey of various bamboo species and *Rhododendron sp.* developed under a layer of dominating *Tsuga dumosa* trees. Ferns, lichens and bryophytes are common due to the high humidity. *Tsuga dumosa* dominated forests have large tracts in western, central and eastern Bhutan.

By WANGDA & OHSAWA (2006) these forests were also classified as cool, humid conifer east Himalayan forest type, with major canopy trees of *Tsuga dumosa* and *Abies densa* mixed with evergreen and deciduous broad leafed understorey.

6.1.1.4 Fir (*Abies densa*) Forests

Fir forests occupy the highest altitudes below the natural treeline. In most of the Himalayan range this is in altitudes of 3200 – 4200 masl. The precipitation exceeds 1300mm/year, of which a considerable amount is retrieved by mist condensation. The dominating species is *Abies densa* in almost pure stands – in lower altitudes mixed with *Picea spinulosa*, *Tsuga dumosa* and *Betula utilis*. Like in hemlock forests a well-developed understorey of various bamboo species, on warmer sites, and *Rhododendron sp.*, on cooler sites, is found. Near the timberline the stands are gradually dominated by *Juniperus sp.* and *Rhododendron sp.* scrub.

6.1.1.5 Alpine Scrub

Above the timberline, in altitudes of 3700 – 4600 masl, only scrubs exist. The layer is subdivided in two sub zones: the moister *Juniperus sp.* -*Rhododendron sp.* scrub and the drier Alpine scrub zone.

6.1.2 Forestry in Bhutan

72% of Bhutan is nowadays covered by forest. Due to the range of altitude and climate zones existing in the country, different forest types have developed. The lower and warmer parts are covered with broadleaf forests, while in the higher altitudes a conifer belt exists. In the conifer belt a considerable part is mixed forest. The typical conifer species in the area are *Picea spinulosa*, *Tsuga dumosa* and *Abies densa*. They are mixed with broadleaf species as e.g. *Betula utilis*, *Acer campbellii*, *Quercus semicarpifolia* and several *Rhododendron sp.* species.

The mixed forests are often in the neighbourhood of settlements and fulfil important roles in the supply of the population.

The timber is used for construction or as fire wood. Also non timber forest products, such as mushrooms, berries, resin and leaf litter manure among others, are supplied by the forests. An additional use of the forests is their function as water catchments areas for the rivers, which are recently used for the production of hydropower. This electricity is the most important export good of Bhutan today.

The forests are also used as grazing grounds by the local herders (RODER et al. 2003). The pivotal role of forest grazing for animal husbandry in Bhutan gives rise to the question, if herbivory through grazing by cattle and yak is constricting natural regeneration.

There is also a possibility that through the grazing of competing herbaceous species or undesired regeneration the desired natural regeneration is facilitated (DARABANT et al. 2007). Of course some damage by trampling or the compaction of the soil remains - the question to be answered is which effects dominate. The problem of soil compaction is not as big as in Europe, because much less animals populate the forests and the cattle races used are not as heavy.

Since the 1950's, a process started in Bhutan to regulate the forest use and put it on a scientific management basis. Before this time, forests were used according to traditional rights and practices of the local communities. With the passing of the Bhutan Forest Act in 1969 the first step to regulating the use and management of the forests was taken. In this act is codified that 60% of Bhutan's area shall remain under forest cover for all times. A further step was the introduction of the National Forest Policy in 1974. Herein ecological and economical considerations were taken into account. This policy was reformed in the 1990's by the Department of Forests. Since then, no legal forest utilization can take place without a previously approved management plan for the area in question. Nowadays a considerable part of the forest is organized in 15 Forest Management Units (FMU's). For these FMU's management plans are compiled on scientific principles, approved and controlled by a government organisation, the Forest Resources Development Division of the Department of Forests (FRDD).

Natural regeneration is favoured by the forestry department of Bhutan, as artificial regeneration has much higher costs and would probably alter the natural species composition with exotic plants or unsuitable genetic material. This would be a contradiction to the national conservation policy. Additionally, the use of artificial regeneration would require the installation of a number of forestry nurseries and to have enough site adapted planting material. In a mountainous and topographically diverse country, like Bhutan, considerable logistic problems would arise.

6.1.3 Gidakom FMU

The information of this chapter derives from the Management Plan for the Gidakom Forest Management Unit (DHITAL et al. 1992).

The Gidakom forest management unit (FMU) is one of Bhutan's forest management districts. It is located at 27°20'N latitude and 89°40'E longitude. The location is marked in *Figure 2* by a yellow flag near the capital Thimphu. The entire forest is owned by the government and under the jurisdiction of the District Forest Officer Thimphu. It has a size of roughly 13000 ha and is located to the Southwest of the capital Thimphu, between the Paro and Thimphu valleys, with parts in both political districts (Dzongkhags).

The elevation in the Gidakom FMU ranges from 2040 to 4300 masl, with an average altitude of 3400 masl. The terrain is characterised by deeply incised valleys, mainly in East – West direction, with small streams and moderate to steep slopes. The slopes are steeper in higher regions and at the bottom of the valleys.

The FMU is further separated into 12 management blocks, which are also divided into compartments and sub-compartments. The demarcation had natural terrain and water drainage features as basis. The selected management blocks for data collection of this study were Selephu and Chumithangkha with an elevation ranging from 3070 to 3360 masl. Selephu has an area of 871 ha with 4 compartments, while Chumithangkha has 2020 ha with 6 compartments.

The gradients of the slopes in this study were in an interval between 5 and 35 degrees, facing north and northeast in most cases. A few were facing northwest.

Geologically the Gidakom area is a part of the Paro formation, with crystalline limestone, quartzitic, garnetiferous mica schist, calc-silicate rocks and narrow bands of graphitic schist as well as some bodies of amphibolites/hornblende schist and quartz-pegmatite veins (DHITAL et al. 1992).

DHITAL et al. (1992) also state that the soil is predominantly well drained sandy loam in the drier blue pine areas. In the middle slopes the soil is clay loam and clayey loam. Under hardwood stands there is a thick humus layer, which is followed by a relatively shallow soil layer. All in all it can be assumed that the geological basis and the soils are suitable for sustainable forestry in the FMU.

The climate data was recorded at Chumithangkha meteorological station located in the FMU. The Temperature maxima range from 17° to 26°C, the minima are between 4° and 22°C.

The warm to hot season is from May to September. Then temperatures are dropping until they start to ascend again in January.

Rain is the common form of precipitation in the FMU, with a unimodal precipitation distribution and the peak rainfall during May, June and July. Snow occurs usually in the months of December to March. The annual average precipitation is about 561mm. In the survey area precipitation is probably higher, because the meteorological station is located at the drier valley bottom.

In January, February and November very little precipitation is recorded. During the months of December to March freezing temperatures and snowfall occur.

The relative humidity is lowest in the months of January to April. In this time there is a high danger of forest fires.

There are big differences between the microclimate in the bottom of the valley and the mountain slopes concerning temperature and precipitation – here the aspect of the slope is also of great importance.

The population in the forest unit, although small, has a considerable impact on the forest surrounding the settlement areas, particularly the transhumant fraction. Here the forest and its products are used for fuel wood, timber and about 80% of the forest area serves as grazing ground for yaks and cows.

The total growing stock in the FMU is estimated to be 2852000m³, of which 1838000m³ are located in 5605 ha accessible forest areas. The annual supply of timber and fuel wood by the FMU in the years 1987 -1991 was about 3000m³. The annual allowable cut on a sustainable basis is set to 15000m³ (DHITAL et al. 1992).

6.1.3.1 Main Forest Types in the FMU

6.1.3.1.1 Blue Pine (*Pinus wallichiana*)

It is mostly located along valley bottoms, up to 3300 masl. It occurs in pure *Pinus wallichiana* stands or in association with shrubs as well as *Quercus semicarpifolia*, *Quercus griffithii* and *Populus nigra*. On the slopes there is a gradual transition to other forest types – broadleaf, *Abies densa*, *Picea spinulosa* and *Tsuga dumosa*.

6.1.3.1.2 Mixed Conifer

They are dominated by *Picea spinulosa*, *Pinus wallichiana*, *Tsuga dumosa* and *Abies densa*, but none of these species has a percentage of more than 50%. *Picea spinulosa* is often mixed with broadleaf species and found rather in lower altitudes than *Tsuga dumosa* and *Abies densa* forests. *Tsuga dumosa* prefers higher altitudes, with a higher precipitation, and is generally in association with other coniferous species. Pure *Tsuga dumosa*, *Pinus wallichiana* and *Abies densa* patches are rare in the mixed conifer forests. This was forest type in which the plots for data collection were located.

6.1.3.1.3 Broad Leaf

The predominant species is Oak (*Quercus semicarpifolia*, *Quercus griffithii*), associated mainly with *Acer campbellii*, *Betula utilis*, *Populus nigra* and *Rhododendron sp.*.

6.1.3.1.4 Fir (*Abies densa*)

This forest type is occurring on high, forested ridges, up to the tree line. These are mainly monospecific stands with only a few *Tsuga dumosa* and *Betula utilis* trees. The dense canopy creates a humid environment with good conditions for a thick understorey of *Rhododendron sp.* and other shrubs.

The current situation in the forest unit, concerning the growing stock in the accessible forest areas, can be improved by productive and protective management. Points of concern for economic operations are overripe stands with a high rot percentage, which is a natural factor in these forests (Gratzer et al. 1997), as well as low increment and little regeneration.

The FMU also has to fulfil a role as habitat for wildlife. It provides some medical plants for practitioners of traditional medicine and edible mushrooms. These additional demands on the forest management have to be taken into consideration.

6.1.3.2 Grazing and Browsing

In the FMU exists a double grazing-pressure from cattle and yaks in summer and winter, this leads to overgrazing. Otherwise the impact of grazing does not have to be negative. Tree regeneration may be facilitated by creation of microsites and reduction of the competing herbs. The amount of grazing and damage or facilitation for certain species is topic of the study of TSHERING (2005).

There were no obvious signs of seed predation in this study, but to confirm this, the amount of dispersed seeds and the ones remaining for germination would have to be examined, because the predation by rodents, birds or other animals is not easy to detect.

6.1.3.3 Management

There is a strong demand for timber and fuel wood – even the residents of Thimphu depend partly on the fuel wood from Gidakom FMU. The demand for fuel wood and even more for timber is expected to rise, due to population growth and an expected better general income situation.

Beginning with 1977 a management plan, based on scientific principles was introduced in the FMU. All harvesting operations had to be done according to the management plan. The silvicultural system used in the mixed conifer area is a group selection system, with prescribed opening sizes of 0.1 ha in pure *Abies densa* and 0.15 ha in mixed conifer stands, but the density of natural regeneration remained low. The actual opening sizes varied and

had different sizes than prescribed in the management plan. This may be due to lack of monitoring and control by the management of the FMU. However during the time of the logging operations of the examined plots not all openings were done according to plan. DORJI (2004) found that smaller openings (< 0.2 ha) facilitated natural regeneration of shade tolerant species like *Abies densa* and *Tsuga dumosa*, while bigger openings (> 0.6 ha) were more favourable for light dependent species like *Pinus wallichiana* and *Pinus spinulosa*. The management plans intention seems to be to get regeneration of the shade tolerant species by simulating small scale natural disturbances, but DORJI found that the openings were not cut according to plan.

For the period of 2002 to 2012, the management plan for Gidakom FMU included 13100 ha, with approximately 9200 ha commercial tree species (with only 100 ha broadleaf forest). Of these, more than 60% are either under protection (this includes soil protection, stream and road buffers, wildlife and alpine protection and religious sites) or in non-production – these are inaccessible, private and cultivated lands and sokshings (forest with rights for the local population for collecting leaf litter). After all roughly 4300 ha – or one third of the total area – remain for timber production.

Harvesting in the FMU is done manually, with chain saw, and skyline gravity cable crane extraction from 4 meter wide corridors. Along these corridors are cut, in irregular distances, group selection openings with less than 0.2 ha (DEPARTMENT OF FORESTRY 2002).

Logging by cable crane is mandatory in the whole country since the Forest and Nature Conservation Act was passed in 1995, to minimize soil compaction and erosion. The logging of steep slopes is also forbidden for reasons of soil protection (FOREST AND NATURE CONSERVATION ACT 1995).

The goal of the FMU's management plan is to install a multiple use management with sustainable harvest of timber and fuel wood, watershed and habitat protection as well as the provisioning of grazing for livestock.

Additional to the different forest types, working classes have been determined with species composition, silvicultural requirements and rotation length as classification factors. In the future there could be done a description and management on stand level.

To keep a reasonable safety margin, the annual allowable cut should be lower than the estimated increment and some areas are totally excluded from harvesting. This is necessary because there is still too little information about the current status of the forests, the increment of the different species and other influential environmental factors.

Future management goals are to manage the forests on a sustainable basis. Still in such a system the goal is to maximize the yields. A vegetation cover shall be kept in the whole area for the whole year. The regeneration of the stands shall be done with natural regeneration

as far as possible. The diverse needs of the local population shall be met and a social forestry promoted. The protection areas must be maintained and damages to the ecosystem minimized.

Strategies to reduce the grazing pressure by installing pastures near villages and improve the alpine pastures are promoted.

There has been a bark beetle outbreak – mainly in spruce. The situation in the affected areas still has to be observed closely, although there are already sanitation measures implemented.

6.2 Data Collection

6.2.1 Site Selection

Sample plots in cable logging lines were selected for data collection. These cable logging lines were operated, in accordance with the management plan, in a group selection system – there had been cut small clear cuts (ranging from 0.08 ha to 0.22 ha in size) along the line to get the right amount of light and facilitate natural regeneration. From an assortment of 83 cable lines, which were operated between the years 1992 and 2002, 6 cable lines were chosen after a thorough reconnaissance survey. The crucial factors for the selection were:

- The presence of regeneration of the main conifer species
- The presence of herbaceous vegetation
- Signs of browsing and grazing in the group openings – as this was the topic of the study of TSHERING (2005), with whom I did a conjoint data collection
- Aspect

These selected cable lines had a range of aspect from NW, N, NE and E to SE. In the whole area the slopes were mainly north to northeast oriented, but we included the other aspects, even if they represented only a small part of the area, to include more site variations.

In each cable line 3 group openings in different altitudes were chosen. Whenever fitting the criteria of this study and recognisable, the sites of the data collection for DORJI`s (2004) study were included in the survey. The idea was to have comparable data from earlier surveys.

6.2.2 Plot Design

All in all 18 plots were selected. Each plot had 5 subplots – one in the estimated centre of the opening and one in each direction (N, E, S and W). This amounts to an overall sample size of 90 subplots.

The subplots were squares with a size of 2 by 2 meters (*Figure 3*). For all plots site factors were written down. These parameters were:

- Length of the opening in West East and in North South direction
- Altitude
- Aspect
- Slope gradient
- Site conditions (homo- or inhomogeneous)
- Macromorphology (upper-, mid- or lower slope, valley, etc.)
- Micromorphology (boulders, creeks, undulated, smooth)
- Signs for browsing (hoof marks, dung, trampling, browsed plants, etc.)
- Signs for human impact (burning, tracks, litter raking, etc.)

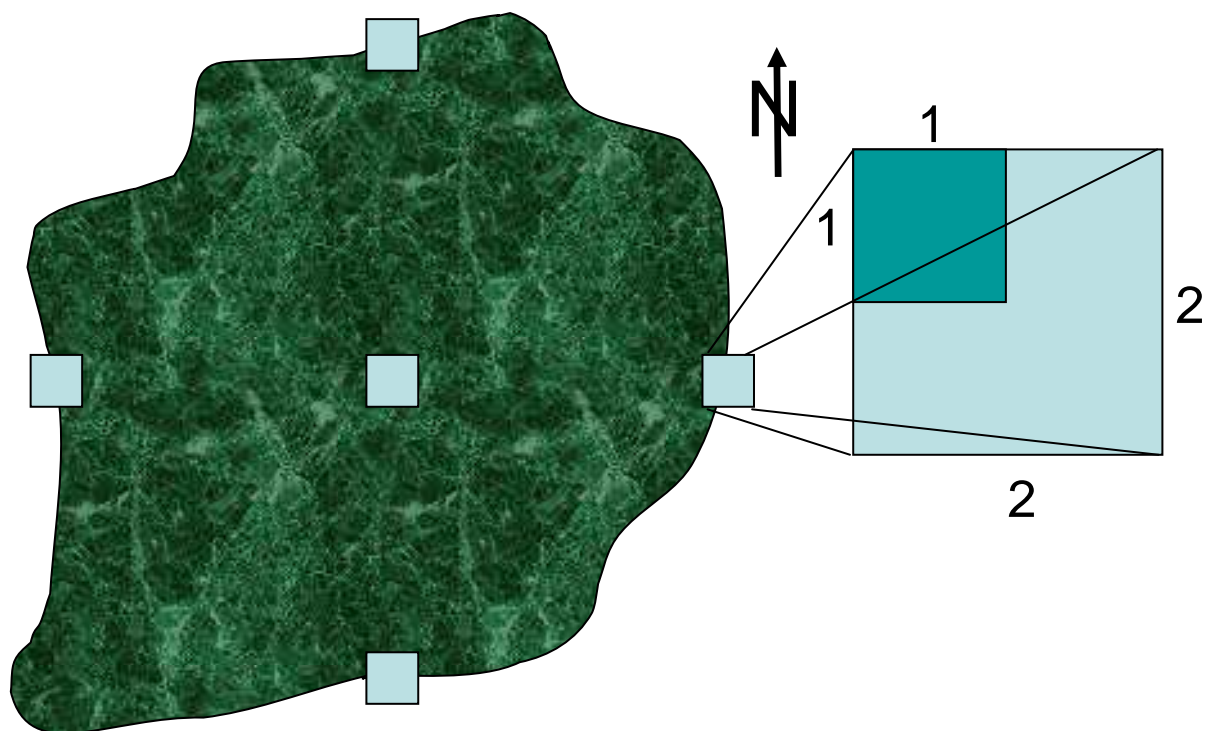


Figure 3: Plot design

6.2.3 Measurements of Tree Regeneration

In these subplot squares species was determined for all tree seedlings (less than 2 m height) and their numbers counted. They were measured for height, collar diameter and the length of the green crown. The number of branch whorls, the length of the last three terminal shoots and the vitality were also recorded. A browse class was determined to get a result for the impact of grazing. The measured variable was the reduced height of the seedling in three classes – up to 1/3, from 1/3 to 2/3 and more than 2/3 (see also TSHERING 2005). The microsites in the plots were listed. Categories were litter, mosses, bare mineral soil, nurse logs, moss logs or boulders.

We failed to record the stand structure in the respective forests for this study. By field observation it is reasonable to assume an old growth phase for the observed forests, with human made regeneration gaps through the gap selection forestry system used in the area.

6.2.4 Sampling and Measurements of Herbaceous Plants

In the subplots a square with a size of 1 by 1 meters was marked in the northwest corner. In these smaller areas all herbaceous species were determined by genera and if possible species. A confining factor was, that for the species recognition the knowledge of the field staff was the limit – they could name 95% of the plants, some even down to subspecies level. The herbs numbers were counted and the height of the tallest individual was measured. Afterwards the biomass of these smaller areas was collected.

These biomass samples were weighed and afterwards dried in a special oven until 0 % water content of the samples. Then the samples were weighed again with an accuracy of +/- 1 gram.

6.2.5 Hemispherical Photography

In the middle of the 2 by 2 meter subplots a hemispherical photograph (hemiphoto - *Figure 4*) was taken to determine the amount of light available during one years time. To get an image which is not influenced by shadows of other herbaceous plants a height of 1.20m was chosen as base level for the photographs. Although the weather conditions were a bit problematic, due to rain and mist, all of the hemiphotos produced results that could be used for further data analysis.

By the method of computerised image analysis of hemispherical photographs the amount of radiation can be determined in one place. This method had been proven to have considerable advantages over other methods like short term measurements of radiation, e.g. photosynthetically active radiation (PAR) – using sensor technology.

Hemispherical photography has been used with good results in other studies to examine and quantify the light regime under forest canopies, e.g. DARABANT et al. (2001). To make a computerised analysis of the pictures possible, the exact location of the edge of the canopy surrounding the sample plot has to be known. For this purpose a wide angle 180° lens is used in the camera, which additionally has to be levelled horizontal by the help of a bubble level. The camera must also be orientated to the north. This is done by magnetic compass and the declination is afterwards used in the computer program to get the right alignment. The cameras lens aperture was set on infinite. To get a clear distinction between sky and canopy leafs and branches, it is necessary to avoid sunlight reflections from the stem and leafs. That means overcast skies are the most favourable conditions. If such conditions are

not present you need to take pictures early morning or late in the evening to make use of the low angle of the sun above the horizon. In the case of this study the sky was clouded nearly all the time, and if there was no rain, the conditions were perfect. To maximise the contrast between sky and plant material, black and white film with an ISO value of 400 was used, which was further pushed to an ISO value of 800 during the development process. The fish eye lens of the camera used equiangular projection – the zenith angle and the length of a radial line are proportional – like most wide angle lenses do. To make a clear identification of the hemiphotos possible, a data back was used with the camera and thereby the pictures were numbered.



Figure 4: Example of a hemispherical photograph

6.2.6 Inventory Data

To get a broader data basis, the data generated in an inventory by RNR Jakar and RNR Yusipang in collaboration with the CORET project in the summer of 2004 was also used for data analysis.

The team of the inventory group selected 39 group openings in 20 cable lines. The inventory was conducted in the Chamgang FMU and also in the Gidakom FMU and the method for data collection was similar to the one used for the data collection in this study. In each plot 5 subplots, with one in the centre and in each orientation, were installed. Microsites as well as species of tree regeneration and herbaceous plants were determined. A difference was that not the individuals, but cover percentages of the different plant species were recorded. For the tree seedlings the height was measured and the microsite listed. Site parameters were also recorded. These were topography, aspect, altitude, slope (in percent), soil moisture, soil nutrients, slope position, size of the opening, grazing intensity (low, medium, heavy) and cover percentage of the overstorey. The list of recorded parameters can be found in *Annex 26* and *Annex 27*.

6.3 Data Analysis

Microsoft Excel was used for the data recording and arrangement. Some analysis and graphics were also generated in Excel. Further analysis and statistical analysis was conducted with SPSS version 12.0. For the arrangement and analysis of the hemiphotos Hemiview version 1.2 was used.

6.3.1 Hemispherical Photographs

The hemiphotos were analysed with Hemiview 1.2. At first the right amount of contrast had to be chosen for each photo. This was done all by one person to reach as much continuity as possible. Then a selection of variables was calculated by the computer programme, the most important one for this study being the global site factor (GSF). The site specific information used for analysis is presented in *Annex 25*.

6.3.2 GSF Value

Based on the assumption that canopy gaps do not impede the direct and indirect solar radiation, it was possible to measure the amount of light in the subplots by hemiphotos. The reflected part of solar radiation was not included in the analysis. As the examined species in the herb layer are very near to the ground, this seemed to be a negligible part of radiation and the measurement would have been very difficult.

By the evaluation and analysis of the hemiphotos the direct site factor (DSF), which is calculated by intercepting solar tracks – the path of the sun over one particular place – with the interfering canopy, is the proportion of direct solar radiation. It can be calculated for a whole year, if the exact location and height of the photo is known, because it is possible to calculate solar tracks for every geographically point and every altitude on every day of the year for the whole planet earth.

The indirect site factor (ISF) is the amount of diffuse solar radiation. It is calculated by dividing the sky into segments and intersecting these segments with the canopy. At the moment two models exist to calculate the diffuse amount of light. Unfortunately none of the two gives a perfect reproduction of the diffuse light (RICH 1990), but these are models and at the moment the only ones that are available. One is the uniform overcast sky model (UOC), which assumes that the diffuse radiation is the same in every sky direction. The second is the standard overcast sky model (SOC). This uses the zenith angle to determine the amount of radiation, with a decreasing amount of radiation for the bigger angles which are nearer to the horizon. For this analysis the UOC model was chosen.

The global site factor (GSF) value, which is a combination of DSF and ISF, was used in the study for determining the amount of radiation. By integration the total amount of solar

radiation is calculated – minus the reflected sunlight. The GSF was chosen as the best available method for looking for an influence of light on the herbaceous plant layer.

6.3.3 Plant Sample Data

The data of the Chamgang Gidakom Inventory was available in a Microsoft Access file. This data was imported into Excel, compiled and sorted and afterwards converted into SPSS data sheets.

The plot data taken for this study was paper recorded field data of the herbaceous plants. This was put into Excel sheets, if necessary put in a usable order and afterwards also converted into SPSS data sheets.

6.3.4 SPSS Analysis

6.3.4.1 Descriptive Statistics

The first step was to get an overview of the data structure. For this purpose and to detect eventual outliers the descriptive statistics in SPSS was used. Some scatter plots of the inventory data and the plot data were created. A special focus was laid upon the site factors, the GSF value, the collected biomass, the most important competing herbs species – determined by the biggest numbers and size of the plants – and the regeneration of the economically most important tree species. Box plots and histograms including the curve of normal distribution were also drawn. To check the normal distribution of the variables, Q-Q plots were drawn and Kolmogorov-Smirnov tests were conducted. The descriptive statistics were calculated. Those included the mean value, its standard error, standard deviation, variance and minimum respectively maximum values.

6.3.4.2 Correlation Analysis

The next step was to find some correlations between the GSF value, the site factors and the competing herbs respectively the tree regeneration with linear regressions. This produced only weakly correlated and only in few cases significant results. Therefore other nonlinear regression possibilities were analysed. In this area the results were also not satisfactory. A different approach was taken. A correlation analysis was conducted on the variables mentioned above and on the different locations in the gaps, represented by the orientation of the subplots – the thresholds for significance were a demanding 1% and 5%.

6.3.4.3 Factor Analysis

There are two main reasons to apply a factor analysis. The first is to reduce a big set of variables to get more efficient analysis results, of following tests, from uncorrelated factors.

For this purpose a principal component analysis is used. This method looks for unrelated components, which are designed to represent as much variance of the original variables as possible. In most cases, a few factors account for most of the variance and the variables can be replaced by their factor scores, thereby reducing the number of variables in following tests.

The second reason is to detect underlying structures and relations in a set of variables. For this mainly the principal axis analysis is used. This analysis assumes that some of the variation cannot be explained by the factors, but with the representation through the factors underlying relations may be detected.

In this study, factor analysis was used to get more insight in the structure of the data set. This analysis can help to determine the factors with the most influence on certain parameters. In a situation with many variables and when it is not exactly clear how they influence each other it can be used to minimise the variables that have to be investigated (BACKHAUS 2006).

As the number of variables had already been reduced on the basis of frequency and plant size, but there was still not known much about the relationship between the variables - although there were some anticipations - the second method was more valuable for the studies purpose.

There have arisen two main questions: "How many factors are needed to represent the original data sufficiently?" and "What do the underlying factors represent, which are the results of the analysis?"

The question of how many factors are needed was solved by the help of a screeplot. Here the variance accounted for by each factor is plotted and usually there is a break in the curve between the factors on the steep side of the slope and the rest. The factors on the steep slope are kept.

In addition to the normal principal axis analysis, the possibility to use a rotation in the analysis exists. By this method the distance in the coordination system from the variables to the component axis is minimised through rotation of the coordinate system. For this purpose exist also different methods.

In this study the orthogonal Varimax rotation was chosen, which minimises the number of variables with high loadings on each factor. This makes the interpretation of the factors easier. Another option was the Quartimax rotation. It minimises the factors needed to explain each variable, thereby simplifying the interpretation of the observed variables. But for this case it was known what the variables were. The underlying process was the question. The Equimax rotation is a combination of Varimax and Quartimax, but still the Varimax rotation was chosen, as it did fit the purpose of the study in a better way.

To get usable results the utilised variables had to be standardised. That also equalises the variance and therefore a correlation matrix, which is used if the variables in the analysis are measured on different scales, could be used for the factoranalysis.

6.3.4.4 Cluster Analysis

To form groups out of the site factors and vegetation species a hierarchical clusteranalysis was used. As squared distances were used for the algorithm, the Ward method was used to minimise the effect that evenly sized groups are generated. In the Ward method the increase of the variance in the groups by new group members is minimised. The analysis clustered the cases with the site factor, GSF values, the collected biomass, the most important competing herbs and the important tree regeneration as variables.

6.3.4.5 Discriminant Analysis

The resulting groups were analysed by discriminance analysis for significant differences between these groups. As variables were again used the site factors and the tree regeneration. Thereby could be tested the grade of suitability of the variables for the clusteranalysis.

7 Results

7.1 The Strongest Herbaceous Competitors for the Tree Regeneration

7.1.1 Inventory Data

Based on the descriptive statistics – the maximum number and the standard deviation of the competing herbaceous species were the most influencing factors for the abundance of tree regeneration – the species for the further analysis were selected. The basic statistical values for the selected species are displayed in *Annex 1* and *Annex 2*. For the herbaceous competing species the following were selected: *Artemisia moorcroftiana*, *Osmunda sp.*, *Salvia sp.*, *Sambucus adnata*, *Senecio graciliflorus*, *Wulfenia abliqua*, *Yushania microphylla* and the overall count of all herbaceous species together denominated Total herbs. To make reading easier, *Yushania microphylla* is included, if the competing herbs are mentioned in the following, although it is a grass.

For the regeneration the targeted species were in conifers *Abies densa*, *Tsuga dumosa*, *Picea spinulosa* and *Pinus wallichiana*, in broadleaves *Acer campbellii* and *Betula utilis*. The total numbers of the overall selected regeneration – Regeneration total – had also been appropriated.

The skewness of the distributions of the competing vegetation, and even more so for the tree regeneration, indicates that none of them is normally distributed. The normal distribution of residuals is a requirement for some statistical methods, like a regression analysis, and therefore important for the following analysis. Only the total number of herbaceous species seems to resemble a normal distribution. This may also be the case because of a small sample size for the single selected species.

As indicated by the descriptive statistics table (*Annex 1* and *Annex 2*) the drawn Q-Q plots and the Kolmogorov-Smirnov, respectively the Shapiro-Wilks tests, showed no normal distribution of the data.

Because the residuals for the dependent variables of the competing herbs and the tree regeneration did not follow a normal distribution a linear regression was not possible, as one of the assumptions for a linear regression is the normal distribution of the residuals of the dependent variables.

A different approach was taken. Correlation analysis was used on the variables mentioned above and on the different locations in the gaps represented by the orientation of the subplots.

Table 1: Correlations Herbs / Tree Species - Inventory Data

	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Pinus wallichiana</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	Total Regeneration	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
<i>Acer campbellii</i>		n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Betula utilis</i>	n.s.		n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Pinus wallichiana</i>	n.s.	n.s.		n.s.	n.s.	+	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Abies densa</i>	n.s.	n.s.	n.s.		+	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	-
<i>Tsuga dumosa</i>	n.s.	n.s.	n.s.	+		+	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-
<i>Picea spinulosa</i>	n.s.	n.s.	+	n.s.	+		+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Total Regeneration	+	+	+	+	+	+		n.s.	n.s.	-	-	n.s.	n.s.	n.s.	-
<i>Artemisia moorcroftiana</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	+	n.s.	n.s.	n.s.	-	+
<i>Osmunda sp.</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	-	+
<i>Salvia sp.</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	+	n.s.		n.s.	n.s.	n.s.	-	+
<i>Sambucus adnata</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.		n.s.	-	-	+
<i>Senecio graciliflorus</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	-	n.s.
<i>Wulfenia abliqua</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	n.s.		+	+
<i>Yushania microphylla</i>	n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.	-	-	-	-	-	+		+
Total Herbs	n.s.	n.s.	n.s.	-	-	n.s.	-	+	+	+	+	n.s.	+	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

The correlation chart (*Annex 5*) indicates only weak correlations overall, because even the significant ones have Pearson Correlation Factors nearly always below +/- 0.25 of +/- 1.00 possible values.

The correlation analysis with the site factors, tree regeneration and the selected competing herbs have shown for the Inventory data the following significant correlations between the herbaceous and the tree regeneration species.

The total number of herbs is positively correlated with all selected competing herbs (*Table 2*), with the exception of *Senecio graciliflorus*. The positive correlation of *Artemisia moorcroftiana* and *Salvia sp.* leads to an also high cover percentage for the total number of herbs as these two species have large leaves. For *Yushania microphylla* negative correlations exist with all selected competing herbaceous species, with the exception of *Wulfenia abliqua*.

Table 2: Correlations Herbs – Inventory Data

	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
<i>Artemisia moorcroftiana</i>		n.s.	+	n.s.	n.s.	n.s.	-	+
<i>Osmunda sp.</i>	n.s.		n.s.	n.s.	n.s.	n.s.	-	+
<i>Salvia sp.</i>	+	n.s.		n.s.	n.s.	n.s.	-	+
<i>Sambucus adnata</i>	n.s.	n.s.	n.s.		n.s.	-	-	+
<i>Senecio graciliflorus</i>	n.s.	n.s.	n.s.	n.s.		n.s.	-	n.s.
<i>Wulfenia abliqua</i>	n.s.	n.s.	n.s.	-	n.s.		+	+
<i>Yushania microphylla</i>	-	-	-	-	-	+		+
Total Herbs	+	+	+	+	n.s.	+	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

The overall regeneration is correlated positively (*Table 3*) with all tree regeneration species – the strongest correlations exist with *Tsuga dumosa* and *Abies densa*. These are the two most abundant tree regeneration species. A negative correlation was noted with *Salvia sp.*, *Sambucus adnata* and the total number of herbs (*Table 1*).

Abies densa is negatively correlated with *Yushania microphylla* and the total number of herbs. The total number of herbs is also negatively correlated with *Tsuga dumosa*. For *Pinus wallichiana* no significant correlation could be noted with the herbaceous species. The same

holds true for *Picea spinulosa*. For the other selected herbaceous competitors no significant correlations were found for the tree regeneration.

Acer campbellii and *Betula utilis* have only one significant correlation with the overall regeneration.

Table 3: Correlations Tree Species – Inventory Data

	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Pinus wallichiana</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	Total Regeneration
<i>Acer campbellii</i>		n.s.	n.s.	n.s.	n.s.	n.s.	+
<i>Betula utilis</i>	n.s.		n.s.	n.s.	n.s.	n.s.	+
<i>Pinus wallichiana</i>	n.s.	n.s.		n.s.	n.s.	+	+
<i>Abies densa</i>	n.s.	n.s.	n.s.		+	n.s.	+
<i>Tsuga dumosa</i>	n.s.	n.s.	n.s.	+		+	+
<i>Picea spinulosa</i>	n.s.	n.s.	+	n.s.	+		+
Total Regeneration	+	+	+	+	+	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

To further investigate the correlations between the variables a principal axis factor analysis with Varimax rotation and standardised values was conducted.

For the first factor given in the factor matrix for the Inventory data (Table 12) *Abies densa* and *Tsuga dumosa* are loading highly, while *Yushania microphylla*, *Salvia sp.* and *Sambucus adnata* have the most negative loadings. Factor 2 has high loadings for *Artemisia moorcroftiana* and *Salvia sp.*. The most negative loadings were found for *Yushania microphylla* and *Picea spinulosa*. For Factor 3 positive loadings can be seen for *Osmunda sp.* and *Yushania microphylla*, with a strong negative loading for *Sambucus adnata*. Factor 4 is loading negatively for *Senecio graciliflorus*, *Osmunda sp.* and *Abies densa* – positively for *Yushania microphylla*. The last given Factor 5 has the strongest positive loadings for the broadleaf species *Betula utilis*, *Acer campbellii* and *Picea spinulosa* as well as *Osmunda sp.*, with negative loadings for *Senecio graciliflorus*, *Yushania microphylla* and *Artemisia moorcroftiana*.

The screeplot (Figure 5) suggests the use of two factors with an explained variance of roughly 25% for the Initial Eigenvalues and 12% for the rotated solutions (Table 12). But for the selected vegetation variables, especially for *Tsuga dumosa*, *Abies densa*, *Yushania*

microphylla, *Sambucus adnata*, *Salvia sp.*, *Senecio graciliflorus* and *Artemisia moorcroftiana* the representation of the cover percentages for each species by the factors is better. A detailed view is presented in the communalities table (*Table 11*).

7.1.2 Plot Data

For the recorded Plot data the same descriptive statistics methods were used and similar results were the outcome, as can be seen in *Annex 3* and *Annex 4*. In the end a pool of species was selected for further analysis, containing the same species mentioned above, with the exception of *Pinus wallichiana*, which did not occur in the survey area for the Plot data.

The resemblance to a normal distribution is even lower than in the Inventory data – probably because the sample size is also smaller. Only the distribution for the occurrence of the total number of herbs shows a normal distribution. At species level, no normal distribution seems to exist. Nearly the same results as for the competing herbs were found for the tree regeneration. Only for the tree seedlings of all species altogether seems a normal distribution to be possible – although the correlation is weak.

A similar correlation analysis as for the Inventory data was done with the selected competing herbaceous species and the relevant tree regeneration for the Plot data (*Annex 6*). The correlations between xxx and yyy were not strong (Pearson Correlation Factor below 0.30), although there were more strong relations than in the Inventory data.

Artemisia moorcroftiana is correlated positively with the additional variable of biomass (*Table 6*), underlining its importance as competitor species, negatively with the total number of competing herbs. *Sambucus adnata* is also positively correlated with biomass. *Yushania microphylla* is positively correlated with the total number of herbs (*Table 4*), but has a negative correlation with biomass.

The total number of competing herbs is positively correlated with *Osmunda sp.*, *Senecio graciliflorus* and *Yushania microphylla*. Negative correlations exist with altitude and the opening area.

No negative correlations between the tree regeneration and the selected competitors were found.

Abies densa is positively correlated with all tree regeneration species (*Acer campbellii*, *Betula utilis*, *Tsuga dumosa*, *Picea spinulosa* and the overall regeneration) and vice versa (*Table 5*), negatively with biomass and GSF values.

Tsuga dumosa is correlated positively with *Salvia sp.*. For *Picea spinulosa* also no significant correlation was found with the competing herbs. *Acer campbellii* is positively correlated with *Salvia sp.* and *Wulfenia abliqua*. It is also negatively correlated with the

opening area and the GSF values. *Betula utilis* is correlated positively with *Wulfenia abliqua* and negatively with the GSF values.

Table 4: Correlations Herbs- Plot Data

	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	<i>Total Herbs</i>
<i>Artemisia moorcroftiana</i>		n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.
<i>Osmunda sp.</i>	n.s.		n.s.	n.s.	+	n.s.	+	+
<i>Salvia sp.</i>	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.
<i>Sambucus adnata</i>	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
<i>Senecio graciliflorus</i>	-	+	n.s.	n.s.		n.s.	+	+
<i>Wulfenia abliqua</i>	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.
<i>Yushania microphylla</i>	n.s.	+	n.s.	n.s.	+	n.s.		+
Total Herbs	n.s.	+	n.s.	n.s.	+	n.s.	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

Table 5: Correlations Tree Species - Plot Data

	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	Total Regeneration
<i>Acer campbellii</i>		+	+	+	n.s.	+
<i>Betula utilis</i>	+		+	+	n.s.	+
<i>Abies densa</i>	+	+		+	+	+
<i>Tsuga dumosa</i>	+	+	+		n.s.	+
<i>Picea spinulosa</i>	n.s.	n.s.	+	n.s.		+
Total Regeneration	+	+	+	+	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

The total tree regeneration is negatively correlated with biomass and the GSF values (Table 7).

For the Plot data also a further factor analysis was done. The same procedure – a principal axis factor analysis with Varimax rotation and standardised values was chosen. The selection of the method and description can be found in Materials and Methods (Factor Analysis).

If you look at Factor 1 of the analysis in the rotated factor matrix (*Table 16*) *Abies densa* and *Picea spinulosa* have a very high positive loading, with low negative values for *Artemisia moorcroftiana*, *Osmunda sp.* and *Yushania microphylla*. Factor 2 is loading very highly for *Betula utilis*, highly for *Wulfenia abliqua*, *Acer campbellii*, *Abies densa* and *Tsuga dumosa*. The highest negative value is for *Yushania microphylla* and this is still low in comparison to the positive loadings. Factor 3 has high loadings for *Acer campbellii*, *Salvia sp.* and *Tsuga dumosa*, negative ones for *Senecio graciliflorus* and *Yushania microphylla*. For Factor 4 the positive loadings of *Yushania microphylla*, *Senecio graciliflorus* and *Osmunda sp.* are relatively high with a moderately high negative loading for *Artemisia moorcroftiana*. Factor 5 has also only moderate loadings. The highest loadings on the positive side are for *Sambucus adnata*, *Senecio graciliflorus* and *Tsuga dumosa*. On the negative side *Yushania microphylla*, *Artemisia moorcroftiana*, *Wulfenia abliqua* and *Acer campbellii* have to be mentioned.

Like for the Inventory data the screeplot (*Figure 6*) implies a two factor solution. This means that a third of the variance of the Initial Eigenvalues and 22% variance of the rotated solution are explained by the factors.

For the single variables, which are the individual numbers of the competing herbaceous and tree regeneration species, the representation by the factors is better. The communalities table (*Table 15*) shows especially good values for *Abies densa*, *Betula utilis*, *Acer campbellii*, *Picea spinulosa*, *Salvia sp.*, *Senecio graciliflorus* and *Yushania microphylla*.

Table 6: Correlations Site Factors / Herbs - Plot Data

	<i>Altitude (masl)</i>	<i>Gradient (deg)</i>	<i>Opening area (m2)</i>	<i>Biomass dry (g)</i>	<i>GSF value</i>	<i>Aspect N (gon)</i>	<i>Aspect E (gon)</i>	<i>Aspect S (gon)</i>	<i>Aspect W (gon)</i>	<i>Aspect Flat (gon)</i>	<i>Artemisia moorcrof tiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflor us</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphyl la</i>	<i>Total Herbs</i>
<i>Altitude (masl)</i>		n.s.	+	n.s.	n.s.	n.s.	+	n.s.	-	n.s.	n.s.	-	-	n.s.	n.s.	n.s.	n.s.	-
<i>Gradient (deg)</i>	n.s.		-	n.s.	n.s.	n.s.	n.s.	+	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Opening area (m2)</i>	+	-		n.s.	n.s.	n.s.	+	n.s.	-	n.s.	n.s.	-	-	n.s.	n.s.	n.s.	n.s.	-
<i>Biomass dry (g)</i>	n.s.	n.s.	n.s.		+	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	+	n.s.	n.s.	-	n.s.
<i>GSF value</i>	n.s.	n.s.	n.s.	+		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.
<i>Aspect N (gon)</i>	n.s.	n.s.	n.s.	n.s.	n.s.		-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect E (gon)</i>	+	n.s.	+	n.s.	n.s.	-		n.s.	n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect S (gon)</i>	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect W (gon)</i>	-	n.s.	-	n.s.	n.s.	-	n.s.	n.s.		n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	+
<i>Aspect Flat (gon)</i>	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Artemisia moorcrof tiana</i>	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	+	n.s.	n.s.		n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.
<i>Osmunda sp.</i>	-	n.s.	-	n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	+	n.s.	+	+
<i>Salvia sp.</i>	-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.
<i>Sambucus adnata</i>	n.s.	n.s.	n.s.	+	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
<i>Senecio graciliflor us</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	+	n.s.	n.s.		n.s.	+	+
<i>Wulfenia abliqua</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.
<i>Yushania microphyl la</i>	n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	+	n.s.		+
Total Herbs	-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	+	n.s.	n.s.	+	n.s.	+	

Note: n. s. indicates non significant relationships at p > 0.05

Table 7: Correlation Site Factors / Tree Species - Plot Data

	<i>Altitude (masl)</i>	<i>Gradient (deg)</i>	<i>Opening area (m2)</i>	<i>Biomass dry (g)</i>	<i>GSF value</i>	<i>Aspect N (gon)</i>	<i>Aspect E (gon)</i>	<i>Aspect S (gon)</i>	<i>Aspect W (gon)</i>	<i>Aspect Flat (gon)</i>	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	<i>Total Regener- ation</i>
<i>Altitude (masl)</i>		n.s.	+	n.s.	n.s.	n.s.	+	n.s.	-	n.s.	-	n.s.	+	n.s.	+	n.s.
<i>Gradient (deg)</i>	n.s.		-	n.s.	n.s.	n.s.	n.s.	+	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Opening area (m2)</i>	+	-		n.s.	n.s.	n.s.	+	n.s.	-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Biomass dry (g)</i>	n.s.	n.s.	n.s.		+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	n.s.	n.s.	-
<i>GSF value</i>	n.s.	n.s.	n.s.	+		n.s.	n.s.	n.s.	n.s.	n.s.	-	-	-	n.s.	n.s.	-
<i>Aspect N (gon)</i>	n.s.	n.s.	n.s.	n.s.	n.s.		-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect E (gon)</i>	+	n.s.	+	n.s.	n.s.	-		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect S (gon)</i>	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect W (gon)</i>	-	n.s.	-	n.s.	n.s.	-	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect Flat (gon)</i>	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	+	n.s.	n.s.	n.s.	n.s.
<i>Acer campbellii</i>	-	n.s.	-	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.		+	+	+	n.s.	+
<i>Betula utilis</i>	n.s.	n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.	n.s.	+	+		+	+	n.s.	+
<i>Abies densa</i>	+	n.s.	n.s.	-	-	n.s.	n.s.	n.s.	n.s.	n.s.	+	+		+	+	+
<i>Tsuga dumosa</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	+	+		n.s.	+
<i>Picea spinulosa</i>	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.		+
<i>Total Regeneration</i>	n.s.	n.s.	n.s.	-	-	n.s.	n.s.	n.s.	n.s.	n.s.	+	+	+	+	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

7.1.3 Aggregation

In the aggregation the corresponding findings for the Inventory and Plot data are listed, as they are of more general relevance.

The found correlations were generally weak, with low Pearson correlations. For the Plot data the representation of the abundance of the species by the factors was slightly better than for the Inventory data with a few really strongly related exceptions. It was not possible to combine the data of the Inventory and the Plot data, because in the Inventory data the competing herbs were recorded as estimated cover percentages, while the herbaceous species in the Plot data were counted individually.

7.2 The Differences in Site Demands of the Herbaceous Competitors and the Regeneration

7.2.1 Inventory Data

In the descriptive statistics analysis for the site factors altitude, gradient, opening area and the groups of different aspect also no normal distribution could be proven with the Kolmogorov-Smirnov test, but the Q-Q plots showed a good approximation of a normal distribution. The exception to this was the variable of aspect, which had to be grouped into one variable per orientation.

Out of the following correlation analysis for the Inventory data (*Annex 5*) the correlations given below were found.

The positive correlations between altitude and the S and W aspects (*Table 8*) as well as between gradient and the S and W aspects show topographical properties of the data collection area. The same applies for the negative correlations between altitude and E aspect as well as for gradient and the N and E aspects. Altitude and the opening area correlated negatively – maybe the openings are smaller in higher regions due to technical reasons of harvesting, but the overall difference in altitude was rather small. For the opening area were found negative correlations with *Tsuga dumosa* and the total regeneration. S aspect correlates negatively with *Artemisia moorcroftiana*, *Salvia sp.*, *Sambucus adnata*, *Senecio graciliflorus*, *Abies densa* and the total regeneration. The flat aspect produces no significant correlations whatsoever, due to very low numbers of occurrence.

The total number of herbs is positively correlated (*Table 9*) with gradient, the opening area, S aspect, W aspect and with all selected competing herbs, with the exception of *Senecio graciliflorus*. It is negatively correlated with E aspect.

Table 8: Correlation Site Factors / Tree Species – Inventory Data

	<i>Altitude (masl)</i>	<i>Gradient (deg)</i>	<i>Opening area (m2)</i>	<i>Aspect N (gon)</i>	<i>Aspect E (gon)</i>	<i>Aspect S (gon)</i>	<i>Aspect W (gon)</i>	<i>Aspect Flat (gon)</i>	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Pinus wallichiana</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	<i>Total Regeneration</i>
<i>Altitude (masl)</i>		n.s.	-	n.s.	-	+	+	n.s.	n.s.	n.s.	-	+	n.s.	n.s.	n.s.
<i>Gradient (deg)</i>	n.s.		n.s.	-	-	+	+	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Opening area (m2)</i>	-	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	n.s.	-
<i>Aspect N (gon)</i>	n.s.	-	n.s.		-	-	-	-	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.
<i>Aspect E (gon)</i>	-	-	n.s.	-		-	-	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect S (gon)</i>	+	+	n.s.	-	-		-	n.s.	n.s.	n.s.	n.s.	-	n.s.	n.s.	-
<i>Aspect W (gon)</i>	+	+	n.s.	-	-	-		-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect Flat (gon)</i>	n.s.	n.s.	n.s.	-	-	n.s.	-		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Acer campbellii</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	+
<i>Betula utilis</i>	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	+
<i>Pinus wallichiana</i>	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	+	+
<i>Abies densa</i>	+	n.s.	n.s.	+	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.		+	n.s.	+
<i>Tsuga dumosa</i>	n.s.	n.s.	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+		+	+
<i>Picea spinulosa</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	+		+
<i>Total Regeneration</i>	n.s.	n.s.	-	n.s.	n.s.	-	n.s.	n.s.	+	+	+	+	+	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

Table 9: Correlations Site Factors / Herbs– Inventory Data

	<i>Altitude (masl)</i>	<i>Gradient (deg)</i>	<i>Opening area (m2)</i>	<i>Aspect N (gon)</i>	<i>Aspect E (gon)</i>	<i>Aspect S (gon)</i>	<i>Aspect W (gon)</i>	<i>Aspect Flat (gon)</i>	<i>Artemisia moorcroft iana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio gracili florus</i>	<i>Wulfenia abliqua</i>	<i>Yushania micro phylla</i>	<i>Total Herbs</i>
<i>Altitude (masl)</i>		n.s.	-	n.s.	-	+	+	n.s.	+	n.s.	-	n.s.	n.s.	n.s.	n.s.	-
<i>Gradient (deg)</i>	n.s.		n.s.	-	-	+	+	n.s.	n.s.	n.s.	n.s.	-	-	n.s.	+	n.s.
<i>Opening area (m2)</i>	-	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect N (gon)</i>	n.s.	-	n.s.		-	-	-	-	+	+	+	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Aspect E (gon)</i>	-	-	n.s.	-		-	-	-	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.
<i>Aspect S (gon)</i>	+	+	n.s.	-	-		-	n.s.	-	n.s.	-	-	-	n.s.	+	n.s.
<i>Aspect W (gon)</i>	+	+	n.s.	-	-	-		-	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.
<i>Aspect Flat (gon)</i>	n.s.	n.s.	n.s.	-	-	n.s.	-		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Artemisia moorcroftiana</i>	+	n.s.	n.s.	+	n.s.	-	n.s.	n.s.		n.s.	+	n.s.	n.s.	n.s.	-	+
<i>Osmunda sp.</i>	n.s.	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	-	+
<i>Salvia sp.</i>	-	n.s.	+	+	n.s.	-	n.s.	n.s.	+	n.s.		n.s.	n.s.	n.s.	-	+
<i>Sambucus adnata</i>	n.s.	-	n.s.	n.s.	n.s.	-	+	n.s.	n.s.	n.s.	n.s.		n.s.	-	-	+
<i>Senecio graciliflorus</i>	n.s.	-	n.s.	n.s.	+	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	-	n.s.
<i>Wulfenia abliqua</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	n.s.		+	+
<i>Yushania microphylla</i>	n.s.	+	n.s.	n.s.	n.s.	+	n.s.	n.s.	-	-	-	-	-	+		+
<i>Total Herbs</i>	-	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	+	+	+	n.s.	+	+	

Note: n. s. indicates non significant relationships at p > 0.05

Artemisia moorcroftiana is positively correlated with altitude, N aspect, *Salvia sp.* and the total number of herbs. A negative correlation exists with S aspect and *Yushania microphylla*.

Osmunda sp. has positive correlations with the total number of herbs and N aspect. A negative correlation with *Yushania microphylla* is another similarity to *Artemisia moorcroftiana* and *Salvia sp.*.

Salvia sp. is positively correlated with N aspect, the opening area, the total number of herbs and *Artemisia moorcroftiana*. A negative correlation exists with S aspect, altitude and *Yushania microphylla*.

Sambucus adnata is positively correlated with W aspect and the total number of herbs, negatively with gradient, S aspect, *Wulfenia abliqua* and *Yushania microphylla*.

Senecio graciliflorus is positively correlated with E aspect. This is the aspect with which the total number of herbs is negatively correlated. *Senecio graciliflorus* is the only one of the selected competitors which is not positively correlated with the total number of herbs. Negative correlations exist with gradient, S aspect and *Yushania microphylla*.

Wulfenia abliqua has only the positive "standard" correlation with the total number of herbs and a single negative one with *Sambucus adnata*. It is the only species not negatively correlated with *Yushania microphylla*.

Yushania microphylla is positively correlated with gradient, S aspect and the total number of herbs. Negative correlations exist with all selected competing herbaceous species, with the exception of *Wulfenia abliqua*.

The overall tree regeneration is correlated positively with all tree species. Negative correlations were found with the opening area, S aspect, *Salvia sp.* and the total number of herbs.

Abies densa is positively correlated with altitude, N aspect and strongly with *Tsuga dumosa* and the overall tree regeneration. It is negatively correlated with S aspect. For *Yushania microphylla* and the total number of herbs was found a negative correlation with *Abies densa*.

Tsuga dumosa is positively correlated with *Abies densa*, *Picea spinulosa* and very strongly with the overall tree regeneration. The number of total competing herbs and also the opening area are negatively correlated with *Tsuga dumosa*.

Pinus wallichiana is negatively correlated with altitude and positively with *Picea spinulosa* and the overall tree regeneration. For the herbaceous species, no significant correlation could be noted with *Pinus wallichiana*.

The same holds true for *Picea spinulosa*, which is positively correlated with *Tsuga dumosa*, *Pinus wallichiana* and also with the overall tree regeneration.

Acer campbellii has only one significant correlation with the overall tree regeneration.

Betula utilis is positively correlated with gradient and the overall tree regeneration.

To further investigate the relations between the variables, a principal axis factor analysis with Varimax rotation and standardised values was conducted. The reasons for the selection of the method were already given in Materials and Methods (Factor Analysis). The following plausibility tests are included in the factor analysis.

The Kaiser-Meyer-Olkin measure (KMO) of sampling adequacy (*Table 10*) is a statistical value that represents the part of the variance of the selected variables that can be explained by underlying factors. It should be close to 1 for good expected results from the factor analysis, if it is below 0.5 the factor analysis will probably yield no good results. In this case, the KMO value is 0.52 and therefore closer to 0.5 than to 1.

Table 10: KMO and Bartlett's Test - Factor Analysis Inventory Data

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.52
Bartlett's Test of Sphericity	Approx. Chi-Square	199.30
	df	66
	Sig.	0.00

The second test is the Bartlett's test of sphericity. It tests the relation between the selected variables. If the test is significant - like in this case with a significance value of 0.0 – the factor analysis may be useful, because the variables are related.

The anti-image-covariance and anti-image-correlation table (*Annex 8*) shows the correlations between the used variables in the same way as in the correlation analysis done before. The values in the diagonal of the matrix show the measures of sampling adequacy (MSA) and should be more than 0.5 – if not it indicates that the used variables are not fitting with the other variables and should maybe be excluded from the tests. Values of the diagonal should be close to zero – otherwise this hints at correlations not explained by the used factors. In the Inventory data there is only the variable pair of *Tsuga dumosa* and *Abies densa* that has a higher value than zero. The MSA values are all close to 0.5 the highest being 0.62.

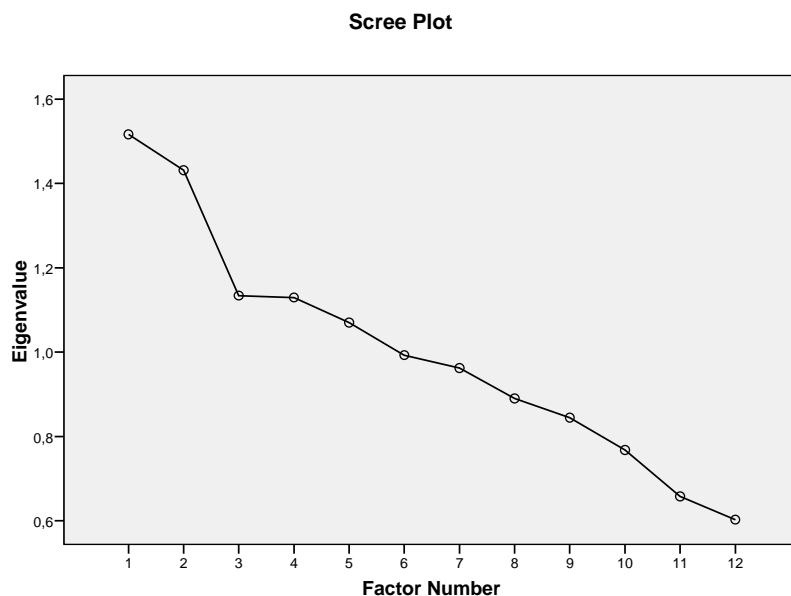
The communalities table (*Table 11*) gives an estimate for the representation of the species cover percentages by the factors for each variable. The values for *Abies densa* and *Tsuga dumosa* are the best for the tree regeneration. On the competing herbs side *Sambucus adnata* and *Yushania microphylla* have relatively high values of explanation. For *Salvia sp.*, *Senecio graciliflorus*, *Artemisia moorcroftiana* and *Betula utilis* the values are also usable. The low values for the other variables indicate that the factor analysis is not very representative for them. This already gives an outlook to the table (*Annex 7*) for the total variance explained by the factor analysis.

Table 11: Communalities - Factor Analysis Inventory Data

	Initial	Extraction
Z-Value: <i>Abies densa</i>	0.16	0.33
Z-Value: <i>Tsuga dumosa</i>	0.16	0.45
Z-Value: <i>Picea spinulosa</i>	0.03	0.06
Z-Value: <i>Acer campbellii</i>	0.01	0.03
Z-Value: <i>Betula utilis</i>	0.02	0.14
Z-Value: <i>Artemisia moorcroftiana</i>	0.07	0.20
Z-Value: <i>Osmunda sp.</i>	0.04	0.07
Z-Value: <i>Salvia sp.</i>	0.07	0.24
Z-Value: <i>Sambucus adnata</i>	0.05	0.40
Z-Value: <i>Senecio graciliflorus</i>	0.04	0.21
Z-Value: <i>Wulfenia abliqua</i>	0.03	0.05
Z-Value: <i>Yushania microphylla</i>	0.12	0.50

Extraction Method: Principal Axis Factoring.

With five factors 22.14 % of the total variance of the variables could be explained. The screeplot (*Figure 5*) suggests the use of two factors. That results in roughly 25% explained variance for the Initial Eigenvalues and 12% for the rotated solution.

**Figure 5: Screeplot - Factor Analysis Inventory Data**

The first factor of the rotated solution in the rotated factor matrix (*Table 12*) is loading high for *Abies densa* and *Tsuga dumosa* – the most important conifer species. The second factor is loading high for *Artemisia moorcroftiana* and *Salvia sp.*, with an additional strong negative loading for *Yushania microphylla*. Factor 3 has the strongest expression in a negative value for *Sambucus adnata* and positive ones for *Yushania microphylla* and *Wulfenia abliqua*. Factor 4 has a high positive loading for *Yushania microphylla* and negative ones for *Senecio graciliflorus* and *Osmunda sp.*. Although very little of the variance is

explained by the factor analysis the factor loadings still provide valuable additional information for the different site preferences of the species, but a further investigation of the results of the factor analysis is not legitimate.

Table 12: Rotated Factor Matrix - Factor Analysis Inventory Data

	Factor				
	1	2	3	4	5
Z-Value: <i>Abies densa</i>	0.56	-0.01	-0.02	-0.10	-0.07
Z-Value: <i>Tsuga dumosa</i>	0.67	-0.06	0.03	0.02	-0.01
Z-Value: <i>Picea spinulosa</i>	0.17	-0.11	0.08	0.00	0.12
Z-Value: <i>Acer campbellii</i>	-0.02	-0.04	0.01	0.02	0.15
Z-Value: <i>Betula utilis</i>	0.01	-0.03	0.05	0.01	0.37
Z-Value: <i>Artemisia moorcroftiana</i>	-0.03	0.42	0.03	-0.07	-0.14
Z-Value: <i>Osmunda sp.</i>	0.06	0.01	0.04	-0.20	0.16
Z-Value: <i>Salvia sp.</i>	-0.09	0.48	-0.02	0.08	-0.03
Z-Value: <i>Sambucus adnata</i>	-0.09	-0.02	-0.61	0.12	-0.07
Z-Value: <i>Senecio graciliflorus</i>	-0.02	-0.05	0.01	-0.42	-0.15
Z-Value: <i>Wulfenia abliqua</i>	-0.01	-0.02	0.17	0.12	0.04
Z-Value: <i>Yushania microphylla</i>	-0.16	-0.39	0.31	0.45	-0.15

Extraction Method: Principal Axis Factoring.

Rotation Method: Varimax with Kaiser Normalization.

a Rotation converged in 7 iterations.

7.2.2 Plot Data

The descriptive statistics and the following calculations indicate that for the site factors, altitude, gradient, the opening area and the additional factors for the Plot data of biomass and GSF value, a normal distribution exists, although the correlation seems to be weak for biomass and the opening area. For the different aspect classes such a distribution could not be found.

As for the site factors of the Inventory data, the Q-Q plots showed a good approximation to a normal distribution, with the exception of aspect values. As already mentioned, the found correlations for the Plot data were also mostly weak (Pearson Correlation Factor below 0.30), but more strong correlations than in the Inventory data existed.

A similar correlation analysis (*Annex 6*) as for the Inventory data was done with the site factors, the important herbaceous species and the relevant tree regeneration species for the Plot data.

Altitude and the opening area are positively correlated with each other (*Table 6*) and E aspect, negatively with W aspect. There is also a negative correlation between gradient and the opening area. The negative correlation between gradient and Flat aspect is only logical. All aspects should of course also be systematically correlated for Plot data, as if one aspect is positive all others are zero, but there are only a few significant correlations noted. The additionally collected data for GSF values and biomass are positively correlated.

Artemisia moorcroftiana is correlated positively with S aspect and biomass, negatively with *Senecio graciliflorus* and the total number of herbs.

Osmunda sp. is positively correlated with *Senecio graciliflorus* and the total number of herbs, negatively with altitude, the opening area and E aspect.

Salvia sp. is also negatively correlated with altitude and opening area, but there exist no significant correlations to the other selected competing herbaceous species.

Sambucus adnata is only positively correlated with biomass and GSF value.

Senecio graciliflorus is positively correlated with *Osmunda sp.*, *Yushania microphylla* and the total number of herbs, negatively with *Artemisia moorcroftiana*.

Wulfenia abliqua produced no significant correlations at all for the site factors and the other competing herbs.

Yushania microphylla is positively correlated with *Osmunda sp.*, *Senecio graciliflorus* and the total number of herbs and negatively with biomass.

The total number of competing herbs is positively correlated with *Osmunda sp.*, *Senecio graciliflorus* and *Yushania microphylla*. Negative correlations exist with gradient, biomass and *Artemisia moorcroftiana*. No significant correlations with the tree regeneration exist (Table 13).

The overall tree regeneration is negatively correlated with biomass and the GSF values (Table 7). It is also positively correlated with all tree species, the strongest connection exists with *Abies densa*.

Abies densa is positively correlated with altitude and all tree regeneration species (*Acer campbellii*, *Betula utilis*, *Tsuga dumosa*, *Picea spinulosa* and the overall tree regeneration) and negatively with biomass and the GSF values (Table 7). For the competing herbs no significant correlation was found.

Tsuga dumosa is correlated positively with *Salvia sp.* and all tree regeneration species except *Picea spinulosa* (*Acer campbellii*, *Betula utilis*, *Abies densa* and the overall tree regeneration).

Picea spinulosa is positively correlated with altitude, the overall tree regeneration and strongly with *Abies densa*. For the competing herbs no significant correlation was found.

Acer campbellii is positively correlated with *Betula utilis*, *Abies densa*, *Tsuga dumosa* and the overall tree regeneration, as well as with *Salvia sp.* and *Wulfenia abliqua*. A negative correlation exists with altitude, the opening area and the GSF values.

Betula utilis is correlated positively with Flat aspect, *Acer campbellii*, *Abies densa*, *Tsuga dumosa*, the overall tree regeneration and *Wulfenia abliqua*. A negative correlation exists with the GSF values.

Table 13: Correlations Herbs / Trees Species - Plot Data

	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	Total Regeneration	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
<i>Acer campbellii</i>		+	+	+	n.s.	+	n.s.	n.s.	+	n.s.	n.s.	+	n.s.	n.s.
<i>Betula utilis</i>	+		+	+	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.
<i>Abies densa</i>	+	+		+	+	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Tsuga dumosa</i>	+	+	+		n.s.	+	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Picea spinulosa</i>	n.s.	n.s.	+	n.s.		+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Total Regeneration	+	+	+	+	+		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
<i>Artemisia moorcroftiana</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	-	n.s.	n.s.	n.s.
<i>Osmunda sp.</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	+	n.s.	+	+
<i>Salvia sp.</i>	+	n.s.	n.s.	+	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.
<i>Sambucus adnata</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.	n.s.	n.s.
<i>Senecio graciliflorus</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	+	n.s.	n.s.		n.s.	+	+
<i>Wulfenia abliqua</i>	+	+	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.		n.s.	n.s.
<i>Yushania microphylla</i>	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	+	n.s.		+
Total Herbs	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	+	n.s.	n.s.	+	n.s.	+	

Note: n. s. indicates non significant relationships at $p > 0.05$

For the Plot data also a further factor analysis was done. The same procedure, a principal axis factor analysis with Varimax rotation and standardised values, was chosen. The reasons for the selection of the method and the description of it can be found in Materials and Methods (Factor Analysis). The plausibility tests included in the factor Analysis had the following results (*Table 14*).

Table 14: KMO and Bartlett's Test - Factor Analysis Plot Data

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.49
Bartlett's Test of Sphericity	Approx. Chi-Square	198.28
	df	66
	Sig.	0.00

As in the analysis for the Inventory data, the KMO measure is not looking good enough for using a factor analysis. Too little of the variance can be explained by the factors in the background.

The variables are again related according to the Bartlett test, with high significance.

The results of the anti image correlation and covariance chart are given in *Annex 10*. The anti-image correlations of the main diagonal are all relatively close to the critical value of 0.5, with a very low 0.38 for *Picea spinulosa*. This indicates that *Picea spinulosa* is probably not related with the other variables. The values of the main diagonal should be close to zero, which they are only in a few cases. This means that there are some correlations between the variables, not explained by the factors of the analysis.

Table 15: Communalities - Factor Analysis Plot Data

	Initial	Extraction
Z-Value: <i>Abies densa</i>	0.60	0.88
Z-Value: <i>Tsuga dumosa</i>	0.26	0.24
Z-Value: <i>Picea spinulosa</i>	0.49	0.55
Z-Value: <i>Acer campbellii</i>	0.42	0.68
Z-Value: <i>Betula utilis</i>	0.44	0.80
Z-Value: <i>Artemisia moorcroftiana</i>	0.16	0.20
Z-Value: <i>Osmunda sp.</i>	0.18	0.21
Z-Value: <i>Salvia sp.</i>	0.37	0.56
Z-Value: <i>Sambucus adnata</i>	0.11	0.22
Z-Value: <i>Senecio graciliflorus</i>	0.22	0.47
Z-Value: <i>Wulfenia abliqua</i>	0.26	0.22
Z-Value: <i>Yushania microphylla</i>	0.20	0.41

Extraction Method: Principal Axis Factoring.

The best representation of the variables (species) counted individuals by the factors, as given in the communalities table (*Table 15*), is given for *Abies densa* and the two broadleaf species *Acer campbellii* and *Betula utilis*. For the competing herbs the values are best for

Salvia sp., *Senecio graciliflorus* and *Yushania microphylla*, but on a lower level. Generally the values for the variables are higher than for the Inventory data and the representation by the factors is better for all species.

The screeplot (*Figure 6*) hints at a two factor solution, with roughly a quarter of the variance explained as given in the table for the explained variance (*Annex 9*).

The first factor in the rotated factor matrix (*Table 16*) is loading high on *Abies densa* and *Picea spinulosa*. Factor 2 has a high loading for *Betula utilis* and medium loadings for *Abies densa*, *Acer campbellii* and *Wulfenia abliqua*. Factor 3 is loading highly positive for *Acer campbellii* and *Salvia sp.*, followed by *Tsuga dumosa*, with negative loadings for *Senecio graciliflorus* and *Yushania microphylla*. Factor 4 is loading positively for *Yushania microphylla*, *Senecio graciliflorus* and *Osmunda sp.*, negatively for *Artemisia moorcroftiana*. Factor 5 is loading positively for *Sambucus adnata*, *Senecio graciliflorus* and *Tsuga dumosa*, negatively for *Yushania microphylla*, *Artemisia moorcroftiana*, *Wulfenia abliqua* and *Acer campbellii*.

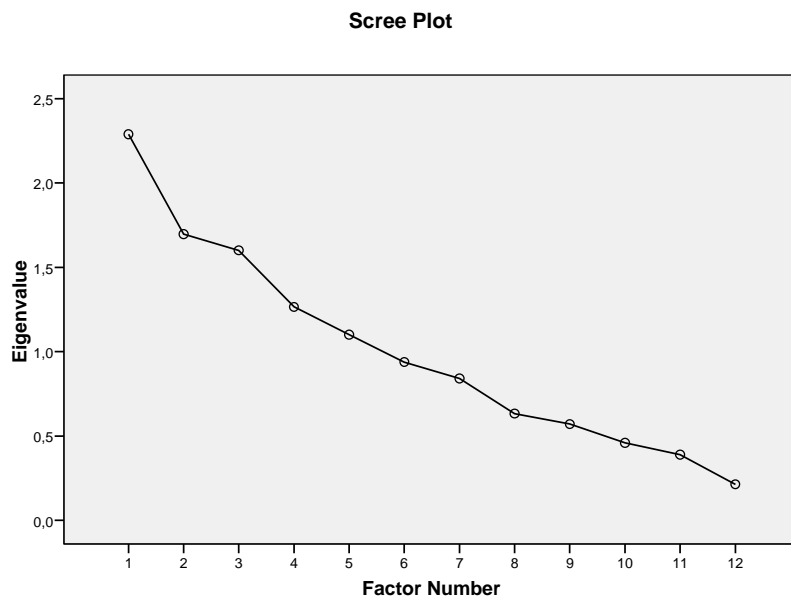


Figure 6: Screeplot - Factor Analysis Plot Data

Overall there is little of the variance explained (*Annex 9*), but the representation of the variables by the factors assists in the explanation of the site demands of the species. A further looking into the factor analysis was not carried out as the explained proportion of variance is rather low.

Table 16: Rotated Factor Matrix - Factor Analysis Plot Data

	Factor				
	1	2	3	4	5
Z-Value: <i>Abies densa</i>	0.87	0.35	0.01	0.00	-0.01
Z-Value: <i>Tsuga dumosa</i>	0.12	0.23	0.33	-0.03	0.24
Z-Value: <i>Picea spinulosa</i>	0.73	-0.10	0.01	-0.07	-0.03
Z-Value: <i>Acer campbellii</i>	0.06	0.35	0.72	0.13	-0.17
Z-Value: <i>Betula utilis</i>	0.15	0.86	0.10	0.03	0.14
Z-Value: <i>Artemisia moorcroftiana</i>	-0.14	-0.10	-0.08	-0.36	-0.20
Z-Value: <i>Osmunda sp.</i>	-0.10	0.00	0.11	0.43	0.04
Z-Value: <i>Salvia sp.</i>	-0.07	-0.11	0.72	-0.08	0.09
Z-Value: <i>Sambucus adnata</i>	-0.05	-0.07	0.03	0.07	0.45
Z-Value: <i>Senecio graciliflorus</i>	0.04	-0.01	-0.21	0.55	0.35
Z-Value: <i>Wulferia abliqua</i>	-0.02	0.44	0.03	-0.05	-0.17
Z-Value: <i>Yushania microphylla</i>	-0.09	-0.15	-0.18	0.56	-0.20

Extraction Method: Principal Axis Factoring.

Rotation Method: Varimax with Kaiser Normalization.

a Rotation converged in 5 iterations.

7.2.3 Aggregation to Plot Level

The correlations found, were generally weak, with low Pearson correlation factors. For the Plot data, the factors received of the factor analysis were slightly better, with a few really strongly correlated exceptions. It was not possible to combine the data of the Inventory and the Plot data, because for the Inventory data the competing herbs were recorded as estimated cover percentages, while the herbaceous species in the Plot data were counted individually. In the aggregation the corresponding findings for the Inventory and Plot data are listed.

The first point is a summary of the site factors. The areas for data collection for the Inventory data and the Plot data differ in some topological aspects. The dominant aspect in the altitude layers is different for the areas. The steepness of the terrain is also laid out differently. The number of plots in different aspects is unequally distributed, with the same ranking in frequency for Inventory and Plot data. Most plots had N aspect followed by E and W aspect. S aspect and Flat aspect had the smallest percentage of plots. The results for the correlations of the different aspects with the plant species were not consistent for the Inventory and Plot data.

The additional data of biomass and GSF values for the Plot data collection produced a reasonable positive correlation between these two variables. *Artemisia moorcroftiana* and *Sambucus adnata* were also positively correlated. GSF values are also positively correlated with *Sambucus adnata*. For the tree regeneration, all correlations with the GSF values were

negative, with significant results for *Acer campbellii*, *Betula utilis*, *Abies densa* and the overall tree regeneration.

The total number of herbs was influenced contradictory by gradient in the data collection areas. *Salvia sp.* was in both areas more abundant in lower altitudes.

Osmunda sp. and *Yushania microphylla* had positive correlations with the total number of herbs – which are all collected species, not only the selected competing herbs. All other selected competing herbaceous species had positive correlations with the total number of herbs, but they were not consistent concerning the significance for both data collection areas.

For *Abies densa* regeneration, the higher altitudes are more favourable.

Generally, seedlings of all tree species had positive correlations with the other tree seedlings.

7.3 Influence of Light on the Herbaceous Competitor Species

The influence of light on the competitor species was recorded in the Plot data via the GSF values, calculated from the hemiphotos. The correlation analysis (*Table 7*) showed that the overall tree regeneration is negatively correlated with biomass and the GSF values.

Abies densa, as the most abundant tree regeneration species in the Plot data, the second most in the Inventory data, is also negatively correlated with the amount of biomass and the GSF values. Even the two broadleaf species *Acer campbellii* and *Betula utilis*, classified as pioneer species, are negatively correlated with the GSF values.

For the selected competing herbs, the only significant linkage with the GSF value was a positive correlation with *Sambucus adnata*.

For the Plot data the total number of competing herbs, *Osmunda sp.* and *Salvia sp.* have shown a contradicting negative correlation with the opening area, which is diminished by the fact that for the Inventory data only one significant positive correlation was found between *Salvia sp.* and the opening area in the correlation analysis (*Table 6*). For the total tree regeneration and *Tsuga dumosa*, the correlations with the opening area were negative. This is also true for *Acer campbellii* in the Plot data.

GSF values and the opening area have also contributed to the group separation in the cluster analysis for the Inventory (*Annex 17*) and the Plot data (*Annex 24*), but only the opening area was used for the creation of a discriminant function for the Inventory data (*Annex 14*).

7.4 Regeneration Types Based on Herbaceous Competitors and Site Factors

7.4.1 Cluster Analysis Inventory Data

To form groups out of the observation plots and to subsequently define regeneration types for the tree seedlings, a hierarchical cluster analysis was conducted. Ward's method was chosen for forming clusters based on recommendations to use this method for interval scaled data (LEONHART 2004). In the Ward method the increase of the variance in the groups by new group members is minimised. Since this method has the tendency to form clusters of equal sizes (BACKHAUS et al 2006), squared distances were used for generating the distance matrix in order to counteract this tendency.

The analysis clustered the cases with the site factors, the important tree regeneration and the selected herbaceous competitors as variables.

To find and eliminate eventual outliers, another clusteranalysis was done beforehand, using the single linkage (a.k.a. nearest neighbour) method. The plots Nr. 317 and Nr. 389 were eliminated as result of this first analysis as outliers.

On the basis of the dendrogram (*Figure Annex 1*) a 10 cluster solution was selected. Even if one of the clusters consists of only two cases (this group was the same for 6 Clusters), it fits best, because the distribution and size of the groups seem to be suitable.

Table 17: Case Processing Summary – Cluster Analysis Inventory Data

	Cases					
	Included		Excluded		Total	
	N	%	N	%	N	%
Number of Order						
* Ward Method	448	95.70	20	4.30	468	100.00

The case processing summary (*Table 17*) shows, that of all cases 4.3% were excluded. In these plots, the site factors had not been recorded, which caused problems in the analysis and led to the exclusion of these sites.

In *Table 18* the group sizes are displayed. Group 3 and 7 include more than 50% of the cases, while a few very small groups were created.

The next step was to determine by discriminant analysis, if there are any and which are the differences between the groups.

Table 18: Case Summaries - Clusteranalysis Inventory Data

Number of Order Ward Method	N	% of Total N
1	13	2.90
2	5	1.10
3	111	24.80
4	74	16.50
5	68	15.20
6	8	1.80
7	141	31.50
8	17	3.80
9	9	2.00
10	2	0.40
Total	448	100.00

7.4.2 Discriminant Analysis Inventory Data

The resulting groups were analysed by discriminant analysis for assessing the quality of the grouping. In order to do so, the same variables as in the cluster analysis were used.

The site factors Flat aspect and W aspect, which failed the tolerance test – this means they are multi collinear related (not independent) –, and the herbaceous species *Osmunda sp.* and *Wulfenia abliqua*, which had no significant influence on group separation, were taken out of the group of variables.

In *Annex 13*, Wilks Lambda is the ratio of the within groups sum of squares to the total sum of squares. The value is between 0 and 1 and the lower the better separated the groups are by the variables. The significance shows the reliability of the variable, with the result that all variables except *Osmunda sp.* and *Wulfenia abliqua* are valuable for the analysis.

Table 19: Test Results (a) - Discriminant Analysis Inventory Data

Box's M	1673.31
F	Approx. 18.59
	df1 66
	df2 2523.64
	Sig. 0.00

Tests null hypothesis of equal population covariance matrices.

a Some covariance matrices are singular and the usual procedure will not work.

The log of its determinant is -18.05.

The non-singular groups will be tested against their own pooled within-groups covariance matrix.

The results of the Box's M test (*Table 19*) mean the covariances in the groups are different and the different group sizes need to be considered in the analysis, which was respected.

According to the Eigenvalues (*Annex 12*) the first 3 functions account for nearly 70% of the variance, while the last function is not as important with roughly 1% of the variance. The Eigenvalues are the ratio of the within group sum of squares to the sum of squares between

the groups and represent also a measure for the importance of the functions. The canonical correlation scores indicate the correlation between the groups and the discriminant functions. In this case with exception of the last group all discriminant functions represent the groups rather well.

The Wilk's Lambda test (*Annex 13*) analyses the difference of the group means. With low Wilk's Lambda values the means differ more. The values are again between 0 and 1. In this case, all group means differ significantly and the 8th, 9th and 10th group means have the smallest differences.

In the structure matrix (*Annex 14*) the correlations between the variables and the different discriminant functions are depicted. The most important function of one variable is marked by a "*". For the calculation of the discriminant function only the most important variable is used. These variables and the resulting function coefficients are presented in *Annex 16*.

With these function-coefficients the data is divided into the different groups. For each plot the results for the functions can be calculated, and the result with the highest value defines the group.

With the exception of the W aspect all site factors were used. Also all the tree species were used in the discriminant function, while none of the competing herbaceous species were incorporated.

The territorial map (*Figure Annex 2*) shows the distribution of the data in a graphical area, assuming all discriminant functions but the most important two are zero. *Figure 7* is an overview of the distribution on a smaller scale.

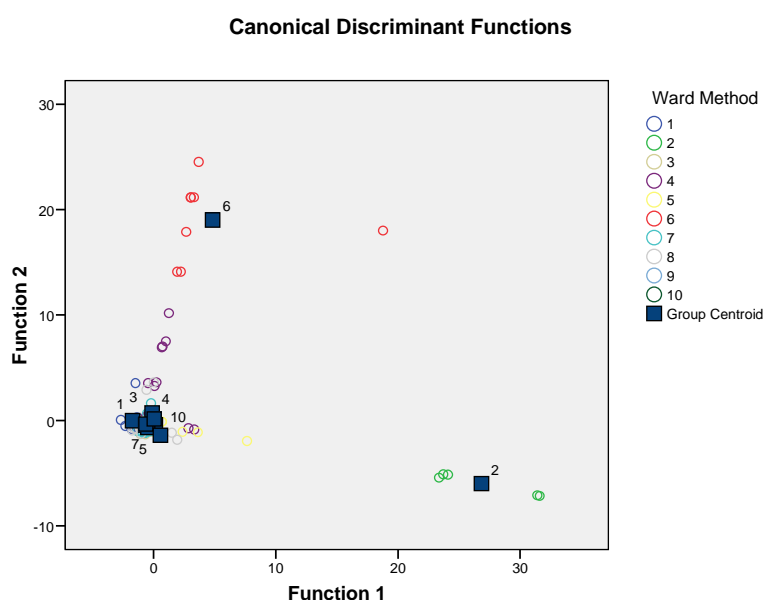


Figure 7: Canonical Discriminant Functions Overview - Cluster Analysis Inventory Data

The groups 2 and 6 are separated rather well, likewise the groups 3, 4, 5 and 7 on the smaller scale. The other groups are very near together. We have to bear in mind that for this

graphic only the first two functions are used. The later functions may help to differentiate the other groups better.

The tests for the classification of the cases by use of the discriminant functions, compared to the original classification by the clusteranalysis, produce overall a rate of 94.4% correctly classified cases, which is a good result (*Annex 16*).

A summary of the distribution of the variables in the ten groups of the clusteranalysis is given in *Annex 17*.

7.4.3 Cluster Analysis Plot Data

To form groups out of the observation plots and in the following define regeneration types for the tree seedlings, a hierarchical clusteranalysis was conducted. In spite of the fact that the Plot data was mainly of count scaled origin, the Ward method was used, because it takes the heterogeneity in the produced groups into account and it is also a space conserving procedure, which takes the original geometrical size and orientation of the group members into account (WIEDENBECK & ZÜLL 2001). In the Ward method, the increase of the variance in the groups by new group members is minimised. The analysis clustered the cases with the site factors, the important tree regeneration and the selected herbaceous competitors as variables.

To find and eliminate eventual outliers, another cluster analysis was done beforehand using the single linkage (a.k.a. nearest neighbour) method. The resulting dendrogramm showed a lot of chaining – meaning that no clear group building and no clear outliers can be seen.

The result of the cluster analysis using the Ward method was much better than the single – linkage clustering (*Figure Annex 3*). There seemed to be a good separation with 9 or 12 groups. It was also tried to use 10 groups to get a comparable result for the analysis of the Inventory data. The group sizes fit even better and finally 10 groups remained the chosen number for the analysis.

Table 20: Case Processing Summary - Cluster Analysis Plot Data

	Cases					
	Included		Excluded		Total	
	N	%	N	%	N	%
Number of Order						
* Ward Method	90	100.00	0	0.00	90	100.00

All plots of the survey were accounted for in the analysis (*Table 20*).

It can be seen in the case summaries (*Table 21*), that the 10 group solution has relatively evenly sized groups. The big group of a 9 group solution, with nearly half of the plots in it, is divided.

Table 21: Case Summaries - Cluster Analysis Plot Data

Number of Order Ward Method	N	% of Total N
1	14	15.60
2	8	8.90
3	2	2.20
4	5	5.60
5	22	24.40
6	3	3.30
7	6	6.70
8	10	11.10
9	19	21.10
10	1	1.10
Total	90	100.00

7.4.4 Discriminant Analysis Plot Data

Although the Box's M test yielded no usable results – mostly because of the small sample sizes – the groups were used according to their sizes in the analysis. The group sizes have a range from 1% to nearly 25%.

In *Annex 18* Wilks Lambda is the ratio of the within groups sum of squares to the total sum of squares. The value is between 0 and 1. The lower the value, the better separated the groups are by the variables. The significance shows the reliability of the variable, with the result that all variables except the different aspects are valuable for the analysis.

The Eigenvalues (*Annex 19*) show that the first 3 functions account for nearly 70% of the variance, while the last function is not as important with roughly 1% of the variance represented by it. The Eigenvalues are the ratio of the within group sum of squares to the sum of squares between the groups and represent also a measure for the importance of the functions. The canonical correlation scores indicate the connection between the groups and the discriminant functions. In this case with the exception of the last group all discriminant functions represent the groups rather well.

The Wilk's Lambda test (*Annex 20*) analyses the difference of the group means. With low Wilk's Lambda values the means differ more. The values are again between 0 and 1. In this case all group means differ significantly with the smallest differences for the 8th, 9th and 10th group.

In the structure matrix (*Annex 22*) the correlations between the variables and the different discriminant functions are depicted. The most important function of one variable is marked by a "*". For the calculation of a function only the most important variable is used. These variables and the resulting function coefficients are presented in *Annex 23*.

The data is divided into the different groups with these function coefficients. For each plot the results for the functions can be calculated and the result with the highest value defines the group.

Of the site factors only altitude and gradient were used for the discriminant functions. Of the tree regeneration variables the most important species *Abies densa* and *Tsuga dumosa* were not used in the discriminant analysis. The overall tree regeneration and some of the herbaceous species with the biggest individual size have been incorporated in the discriminant functions (*Artemisia moorcroftiana*, *Salvia sp.*, *Sambucus adnata*, *Wulfenia abliqua* and *Yushania microphylla*).

The territorial Map (*Figure Annex 4*) shows the distribution of the data in a two dimensional graphical area, assuming all discriminant functions but the most important two are zero. *Figure 8* is an overview of the distribution on a smaller scale.

The groups 6, 3, 10 and 7 are separated rather well, as well the groups 5 and 9 on the bigger scale. The other groups are very near together. It has to be kept in mind that for this graphic only the first two functions are used. The other discriminant functions may help to differentiate the other groups better.

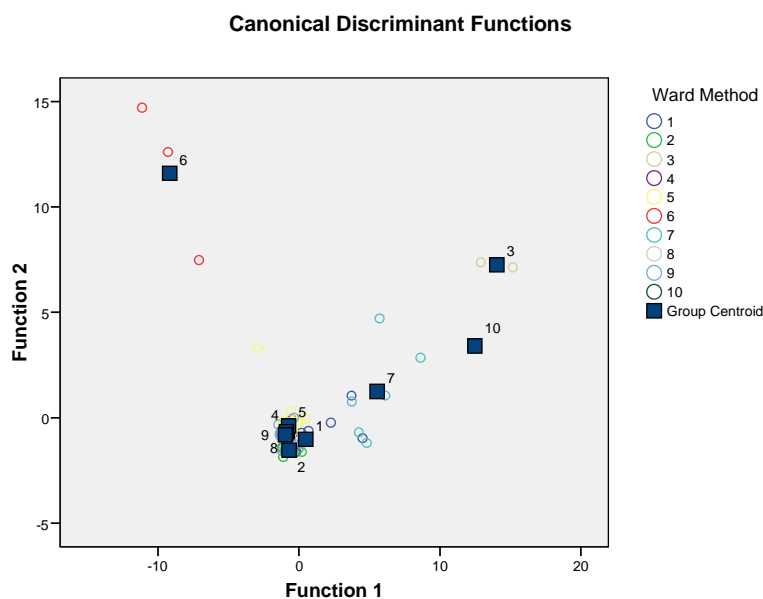


Figure 8: Canonical Discriminant Functions Overview - Cluster Analysis Plot Data

In *Annex 23* are displayed the tests for the classification of the cases by use of the discriminant functions compared to the original classification by the clusteranalysis. The rate of correctly classified plots is 90% and a good result.

Annex 24 is a summary of the distribution of the most important variables in the ten groups.

8 Discussion

8.1 The Strongest Herbaceous Competitors for the Tree Regeneration

The ecological and the physical optimum of plants are not the same – in the field the abundance of species is often determined by its relative competitive ability versus its neighbours and the relative susceptibility to herbivores and pathogens (CRAWLEY 1997a). Not all species have the best chances of success on good sites. Some need less favourable conditions to have a chance in competition versus the other species. Sometimes one species is better equipped for special conditions than others.

In this study most of the regeneration species are negatively influenced by the size of the openings in the forest canopy. This is probably more a function of the increasing competition by herbs than of too much light and drought phenomena, because the openings were rather small and the climate is humid mountainous climate.

For the Inventory data all selected competing herbs, except *Osmunda sp.*, were negatively related with the total regeneration – but not significantly. So the tree regeneration and the selected herbaceous species are competing for resources and the herbs are probably better equipped for the struggle. The additional collected data for GSF values and biomass are positively correlated. It is fact, that with more light more herbaceous species grow and they grow much better. This can also be seen for *Tsuga dumosa* – one of the two most dominant tree species in the survey. It is disturbed in its recruitment by large openings and a high abundance of the competitors. Here the effective connection of the size of the opening area and the competing herbs is evident.

Salvia sp. is, probably due to its size and maybe similar site demands, a fierce competitor for all tree species, as the correlations for the Inventory data have shown. It is also positively correlated with *Artemisia moorcroftiana* and these two species form, due to their size, a very dominating layer over the tree regeneration. This is especially negative for *Picea spinulosa*. Its sites were affected negatively and this may also be responsible for the low abundance of *Picea spinulosa*. Nonetheless in the Plot data *Salvia sp.* is positively correlated with *Tsuga dumosa* and *Acer campbellii* and *Tsuga dumosa* is also one of the two dominating tree species. This fact may help to discern between the regeneration types for the *Abies densa* and *Tsuga dumosa*.

Artemisia moorcroftiana is correlated positively with S aspect and biomass, negatively with *Senecio graciliflorus* and the total number of herbs. The size of the species makes these facts plausible, because probably only few of the smaller more numerous species are able to grow in the shade of the bigger selected competing herbs. In the study the number of plants

was recorded and not the cover percentage. The selected herbs had mostly large leaves and a large phenotype, but they were not the most numerous. The selected herbaceous species are also dominating other plant species, not only the tree regeneration.

Osmunda sp. has apparently different site demands than *Artemisia moorcroftiana*. Surprisingly even the opening area is negatively correlated. Maybe it is more of a shadow species or the competition in the open is too strong, as it is not growing as high as for example *Artemisia moorcroftiana*.

Sambucus adnata is only positively correlated with biomass and GSF value, which is sensible for one of the bigger species. This qualifies it also as a strong competitor for the tree regeneration, as the tree seedlings face the most competition in open conditions with high light levels and in the Inventory data it also showed negative correlations with the total regeneration.

Yushania microphylla is a strong competitor for *Abies densa* – one of the two most dominating tree species. Also a negative correlation exists between *Picea spinulosa* and *Yushania microphylla*. One could therefore argue, that with the connection within the tree regeneration, it is probably also a strong competitor for the other tree seedlings. *Yushania microphylla* is positively correlated with the total number of herbs. Negative correlations exist with all selected competing herbaceous species in the Inventory data, with the exception of *Wulfenia abliqua*. These are oppositional demands on site conditions or strong competitive mechanisms with the other selected competing herbs. It can probably tolerate drier conditions and is therefore able to dominate the other species. In the Plot data *Yushania microphylla* is negatively correlated with biomass and positively with the total number of herbs. This negative correlation with biomass is weird especially in connection with the positive correlation with the total number of herbs. An explanation may be, that more small plants grow below the layer of *Yushania microphylla*, but they contribute only a little to the biomass and *Yushania microphylla* itself has also not enough biomass to establish a positive correlation. These smaller species have not been selected for the competing herbaceous species, but are represented in the variable total herbs. Nonetheless is *Yushania microphylla* able to form an understorey layer, which impedes the growth underneath by overshadowing it (GRATZER et al. 1999). The results show that *Yushania microphylla* is apparently also a strong competitor for *Abies densa*. A fact that is supported by the findings of GRATZER et al. (1999), who ascertained that *Yushania microphylla*, had a big influence on the recruitment, growth and survival rate of *Abies densa* seedlings. This influence was mainly due to shading by the bamboo undergrowth and correlated with the height of the bamboo plants. The results of the factor analysis also suggest that the biggest competitors for *Abies densa* and *Tsuga dumosa* are *Yushania microphylla*, *Salvia sp.*, *Artemisia*

moorcroftiana and *Sambucus adnata*, even if *Tsuga dumosa* is correlated positively with *Salvia sp.* in the Plot data.

In a study of tree regeneration in canopy gaps after Sasa (Bamboo) dieback, ABE et al. (2002) found, that the death of Bamboo (Sasa) communities has a bigger effect in tree regeneration establishment than the formation of gaps alone. The soil coverage of Sasa is the determining factor. Also the fluctuation in light and temperature was bigger in these open sites and lead to germination of seed banks. Here shade tolerant species have obviously advantages, because of their seedling bank. Wind dispersed seed rain species are less affected by the competition of Sasa and therefore influenced more by gap formation.

Wulfenia abliqua seems to have only in connection with *Yushania microphylla* a significant negative influence on the tree regeneration. On it's own it is no such a big competitor. This is supported by the positive correlations for *Betula utilis* and *Acer campbellii* in the Plot data. These positive correlations show probably a preference for the same site conditions as the respective species.

The total number of competing herbs is positively correlated with *Osmunda sp.*, *Senecio graciliflorus* and *Yushania microphylla*. Negative correlations exist with gradient, biomass and *Artemisia moorcroftiana*. No significant correlations with the tree regeneration exist. This supports the selection of the competition species with a larger phenotype, as numbers alone have obviously not as much influence on the tree seedlings. A little surprise was the negative correlation for biomass and the number of total herbs for the Plot data. Partly this can be explained by the also negative influence on *Yushania microphylla*, which is an important factor for the number of total herbs, and the influence of smaller herbaceous species, which were also very abundant but had been considered of less importance for the tree regeneration and were therefore not included in the analysis of correlations. These species had also a smaller share of the biomass, but were numerous and had therefore an augmenting influence on the total number of herbs. *Sambucus adnata* and *Artemisia moorcroftiana* – two of the biggest species in the study had naturally a positive correlation with biomass.

The total tree regeneration is negatively correlated with biomass and the GSF values – one of the expected correlations, as this confirms that the tree regeneration is under pressure by the competition of herbaceous species. It is also positively correlated with all selected tree species, the strongest connection exists with *Abies densa*. This is a systematic connection because *Abies densa* is the most abundant tree species in the Plot data – for the Inventory data it was *Tsuga dumosa*.

Abies densa is positively correlated with all tree regeneration species (*Acer campbellii*, *Betula utilis*, *Tsuga dumosa*, *Picea spinulosa* and the overall regeneration) and vice versa, negatively with biomass and GSF values. This fits for the most abundant tree regeneration

species in the Plot data and supports the assumption that the competing herbs have influence on the tree regeneration.

The pioneer species *Betula utilis* and *Pinus wallichiana* were weakly positively correlated with the opening area, in spite of the stronger herbaceous competition. This emphasises the higher light demands of these species, although there are hints that in the early stages of regeneration the differences between shade tolerant and shade intolerant species are not as pronounced as in older trees.

In many cases in the beginning of succession soil properties are the limiting factor, while in later stages light becomes more important as the limiting resource (PICKETT and CADENASSO 2005). TSHERING (2005) found that the microsites of moss and nurse logs prove to be more favourable for *Abies densa*, *Tsuga dumosa* and *Picea spinulosa* seedlings, than litter – which has also in other studies been identified to restrict the roots of regeneration from reaching the soil by a thick layer of dead leaves. On the study site burial with litter and competition with the herbaceous vegetation might have played a greater role than microsite topography, especially as nurse logs were also hardly present in the relatively young stands of the study site.

The general regeneration mode for this study area is the gap phase regeneration mode, with small to intermediate patches (e.g. tree fall from age) and a mosaic of different age patches. It occurs mostly in old growth stands or in stands near the compositional equilibrium, but also for the respective and relatively young stands in the study area.

Different life strategies of species can also contribute to coexistence – e.g. long lived species versus high fertility species, with long time coexistence (VEBLEN 1992). This should represent partly the competition between herbs and tree regeneration in this study. CRAWLEY (1997a) reckons that for trees different strategies exist with implied trade offs. One is the better colonization versus competition advantages, another root growth versus shoot growth – early successional species have relative large root systems, late successional species need larger shoots to reach the canopy. This would represent the competition of pioneer tree species like *Betula utilis* and shade tolerant climax phase tree species like *Abies densa* and *Tsuga dumosa*.

Seed size has trade offs with the seed numbers and seedling performance. The limited resources need to be used in an optimal way. Bigger seeds make more competitive seedlings – this advantage quickly saturates, especially if the bigger seeds are much more attractive to herbivores. Larger seeds are also not as suited for long dormancy periods. Long living, shade tolerant, slow growing trees may outcompete faster growing species over time. These effects should also be seen in the study area. Although the pioneer species like *Betula utilis* are more numerous in the subplots with the highest radiation levels, they are not the tree species with the highest seedling abundance. These are *Abies densa* and *Tsuga dumosa*.

Shade tolerance and slow growth, paired with long time survival in shady conditions, is in competition with rapid growth in shade and a high mortality if no light source is reached. Shade tolerance often means a large area where reproduction is possible, but the high light levels of large gaps are not always tolerated. Also were the seedlings in a waiting position, although few in numbers, of these shade tolerant species with a low mortality in low light conditions.

Seed and fruit morphology are some of the most important aspects for colonization – for larger seeds less disturbance is necessary. Other attributes that facilitate colonization are shade tolerance, resistance against fungal attack, low palatability to herbivores and longevity (dormancy). TSHERING (2005) found for the study area that because seedlings have occurred even in the centres of gaps, the seed dispersal seems not to be limited.

8.1.1 Impact of Herbivory on the Tree Regeneration

In habitats with multiple trophic levels not only the use of the resources but also the susceptibility to predation is a determining factor. MOONEY & EHLERINGER (1997) found that leaf with high photosynthetic capacity are often very attractive to herbivores due to high protein content.

The path of succession present, if only plants are competing with each other, can be altered by the presence of herbivores or other external effects (PICKETT and CADENASSO 2005). Plants have more impact on the distribution and abundance of specialist herbivores than vice versa, while generalist herbivores like ungulates have more impact on the abundance and distribution of their preferred food plants than the other way around. In low productive, open plant communities, where plant recruitment is typically seed limited herbivores have a stronger impact than in high productive, closed communities, where recruitment is often microsite limited (CRAWLEY 1997b). TSHERING (2005) found for the study area that the browsing damage in the area was minimal – 5% of the seedlings. This concerns at least cattle grazing in summer. Also the hints for extensive browsing damage by Yaks in winter were scarce. However, the method applied in this study does not reflect seedlings which were removed by browsing or died back and decomposed quickly.

In another study concerning the influence of browsing in Bhutan DARABANT et al. (2007) found that the grazed plots showed an increase in tree seedlings (mainly due to an increase in the numbers of Hemlock seedlings) and less bamboo cover percentage and bamboo height. In the grazed plots *Tsuga dumosa* was even overrepresented concerning the percentage of *Tsuga dumosa* in the parental canopy. *Pinus wallichiana* and *Picea spinulosa* were underrepresented. In the ungrazed plots the species composition corresponded with the canopy layer. The growth rates of the seedlings were higher in the ungrazed plots. Bamboo height and seedling abundance were inversely related. Herbivore density in the

study area was low enough for the indirect positive effects of grazing to outweigh the direct negative effects (trampling, nutrient loss, compaction, browsing...).

A major difference between this study and the study by DARABANT et al. (20007) was that the competitors to tree regeneration in the latter study were palatable, whereas this is not the case for some of the major competitors in this study (e.g. *Artemisia moorcroftiana*, *Salvia sp.* and *Osmunda sp.*). The herbivores thus have to browse tree seedlings or *Dahpne sp.* and other herbs and shrubs. The dominance of plants like *Artemisia moorcroftiana* however is so strong that the pressure on tree seedlings, although lower in fodder quality than herbs or grasses, is high. More palatable plants need to be more competitive – otherwise they would vanish soon in an environment with herbivores and plant competition. Some of the strongest competitors in this study, like *Artemisia moorcroftiana* or *Salvia sp.* are not palatable and maybe this further strengthens their supremacy.

AMMER (1996) found in his study that in the very open heavy shelterwood cut plots, heavy ground vegetation prevented regeneration from using the relatively good light conditions. In the fenced plots of the study – located in the clearcut plots – interspecific competition played a major role for successful tree regeneration, outside the fences browsing damaging was the sole important factor for the growth of tree regeneration.

DE LA CRETAZ & KELTY (2002) studied the tree regeneration in a fern-dominated pine forest understorey after the browsing pressure by deer was removed. The fern layer had formed a stable understorey layer prohibiting tree regeneration. It showed characteristics of an invasive plant species and the forest understorey had reached a so called alternate stable state. Even after the removal of the browsing pressure the system could not return to the former state, with mixed species shrub and tree regeneration in the understorey. The success of tree regeneration was dependent on the moment of sprouting of the foliage. If a time period for photosynthesis was possible, due to the delayed opening of the fern foliage, the tree regeneration has a chance. The conifer species could also use this time gap because the needles of two years remained on the plants. In this study the fern species *Osmunda sp.* has no negative influence on the tree regeneration according to the analysis results. This may be due to smaller size or less abundance of *Osmunda sp.*.

8.1.2 Plant Size and Location in the Gap

Competition is asymmetric with the larger plants exerting much more influence on the smaller plants than the other way around. This means for this study, that the small tree regeneration is dominated by the bigger herbaceous plants. A competition between the tree species itself is not important in this particular period of regeneration, due to small numbers and size of the regeneration. This view that is supported by RESCO DE DIOS et al. (2005) who also found no intraspecific competition in the tree regeneration in their study. The supposed stronger competition by larger plants supports the field observations of this study

and the selection of the bigger herbaceous species as main competitors, rather than the more numerous but smaller plants. The negative correlation of the total tree regeneration with biomass proves this view to be true. No significant correlations with the tree seedlings exist for the number of competing herbs. This supports the selection of the competition species with a larger phenotype, as density of individuals alone has not as much influence on the tree regeneration.

The examined tree regeneration as a whole has negative correlations with the opening area and the total number of herbs. It seems that the size of the plants and also large numbers have a negative influence on the tree regeneration.

VEBLEN (1992) declares the density of understorey species in gaps is dependent on their density before the gap creation – lower light levels before gap creation may result in greater resource availability and less competition for the regenerating tree species after the gap creation. Larger gaps also often favour understorey species (bamboo). The additional collected data for GSF values and biomass are positively correlated in this study. *Abies densa* is negatively correlated with biomass and the GSF values. For the total tree regeneration and *Tsuga dumosa* the correlations with the opening area were negative. This is also true for *Acer campbellii* in the Plot data. Even the two broadleaf species *Acer campbellii* and *Betula utilis*, a pioneer species, are negatively correlated with the GSF values. The overall tree regeneration is also negatively correlated with the biomass and GSF values – with too much light the competition just gets too strong. As an example for the facilitation of growth for the herbaceous competitor species by high light levels, *Sambucus adnata* is positively correlated with biomass and GSF value, but significant correlations of single herbaceous species with the GSF value have been rare.

TSHERING (2005) states that in Gidakom FMU *Abies densa* and *Tsuga dumosa* species had no problem with the supply and germination of viable seeds. He also comes to the conclusion, that the competition by herbaceous species is one of the reasons for the failure of tree regeneration. He found that the bigger openings of this study, which equal e.g. the smaller opening size classes in DORJI's (2004) study, had more regeneration, although the range in size was very small (0.11 – 0.19 ha).

The highest tree regeneration densities were found on the south edges of the openings, the lowest in the centre. This seems reasonable for shade tolerant species, with a high competition by herbaceous light loving species. DORJI (2004) found similar results. For *Picea spinulosa* the lack of mother trees may be the most important limiting factor for its regeneration.

In a survey of *Picea abies* regeneration, conducted in Alpine forests by BAIER et al. (2007), with special focus on site factors concerning snow gliding, browsing, humus layer and herbal

competition, the coverage of ground vegetation was less dense in sites with *Picea abies* saplings, although radiation was not a limiting factor in the survey. The thickness of the humus layer and the occurrence of obstacles had also a positive influence on *Picea abies* regeneration.

Table 22: Abundance of Species According to Gap Position

Gap Position	Gap Centre	Subplot North	Subplot East	Subplot South	Subplot West
<i>Acer campbellii</i>	0	+	++	+	+
<i>Betula utilis</i>	+	0	0	+	+
<i>Pinus wallichiana</i>	0	0	0	0	0
<i>Abies densa</i>	0	++	++	++	+
<i>Tsuga dumosa</i>	0	0	++	++	+
<i>Picea spinulosa</i>	0	0	++	++	0
Total Regeneration	0	0	++	++	+
<i>Artemisia moorcroftiana</i>	++	++	0	0	0
<i>Osmunda sp.</i>	+	+	++	++	+
<i>Salvia sp.</i>	++	+	++	0	0
<i>Sambucus adnata</i>	++	+	0	0	0
<i>Senecio graciliflorus</i>	0	+	++	++	++
<i>Wulfenia abliqua</i>	0	0	0	+	+
<i>Yushania microphylla</i>	0	+	+	++	++
Total Herbs	+	0	+	+	+

Legend: "0" ... present, "+" medium abundance, "++" ... high abundance

It seems reasonable that in this study the competition by herbaceous species is the main factor responsible for the lack of tree regeneration. Therefore an adequate silvicultural system and light management will have a big influence on the future tree regeneration and the necessity of possible afforestation.

TSHERING (2005), who used the same data as in this study for his analysis, found that the highest density of tree seedlings was observed in the south position of the gaps, the lowest in the centre. The herbaceous competitors had the highest densities in the gap centres and in the western positions. The different competitors had a different prevalence for the gap positions, according to their site demands and the interspecific competition between the herbaceous species. An overview is given in *Table 22*. In this table the abundance of the species is separated in levels of presence, relatively low and relatively high abundance. The level of abundance is always related to the highest number of the respective species and the results of the Inventory and the Plot data are combined, although the results for the two areas have not always been consistent. It can be seen that the regeneration species prefer different positions in the gaps, especially in relation to their biggest competitors – *Artemisia moorcroftiana*, *Salvia sp.*, *Sambucus adnata* and *Yushania microphylla*.

8.2 The Differences in Site Demands of the Herbaceous Competitors and the Regeneration

To get regeneration types for the selected tree species, the different site demands of the tree regeneration and the herbaceous competitors have to be examined.

The areas for data collection for the Inventory data and the Plot data differ in some topological aspects. The dominant aspect in the altitude layers is different for the areas. The steepness of the terrain is also laid out differently. The number of plots in different aspects is unequally distributed, with the same ranking in frequency for Inventory and Plot data. Most plots had N aspect followed by E and W aspect. S aspect and Flat aspect had the smallest percentage of plots.

The results for the correlations of the different aspects with the plant species were not consistent for the Inventory and Plot data. Nonetheless in this study S aspect seems also to be generally unfavourable for the selected vegetation species, maybe due to higher radiation and desiccation, as it correlates negatively with *Artemisia moorcroftiana*, *Salvia sp.*, *Sambucus adnata*, *Senecio graciliflorus*, *Abies densa* and the total regeneration. The number of the overall competing herbs was in contrast higher in the plots with S aspect. The smaller species seem to grow better or have less competition in these spots. The environmental conditions in these plots are probably better suited for other species than the ones selected for this study. These should be adapted to drier sites with higher radiation levels.

Altitude and the opening area are positively correlated with each other and E aspect, negatively with W aspect. An interesting fact is that in the Inventory area in higher altitudes there were smaller openings and vice versa in the Plot data area, where the range of different altitudes was admittedly relatively small. This represents topographical features and as more plots were located below forest roads, maybe technical reasons of harvesting are

the reason for the correlation between altitude and opening area. The expression of local topographic conditions may also hold true for the negative correlation between gradient and the opening area. The also negative correlation between gradient and Flat aspect is only logical. All aspects should of course also be systematically, as if one aspect is positive all others are zero, but there are only a few significant correlations noted for the Plot data.

Artemisia moorcroftiana has a preference for sites with higher altitude, N aspect and other herbaceous competition – it seems sensible that it is suited for lower temperature and lower light levels. *Artemisia moorcroftiana*, *Salvia sp.* and *Osmunda sp.* seem to generate a vegetation type, as they have similar site requirements. *Artemisia moorcroftiana* is correlated positively with biomass, negatively with *Senecio graciliflorus* and the total number of herbs. The size of the species makes these facts plausible, because probably only few of the smaller more numerous species are able to grow in the shade of the bigger competitive herbs. The S aspect seems to suit the demands of the species in the Plot data and creates a special environmental niche for *Artemisia moorcroftiana* as most species are negatively correlated with S aspect. To make things less clear this positive correlation with S aspect was only observed in Plot data; in Inventory data it was negative.

Osmunda sp. has positive correlations with the total number of herbs and N aspect. It seems to have similar site preferences to *Artemisia moorcroftiana* and *Salvia sp.*, although it is not significantly correlated with those species. It is also one of the bigger herbaceous species, but seems still to allow the smaller more numerous species to grow in the same plots, therefore the correlation with the total number of herbs. A negative correlation with *Yushania microphylla* is another similarity to *Artemisia moorcroftiana* and *Salvia sp.*. *Osmunda sp.* and *Yushania microphylla* had positive correlations with the total number of herbs – which are all collected species, not only the selected competing herbs. All other selected competing herbaceous species had positive correlations with the total number of herbs in one of the data sets, but they were not consistent concerning the significance for both data collection areas. *Osmunda sp.* is negatively correlated with the opening area. Maybe it is more of a shadow species or the competition in the open is too strong, as it is not growing as high as for example *Artemisia moorcroftiana*.

Artemisia moorcroftiana and *Salvia sp.* have a positive correlation. On plots with these two species, a dense herbaceous layer evolves, as these species have large leaves. For *Salvia sp.* were found no significant correlations to the other selected competing herbaceous species. *Salvia sp.* prefers sites with N aspect. It needs open conditions, with higher light levels. It occurs in similar sites as *Osmunda sp.* and *Artemisia moorcroftiana* – with a preference for lower regions. *Salvia sp.* was in both data collection areas more abundant in lower altitudes. This could be a general preference of *Salvia sp.*, but the variation in altitude was rather small in the survey area. Therefore this correlation has to be viewed with cautiousness. The drier

sites with S aspect and higher altitudes are avoided. *Yushania microphylla* is occurring on different sites or a very strong competitor for *Salvia sp.*.

Sambucus adnata is positively correlated with biomass and GSF value, which is sensible for one of the bigger species. As it is also positively correlated with the total number of herbs in the Inventory data, it seems to allow other species to grow in the same plots and maybe forms a less dense vegetation layer. It has also the only noted preference for W aspect. Negative correlations exist, as for most of the other species, for S aspect. The negative correlation with gradient can be a function of the microsite situation in steeper areas. Like *Salvia sp.* it occurs on different sites than *Wulfenia abliqua* and *Yushania microphylla*.

There seem to be oppositional demands on site conditions for *Yushania microphylla* and the other main herbaceous competitors or it is a very superior competitor as it had negative correlations with all herbaceous species besides *Wulfenia abliqua*. Especially with *Artemisia moorcroftiana* and *Salvia sp.* a strong negative influence was recorded. *Sambucus adnata* may also be adjacent to this group, because it has positive links with *Wulfenia abliqua* but negative ones with *Yushania microphylla*. It may be that *Wulfenia abliqua* is shade tolerant and can survive under the coverage of *Yushania microphylla* or *Sambucus adnata*. Together these species form an even denser layer, with less light below, and should impede the tree regeneration even more. This is true for the centre subplots, where other species, which have not been part of the analysis of this study, are also able to survive in the shadow of the bigger competitor species and strengthen their diminishing effect on the tree regeneration. *Yushania microphylla* is positively correlated with gradient, S aspect and the total number of herbs. These are oppositional demands on site conditions or strong competitive mechanisms with the other selected competing herbs.

Senecio graciliflorus has a regeneration niche of its own, with different site demands, if you look at the results. *Senecio graciliflorus* is positively correlated with E aspect. This is the aspect with which the total number of herbs is negatively correlated. Also is *Senecio graciliflorus* the only one of the selected competitors, which is not positively correlated with the total number of herbs. It seems to have a different regeneration niche. It may be that the other selected herbaceous competitors put too much pressure on *Senecio graciliflorus* and therefore force it to sites, where the competition by the other species is not as hard. *Senecio graciliflorus* is positively correlated with *Osmunda sp.*, *Yushania microphylla* and total number of herbs, negatively with *Artemisia moorcroftiana*. This hints at site demands and plant communities still to be defined.

The total number of herbs was influenced contradictory by gradient in the data collection areas. Maybe the steepness of the terrain did not reach values that were limiting for the any of the selected species and on the less declining spots other environmental factors had probably more influence on the herbaceous species. The additional data of biomass and GSF

values for the Plot data collection produced a reasonable positive correlation between these two variables. *Artemisia moorcroftiana* and *Sambucus adnata* were also positively correlated with biomass. GSF values are also positively correlated with *Sambucus adnata*. The higher the light levels on the ground floor in the survey plots the more ground vegetation could develop. This supports the presumption, that with more light more herbaceous species grow and they grow much better and bigger openings are good for the herbaceous competitors in general.

Abies densa is positively correlated with altitude, N aspect and strongly with *Tsuga dumosa* and the overall tree regeneration – in the Plot data it is even positively correlated with all tree species (*Acer campbellii*, *Betula utilis*, *Tsuga dumosa*, *Picea spinulosa* and the overall tree regeneration). For *Abies densa* regeneration, the higher altitudes are more favourable. This coincides with the general habitat of *Abies densa*. It is negatively correlated with S aspect, like most selected species of tree regeneration and herbaceous competitors. The strong correlation with *Tsuga dumosa* and the overall tree regeneration can be explained by the large number of *Abies densa* and *Tsuga dumosa* seedlings, which represent the main part of the tree regeneration. *Abies densa* is negatively correlated with biomass and the GSF values. This fits its general qualification as a relatively shade tolerant species (DARABANT et al. 2001). For *Yushania microphylla* and the total number of herbs was found a negative correlation. These hints either at a competition situation or site demands – probably the competition mechanism is stronger.

Tsuga dumosa is positively correlated with *Abies densa*, *Picea spinulosa* and very strongly with the overall tree regeneration. Again this is explainable by the dominance of *Tsuga dumosa* seedlings. The number of total competing herbs and also the opening area are negatively correlated with *Tsuga dumosa*. *Tsuga dumosa* is one of the two most dominant tree species in the survey. It is therefore justified that *Tsuga dumosa* is also disturbed in its development by large openings and a high abundance of the competitors like the total tree regeneration. Here the effective connection of the size of the opening area and the competing herbs is evident.

Picea spinulosa is positively correlated with altitude, the overall tree regeneration and strongly with *Abies densa*. For the competing herbs no significant correlation was found. The site demands seem to be very similar to the ones of *Abies densa* although *Picea spinulosa* is classified as a shade intolerant species (DARABANT et al. 2001). This contradiction may be a stochastic effect as the overall numbers of *Picea spinulosa* were very low.

Acer campbellii is positively correlated with *Salvia sp.* and *Wulfenia abliqua*. Here similar site demands may be the reason. No negative correlations were found for *Acer campbellii*.

Betula utilis is correlated positively with Flat aspect, *Acer campbellii*, *Abies densa*, *Tsuga dumosa*, the overall tree regeneration and *Wulfenia abliqua*. A negative correlation exists with the GSF values, which contradicts its status as a pioneer species.

The tree regeneration of all species is preferably located in smaller openings, where the competition by herbaceous species is less. For the opening area were found negative correlations. This confirms the assumption, that with bigger openings more competing herbs and less tree seedlings occur. The overall tree regeneration is also positively correlated with all tree species, the strongest connection exists with *Abies densa*. This is a systematic relation because *Abies densa* is the most abundant tree regeneration species in the Plot data – for the Inventory data it was *Tsuga dumosa*. Generally, seedlings of all tree species had favourable correlations (or at least tendencies) with the other tree seedlings. The correlations between the different tree seedlings imply that favourable competition situations have more or less the same requirements for regeneration of all tree species. The exact definition of this positive situation by its environmental conditions has yet to be found, but high light levels and very open conditions are not among them. Another hint for this fact is that the overall tree regeneration is negatively correlated with biomass and the GSF values, with significant results for *Acer campbellii*, *Betula utilis*, *Abies densa* and the overall tree regeneration. This may not be because of the light demands of the species themselves, but could be caused by the higher abundance of competing herbaceous species.

8.3 Influence of Light on the Herbaceous Competitor Species

Light is a key resource a plant needs for growth and survival (TILMAN 1997). This also sets the stage for competition between different species, with different abilities to use certain levels of light for photosynthesis. MOONEY & EHLERINGER (1997) say that the abundance of herbaceous vegetation is higher at higher light levels and that photosynthesis is very sensitive to variations in the supply rates of light and CO₂. In this study, the results show a positive correlation between biomass and the GSF values, which supports these statements. The principal mechanism of photosynthesis is the same for all plants, but they differ greatly in their performance in different environmental conditions like light levels, water and nutrient situations. The importance of light levels and size of the openings or gaps is fortified by the fact that GSF values and area of the opening were influential for the separation of the vegetation groups. These variables were used for the discriminant function separating the groups, which led to a good qualification.

The competition for light is of special importance in succession dynamics. VAN ANDEL (2005) argues that in plant communities equilibrium, as proposed by TILMAN (1990), cannot always be reached. This is especially the case, if the competition is for light as a resource. One of the competitors is dominant and does not leave enough light for the dominated

species to survive or this species has not enough capacity to live under shadowy conditions. The result is that the dominated species cannot use its long term advantages for more efficient use of the resources. This may result in insufficient regeneration of the desired tree species or economically unbearable long regeneration periods in a managed forest.

In old growth forests, succession is often occurring in gaps of various sizes. This mosaic of regeneration patches spread over the stand, occurs in natural forests as well as in managed forests, if a silvicultural system like group selection is used. This is the case in the study area.

The light environments in gaps are particularly diverse. It is influenced by geographical position, seasonal changes, gap size, position in the gap and gap shape, as well as the structure of the surrounding stand and the morphology of the relief. In general there is thought to be much more variance in forest gaps in light and other resources, like moisture or nutrients, than under forest canopies (BAZZAZ 1996).

As this study wanted to look into the competition between early tree regeneration and herbaceous species in forest gaps, the light levels in the study plots were important and had to be reckoned. There are different methods to measure the amount of light reaching a certain spot. The chosen method of analysing hemispherical photographs considers the aspect and the given altitude. Also the geographical latitude and longitude are incorporated into the analysis. Another advantage is that the analysis is not only a snapshot in time, but the amount of radiation for the whole year is calculated RICH (1989). The conditions for the taken photographs had been good.

8.3.1 Light Levels and Tree Regeneration

The influence of light on the competitor species and tree regeneration was recorded in the Plot data via the GSF values, calculated from the hemiphotos. The correlation analysis showed that the overall tree regeneration is negatively correlated with biomass and the GSF values. *Abies densa* – the most abundant tree regeneration species – was also negatively correlated with the GSF values.

The correlations between the different tree seedlings imply that favourable competition situations have more or less the same requirements for all regeneration species. The exact definition of this positive situation by its environmental conditions has yet to be found, but high light levels and very open conditions are not among them. These open conditions lead to a higher amount of biomass, which is consisting mainly of herbaceous competitor species. The conclusion is that higher levels of radiation facilitate the competing herbaceous species more than the tree regeneration. This may also be the reason, why only few saplings were found. They were dominated by the competing herbaceous plants and faded.

Even for the tree species classified as pioneer species, like *Acer campbellii* and *Betula utilis*, no positive correlation with the GSF values on the spots could be found. These species had

comparatively high growth rates in shady conditions of the selected tree species (DARABANT et al. 2001), which can be assumed to be traded off with a high mortality risk at low light. The conclusion is that the individual light sensitivity of the tree regeneration seems to be less important in this early stage of development. The lack of diversification in site preferences of the tree seedlings supports also the view that the separation in shade tolerant and shade intolerant species happens in a later period of the trees life.

In this early age – most of the recorded seedlings have been younger than three years – the separation in shade tolerant and shade intolerant species is probably not as pronounced as in the later development stages of the trees. This view is supported by a study of COATES (2002), who found no difference in recruitment success and preferences of the different species in a regeneration analysis in gaps.

Overall, the germination was more successful in the shady areas of the gaps – regardless of the shade tolerance rating of the tree species. YORK et al. (2003) also found in their survey of edge effects that the different species had the same ranking in growth rates in all opening sizes, which had a range from 0.1 ha to 1.0 ha, except smallest gaps. This shows that for establishment, light availability is not the main driving factor, but microsites and desiccation of seedbeds seem to play a more important role in the early establishment phase. Over time, the seedling density of the more shade tolerant species increased those of shade intolerant species decreased. This indicates an effect of competition and a higher mortality on the shade intolerant, more r-selected species.

These later competition mechanisms were not topic of this study and the few numbers of saplings in the area would have made it hard to observe it.

8.3.2 Light Levels and Herbaceous Competitors

An expected result was the positive correlation between biomass and the GSF values. It can be observed in any clearing, that with more light the mass of plants and herbs, which are in most cases competitors for the tree regeneration, increases. Although the total biomass had a positive correlation with the GSF values for the selected competing herbs species, with the exception of *Sambucus adnata*, no positive correlation with the light levels could be proven. This may be a result of the recording system.

It has to be seen in relation to the correlations with biomass on the survey plots. The most of the biomass was contributed by the larger herbaceous competitors – e.g. *Artemisia moorcroftiana* and *Sambucus adnata* are positively correlated with biomass. These herbs were chosen as the main competitors for the analysis. The fierce competition by these species was assessed in the field and this was one of the reasons for the implementation of the study in the first place.

8.3.3 Shade Tolerance/Mortality of Tree Species

The species composition in forest communities is the result of many ecological influences. Seed rain and dispersal possibilities of tree species are the basic requirements for their establishment. For the further survival of the germinants and seedlings microsites, thickness of soil layer, light availability by canopy composition and competition in the shrub and herb layer play an important role. Further composition driving forces are nutrient availability and below ground competition.

The selection of the microsite is also dependent of the size of seeds and therefore the availability of favourable microsites could be controlled. CHRISTIE & ARMESTO (2003) found that tree species with smaller seeds were found more commonly on logs, while species with larger seeds were also often found on soil. The depth of the litter layer on soil sites affects the number of seedlings of species with small seeds negatively. The litter layer, if thick enough, proves to be an effective barrier for species with smaller seeds, facilitating the germination of species with bigger seeds and giving them an advantage. This should facilitate the shade tolerant species, like the main regeneration species *Tsuga dumosa* and *Abies densa*, as they are equipped with bigger seeds than their herbaceous competitors.

The long term dynamics of an intermediate shade tolerant species are especially difficult to predict and the data on this problem is scarce so far (DOVCIK et al. 2003). One of the two main regeneration species in this study *Abies densa* has also been classified as highly shade tolerant, with low growth rates in very low light conditions and a sharp rise in productivity as light levels increase (DARABANT et al. 2001). Even more important than the growth in low light conditions is the ability of survival in very shady conditions of these species (GRATZER et al. 2004). In the same study *Tsuga dumosa* – the most or second most numerous tree species (depending on the two different study sites) – was classified as most shade tolerant. *Tsuga dumosa* is able to survive for a long time in shady conditions. *Picea spinulosa* was classified as highly shade intolerant species, with nearly no regeneration at all under closed canopies. This can be confirmed by this study as the amount of regeneration was very low in an area where regeneration occurred in relatively small gaps and no mother trees were recorded in the neighbourhood.

Light levels for tree seedlings are often influenced by understorey shrubs or small understorey trees. DOVCIK et al. (2003) tested in their study of *Pinus strobus* recruitment also a shrub recruitment filter hypothesis. Gaps in the woody understorey were responsible for the recruitment of *Pinus strobus* into intermediate size classes. The recruitment into intermediate size classes was hindered as proposed by the shrub layer and dense canopies as well. Even if the canopy layer has an adequate density the shrub layer can be a problem and this is also true for the herbaceous layer in this study. The negative canopy effects could be partly confirmed, with more successful and faster recruitment of the *Pinus strobus*

seedlings under less dense canopy or in gaps. In this study only very few seedlings had grown into the sapling stage. The most seedlings were younger than three years and it seems that their development is constricted by the herbaceous layer, as shrubs were not of high abundance in the area.

The proposition of PACALA (1997) makes successful tree regeneration over a longer regeneration period plausible. He says that in gap colonization tree species with longer survival in shady conditions are better colonizers than species with a higher growth rate in low light levels, because they have greater numbers with a head start when the gap is formed. In the traditional view these tree species were classified as the better competitors. In PACALA's view the lower mortality under shady conditions is the reason, that these tree species dominate late successional forests. BAZZAZ (1996) states that light demanding tree species are found in early successional phases, while shade tolerant tree species can be assumed to regenerate under their own shade and dominate late successional phases. He has to admit anyhow, that in spite of these assumptions many shade tolerant tree species need gaps to reach maturity.

Unfortunately in the study area only very few individuals of the tree regeneration were found in the sapling stage – nearly the whole tree regeneration has germinated after the formation of the gap with the herbaceous competitors either already in place or at least developing faster.

DORJI (2004) found in his study, conducted in the same study area, that tree regeneration in the larger openings was not sufficient, but in the smaller openings (<0.2 ha) *Tsuga dumosa* and *Abies densa* regeneration is adequate for management purposes. The maximum species diversity has occurred in openings from 0.05 to 0.4 ha. *Picea spinulosa* and *Pinus wallichiana*, the more shade intolerant species, can only establish in larger openings. In this study, the smaller openings have been also more favourable for the regeneration of the most desired tree species *Tsuga dumosa* and *Abies densa*.

In his study of regeneration in gaps in a mixed conifer forest COATES (2002) gets to similar results as DORJI found for the survey area. The tree seedlings were abundant in a wide range of gap sizes (20-5000m²), but the numbers sank rapidly in open conditions, with the exception of two pioneer species. Even for these most shade intolerant tree species no increase in seedling density could be found with increasing gap size. This was probably due to unfavourable microclimate conditions, especially drought seemed to be responsible for the tree seedlings mortality. Low numbers of tree regeneration were also recorded under closed canopy, with the exception of the most shade tolerant tree species. *Tsuga heterophylla* was most abundant in the canopy and had the highest seed and seedling production – even under the closed canopy, but survival of these tree seedlings was very low. BAZZAZ (1996) states, those large gaps receive two to three times as much direct radiation as small gaps.

The duration of the direct radiation impact is also longer and the geographical position in the gap is of great importance for the percentage and duration of direct and indirect radiation. All this leads to a variety of many different microsites concerning light availability. Air and soil temperature gradient follow the radiation gradients with a certain delay.

Tsuga dumosa and *Abies densa*, the most desired tree species in the survey area of this study, were also the most abundant. The fact that individuals of these species were almost exclusively found in very early life stages, underlines that further studies on the reasons for the lack of larger individuals are needed. In the first stages of life mortality is highest – the small plants are much more vulnerable and the unfavourable sites, which were hit by chance, are removed from the habitat selection. In an earlier study CHRISTY & MACK (1984) recorded the highest death rate among the youngest seedling cohorts, while already established regeneration had the highest survival rate. Herbivory and desiccation seemed to be the major factors in the death of the seedlings in their study.

8.4 Regeneration Types Based on Herbaceous Competitors and Site Factors

Light is not the only resource determining the chances of successful recruitment and long-term survival for tree seedlings, site factors and competition play also a major role. In this study the soil moisture or nutrient situation in the different plots were not measured.

At least for the two main tree species *Abies densa* and *Tsuga dumosa* it was tried to find a kind of regeneration site index on the basis of the site factors and main competitor vegetation species. CRAWLEY (1997c) says that abrupt environmental transitions – especially in plant communities influenced by human impact – create distinctive plant communities. Even in these it is necessary to eliminate vegetation samples including obviously unstable communities, small fragments, ecotones and mosaics to permit the development of a taxonomy classification.

In more natural forests, ecologists have found more gradual, smooth changes in environmental conditions. This sometimes made the erection of taxonomy impossible, as no areas were found with the same set of species in the same relative abundances (CRAWLEY 1997c). In this study it was also difficult to find distinctive regeneration types with clear limits for the vegetation species. There are positive correlations for the regeneration species among each other and with the overall tree regeneration. The assumption is that a positive regeneration situation for one tree species is also favourable for the others.

There is a strong connection between the two most important regeneration species *Tsuga dumosa* and *Abies densa*, which only made it harder to define separate regeneration types. Of the tree regeneration variables the most important species *Abies densa* and *Tsuga dumosa* were not used in the discriminant analysis. These two species as the most abundant ones had probably too little separating effect.

Abies densa was located in the higher altitudes, which coincides with its general habitat and it is a worse competitor than *Tsuga dumosa* concerning the selected competing herbs.

Tsuga dumosa is not as sensitive to the herbaceous competition, especially *Salvia sp.* and *Osmunda sp.* – the fern species –, may occur in higher numbers.

The differences in their competitive ability are not strong enough, so both species require small openings with relatively low light levels to keep the herbaceous competitors under control. The presence of other coniferous regeneration hints at good sites for *Abies densa* and *Tsuga dumosa* germination and recruitment – the long term survival and growth on the respective sites is a different matter.

In the study site some tree species, in particular *Picea spinulosa* and *Pinus wallichiana*, were limited in their occurrence, because no mother trees were stocking in the old growth. This result is supported by the study of DORJI (2004), who also recorded the lack of mother trees of these species in the same area.

TSHERING (2005) found for the data material of this study, that moss was the favoured microsite of germination for the tree species. The distribution of the regeneration on microsites shows, that most of the *Abies densa*, *Tsuga dumosa* and *Picea spinulosa* regeneration occurred on moss, moss covered or rotten logs. The second most favourable microsite was other litter than bamboo litter. So the preference for microsites provides also no clear separation between *Abies densa* and *Tsuga dumosa*.

No significant correlations of *Artemisia moorcroftiana* with the tree regeneration exist. That is unsatisfying, as field observation suggested it to be a major competitor. Maybe the reason is a too small sample size and demands further analysis.

For *Yushania microphylla* and the tree regeneration a negative tendency was noted – although not significantly. All other selected competing herbaceous species produced no consistent results for the two data collection areas.

The tree regeneration was hindered by the amount of biomass in the plots, which supports one of the basic assumptions of the thesis. Only for *Abies densa* this statement could be made on a species level. Although the other species were also negatively influenced, there were no significant results. A supporting fact of the negative influence of larger openings is that the additional GSF data for the plot sites produced also negative correlations with all tree seedlings – significant ones for *Acer campbellii*, *Betula utilis*, *Abies densa* and the total tree regeneration.

The regeneration types are limited to one for *Abies densa* and one for *Tsuga dumosa* as these were the most abundant and most important observed tree species. As variables have been used the selected competing herbs, the site factors and the other selected tree species. The values of the variables were classified into classes of low medium or high influence for

Abies densa respectively *Tsuga dumosa* regeneration regarding the results of the different analysis’.

Table 23: Regeneration Types

		low	medium	high
Abies densa	<i>Artemisia moorcroftiana</i>	x	x	
	<i>Osmunda sp.</i>	x	x	
	<i>Salvia sp.</i>	x	x	
	<i>Sambucus adnata</i>		x	
	<i>Senecio graciliflorus</i>		x	
	<i>Wulfenia abliqua</i>	x		
	<i>Yushania microphylla</i>	x		
	Total competing herbs	x		
	Altitude			x
	Gradient		x	
	Opening area		x	
	Biomass	x		
	GSF	x		
	Aspect N		x	x
	Aspect E		x	x
	Aspect S	x	x	
	Aspect W	x	x	
	Aspect Flat		x	
	<i>Abies densa</i>			x
	<i>Tsuga dumosa</i>			x
	<i>Picea spinulosa</i>		x	x
	<i>Pinus wallichiana</i>		x	
	<i>Acer campbellii</i>		x	x
	<i>Betula utilis</i>		x	x
	Total regeneration			x
Tsuga dumosa	<i>Artemisia moorcroftiana</i>	x	x	
	<i>Osmunda sp.</i>		x	x
	<i>Salvia sp.</i>	x	x	x
	<i>Sambucus adnata</i>	x	x	
	<i>Senecio graciliflorus</i>	x	x	
	<i>Wulfenia abliqua</i>		x	
	<i>Yushania microphylla</i>	x	x	
	Total competing herbs	x	x	
	Altitude	x	x	
	Gradient		x	x
	Opening area	x	x	
	Biomass	x		
	GSF	x		
	Aspect N		x	
	Aspect E		x	
	Aspect S		x	
	Aspect W	x	x	x
	Aspect Flat		x	
	<i>Abies densa</i>			x
	<i>Tsuga dumosa</i>			x
	<i>Picea spinulosa</i>		x	x
	<i>Pinus wallichiana</i>		x	
	<i>Acer campbellii</i>		x	x
	<i>Betula utilis</i>		x	x
	Total regeneration			x

Regeneration types for the main tree species should be deduced from the clusteranalysis, the factor and the correlation analysis. No mathematical method was available to summarize

the different methods, therefore the influence and importance of the different analysis results was estimated. The results can be seen in *Table 23*.

According to the results *Abies densa* needs an area of higher altitude with N or E aspect. Openings shall be small, with low levels of radiation. At best *Artemisia moorcroftiana*, *Salvia sp.*, *Osmunda sp.*, *Wulferia abliqua* and *Yushania microphylla*, the strongest competitors, shall not occur or only in small numbers. The presence of moss microsites and other tree regeneration hints also at favourable sites.

Tsuga dumosa is most impeded by competition of *Artemisia moorcroftiana*, *Sambucus adnata*, *Senecio graciliflorus* and *Yushania microphylla*. Generally it occurs more often in lower altitudes than *Abies densa* and on steeper slopes. It showed no preference for a single aspect. Large openings and high radiation levels are also less favourable, due to higher herbaceous competition. The presence of moss microsites or nurse logs and other tree regeneration is also a hint for good regeneration conditions.

8.5 Management Implications

The results of the study suggest that small gaps are better for the regeneration of the desired tree species *Abies densa* and *Tsuga dumosa*. CARSWELL et al. (2007) says that without major disturbances angiosperms will strongly dominate the canopy as a result of shade tolerance and competition.

YORK et al. (2003) defines the group selection system as an uneven aged silvicultural system, with periodic harvesting of small groups of trees, with a stand density control system for the standing trees surrounding the openings. The openings resemble natural forest gaps. Over time the forest is rejuvenated in a mosaic like structure.

COATES (2002) also favours regeneration in gaps because in his study by far the best seedling recruitment for most species was found in canopy gaps. No difference in recruitment success and preferences of the different species could be found. The germination was more successful in the shady areas of the gaps – regardless of the shade tolerance rating of the tree species. Also most species in the canopy are wind-dispersed and the seed dispersal distances were much lower in partially cut stands than at clear cut edges. Over time the seedling density of the more shade tolerant species increased, those of shade intolerant species decreased. Patience is necessary to really assess the regeneration success of a silvicultural measure.

The already implied group selection system should work for the purpose, if the gaps are kept small enough and circular. It is especially important for small gaps to cut the gaps in circular shape, because small gaps have a higher edge/interior ratio due to edge effects and a circular shape minimises the ratio. YORK et al. (2003) found that the calculated edge effects were strongly species dependent. For management the planting pattern should be adapted according to light and water demands of the different species. In spite of this,

planning later silvicultural measures, like thinning or harvesting the surrounding canopy, may change the edge effects considerably.

COATES (2000) reckons that in harvest operations the distribution of canopy trees after harvest has to be taken into special consideration, because of growth impeding effects on the regeneration. Therefore patch applications like group selection systems shall be favoured over evenly distributed systems like shelterwood systems. He also recommends planting the light demanding species not in the shady areas of the gaps. The gaps need not be bigger than 0.1 – 0.2 ha, because most species reach in this size of gaps a similar performance to open conditions in clearcuts.

DORJI (2004) found in his study conducted in the same study area, that regeneration in the larger openings was not sufficient, but in the smaller openings (<0.2 ha) *Tsuga dumosa* and *Abies densa* regeneration is adequate for management purposes. The maximum species diversity is occurring in openings from 0.05 to 0.4 ha. *Picea spinulosa* and *Pinus wallichiana*, the more shade intolerant species, can only establish in larger openings.

Another reason for small openings is that canopy openings may cause stress or even death to the species in the gap, due to radical changes in resources. Even the increase in, formerly observed as growth limiting, resources may not always lead to positive reactions, because the congruence of the resources like light, water and nutrients is disturbed (BAZZAZ 1996).

In this study regeneration density was also highest on the southern edge of the openings. The main regeneration species are shade tolerant and regenerate better at the edges of the gaps, shade intolerant ones at the centre. It may be necessary to plant additional trees from forest nurseries on the northern edges respectively centres of larger gaps. These fostered plants should be grown from local seeds. Planting is inevitable if more light demanding species are wished for (CARSWELL et al. 2007).

One example of impeded tree regeneration is given by DOVCIK et al. (2003) who found that the recruitment into intermediate size classes was hindered as proposed by the shrub layer and dense canopies as well. Even if the canopy layer had an adequate density the shrub layer can be a problem. When the saplings reach a certain height (> 1m), shrub elimination has only positive effects, if paired with a reduction in the canopy layer. Short cutting cycles and frequent competition control should secure the desired regeneration, together with following harvesting operations to facilitate the grown regeneration. DE LA CRETZ & KELTY (2002) defined three reasons for treatment, depending on the density of herbaceous coverage (in this case fern coverage) and the abundance of tree seedlings. 1 – to allow any tree regeneration at all, 2 – to broaden the range of species diversity and 3 – to speed up the development of tree regeneration. A suggested treatment would be mowing or using herbicides, other practices that involve disturbance of the soil only result in a higher density of herbs than before.

The removal of desired advance regeneration in harvesting operations has to be avoided, given the saplings are unharmed by the harvesting. This is especially necessary as the shade tolerant species often have a sapling bank with established regeneration in a waiting stage under the existing canopy.

If the group selection system does not yield the desired results, in spite of the good prospects, another option might be a shelterwood cutting system. The shade tolerant desired tree species of *Abies densa* and *Tsuga dumosa* should regenerate well under low light levels and the competition by herbaceous plants should be less. A preposition for a successful shelter wood cutting system is that the degree of stocking is lowered only a little (maximum to 0.8) to keep the light levels low. This silvicultural system is only possible to use, if single tree harvesting techniques are possible and the costs are justifiable.

Seedbed manipulation to get mineral soil and humus layer microsites is not asked for, because the desired species have shown to prefer rotten logs or litter as germination microsites. Also the seedbed manipulation improves germination for many species, the desired tree species as well as the herbaceous competitors. The effect may also be very time limited as for example CALOGEROPOULOS et al. (2004) found that one year after treatment the germination on manipulated seedbeds already decreased significantly, through new litter on the seedbeds.

Amelioration of the sites seems not to be necessary, as the growing plants indicate mostly sufficient nutrient and water levels. Also the costs of such measures would be rather high.

Browsing by yaks and cows as well as other mammal species may also play a role in the future. TSHERING (2005) looked into the facilitation or impediment by browsing in the study area and found only minor effects, but possible future effects imply that this must be kept under observation.

8.5.1 Field Guide

Special attention has to be paid to the small size of openings in the group selection system, if the strongest herbaceous competitors are already present at the respective sites or in the immediate neighbourhood. In these conditions it could also be advisable to use a shelterwood cutting system.

These strongest competitors for *Abies densa* and *Tsuga dumosa* regeneration are:

- *Artemisia moorcroftiana*
- *Salvia sp.*
- *Sambucus adnata* & *Senecio graciliflorus*
- *Osmunda sp.*
- *Yushania microphylla* & *Wulfenia abliqua*

9 Conclusions

The study shows that the herbaceous competitors have a strong influence on the desired tree regeneration in the study area. *Abies densa* and *Tsuga dumosa* were the most abundant species in the seedling and sapling stage, while *Picea spinulosa* occurred only in low numbers. The most important competitor species have been *Artemisia moorcroftiana*, *Salvia* sp., *Sambucus adnata* and *Yushania microphylla*. For the herbaceous competitors as a whole a negative trend of influence has been found for the coniferous tree regeneration. The correlations have been sometimes weak and not always coherent for the two study areas of Gidakom FMU and Chamgang FMU, but the general picture supports the assumption of negative influence on the tree regeneration by the selected herbaceous species.

No clear differences in the site demands of the competitor species have been recognisable, although different preferences and hints at plant communities were found. A general principle found by the analysis in the study is that bigger openings with higher light levels facilitate the herbaceous competitors more than the tree regeneration. The shade tolerance rating of the tree species seems to play a subordinate role in the early development stages of the regeneration found in the study area. A separation of the competitor species, due to their light demands, could not be done on species level.

For the two most abundant tree regeneration species *Abies densa* and *Tsuga dumosa*, regeneration types were developed. Because of site differences of the two study areas and because these two most abundant species were also rather similar in its site requirements, the distinction between the groups was rather smooth. For the other species it seemed not sensible to segregate special regeneration types, due to low numbers of occurrence and less importance of the species.

The management implications recommend the further use of the group selection system, with small circular gaps and additional afforestation in the bare spots. Another possibility might be the use of a shelterwood system, if this is economically and technically feasible. The shade tolerance of *Abies densa* and *Tsuga dumosa*, the mainly desired tree species, should allow their recruitment under low light levels in low grade thinnings. This should also keep the herbaceous competition under control. The impact of browsing has also to be kept under surveillance for the future development of the tree regeneration.

10 References

- ABE M.; IZAKI J.; MIGUCHI H.; MASAKI T.; MAKITA A.; NAKASHIZUKA T.; (2002); The effects of *Sasa* and canopy gap formation on tree regeneration in an old beech forest; *Journal of Vegetation Science*, 13, 565 – 574.
- AMMER C.; (1996); Impact of ungulates on structure and dynamics on natural regeneration of mixed mountain forests in the Bavarian Alps; *Forest Ecology and Management*, 88, 43 – 53.
- ANTOS J.A.; HEIDI J.G.; PARISH R.; (2005); The tree seedling bank in an ancient montane forest: stress tolerators in a productive habitat; *Journal of Ecology*, 93, 536 – 543.
- BACKHAUS K.; ERICHSON B.; PLINKE W.; WEIBER R.; (2006); *Multivariate Analysemethoden – Eine anwendungsorientierte Einführung*; Verlag Springer, Berlin, GER.
- BAIER R.; MEYER J.; GÖTTLEIN A.; (2007); Regeneration niches of Norway spruce (*Picea abies* [L.] Karst.) saplings in small canopy gaps in mixed mountain forests of the Bavarian Limestone Alps; *Eur. J. Forest Res*, 126, 11 – 22.
- BAZZAZ F.A.; (1996); *Plants in changing environments: linking physiological, population and community ecology*; Cambridge University Press, Cambridge, UK, 239 – 263.
- BOTKIN D.B.; (1992); *The ecology of forests: theory and Evidence*; Oxford University Press, New York, US.
- CALOGEROPOULOS C.; GREENE D.F.; MESSIER C.; BRAIS S.; (2004); The effects of harvest intensity and seedbed type on germination and cumulative survivorship of white spruce and balsam fir in north-western Quebec; *Can. J. For. Res.*, 34, 1467 – 1476.
- CARSWELL F.E.; RICHARDSON S.J.; DOHERTY J.E.; ALLEN R.B.; WISER S.K.; (2007); Where do conifers regenerate after selective harvest? A case study from a New Zealand conifer-angiosperm forest; *Forest Ecology and Management*, in press, doi: 10.1016/j.foreco.2007.07.011.
- CHRISTY J.E.; MACK R.N.; (1984); Variation in demography of juvenile *Tsuga heterophylla* across the substratum mosaic; *Journal of Ecology*, 72, 1, 75 – 91.
- CHRISTIE D.A.; ARMESTO J.J.; (2003); Regeneration microsites and tree species coexistence in temperate rain forests of Chiloé Island, Chile; *Journal of Ecology*, 91, 776 – 784.
- COATES K.D.; (2000); Conifer seedling response to northern temperate forest gaps; *For. Ecol. Manage.*, 127, 249 – 269.
- COATES K.D. (2002); Tree recruitment in gaps of various size, clearcuts and undisturbed mixed forest of interior British Columbia, Canada; *For. Ecol. Manage.*, 155, 387 – 398.
- CRAWLEY M.J.; (1997a); Life history and environment; In: CRAWLEY M.J. (ed.); *Plant Ecology*; Blackwell Science, pp. 73 – 131.
- CRAWLEY M.J.; (1997b); Plant – herbivore dynamics; In: CRAWLEY M.J. (ed.); *Plant Ecology*; Blackwell Science, pp. 401 – 474.

CRAWLEY M.J.; (1997c); Structure of plant communities; In: CRAWLEY M.J. (ed.); Plant Ecology; Blackwell Science, pp. 475 – 531.

DARABANT A., CHHETRI P.B., RAI P.B., DORJI K., GRATZER G.; (2001); Light requirements of the main tree species in Bhutan's conifer belt; RNR-RC Jakar Special Publication No. 4.

DARABANT A.; RAI P.B.; TENZIN K.; RÖDER W.; GRATZER G.; (2007); Cattle grazing facilitates tree regeneration in a conifer forest with palatable bamboo understorey; Forest Ecology and Management, in Press, doi: 10.1016/j.foreco.2007.06.018

DE LA CRETAZ A.L.; KELTY M.J.; (2002); Development of tree regeneration in fern dominated forest understoreys after reduction of deer browsing; Restor. Ecol., 10, 416 – 426.

DEPARTMENT OF FORESTRY; (2002); Management Plan for Gidakom Forest Management Unit (2002 – 2012); Department of Forestry, Ministry of Agriculture, Royal Government of Bhutan, Thimphu, Bhutan.

DHITAL D.B., PUSHPARAJAH M., MÄÄTTÄ M.; (1992); Management plan for Gidakom forest management unit – Thimphu district; Forest Resources Management Division; Thimphu; Bhutan.

DORJI S.; (2004); Natural regeneration at cable crane logged sites in the mixed conifer belt of Gidakom Forest Management Unit, Thimphu, Bhutan; M.Sc. thesis, University of Applied Life Sciences, Vienna, Austria.

DOVCIK M.; REICH P.B.; FRELICH L.E.; (2003); Seed rain, safe sites, competing vegetation, and soil resources spatially structure white pine regeneration and recruitment; Can. J. For. Res., 33, 1892 – 1904.

ESKELINEN A.; VIRTANEN R.; (2005); Local and regional processes in low-productive mountain plant communities: the roles of seed and microsite limitation in relation to grazing; OIKOS, 110, 360 – 368.

FOREST AND NATURE CONSERVATION ACT; (1995); Ministry of Agriculture, Thimphu, Royal Government of Bhutan.

GLENN-LEWIN D.C.; VAN DER MAAREL E.; (1992); Patterns and processes of vegetation dynamics; In: GLENN-LEWIN D.C., PEET R.K., VEBLEN T.T. (Eds.); Plant Succession; Chapman and Hall, London, UK, pp. 11 – 60.

GODER H.A.; (1961); Hemlock reproduction and survival on its border in Wisconsin; Wisc. Acad. Of Sci.; Arts and Let., 50, 175 – 181.

GOERLICH D.L., NYLAND R.D.; (1999) Natural Regeneration of Eastern Hemlock: A Review; Proceedings: Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America; GTR-NE-267.

GRATZER G., RAI P.B., GLATZEL G.; (1999); The influence of the bamboo *Yushania microphylla* on the regeneration of *Abies densa* in central Bhutan; Can. J. For. Res., 29: 1518 – 1527.

GRATZER G., DARABANT A., CHHETRI P.B., RAI P.B., ECKMÜLLNER O.; (2004); Light response of six tree species in the conifer belt of the Bhutan Himalayas; Can. J. For. Res., 34: 1093 – 1107.

- GRIERSON A.J.C., LONG D.G.; (1983); Flora of Bhutan, Part 1, Volume 1; Royal Botanic Garden, Edinburgh, p 186.
- GRIME J.P.; (2001); Plant strategies, vegetation processes and ecosystem properties; 2nd edition, John Wiley and Sons, New York, N.Y..
- GYELTSSEN N.; (2008); Regeneration ecology of broadleaved forests of Bhutan – Effects of Strobilanthes competition on tree regeneration; M.Sc. thesis, University of Applied Life Sciences, Vienna, Austria.
- KOZLOWSKI T.T.; (2002); Physiological ecology of natural regeneration of harvested and disturbed stands: implications for forest management; For. Ecol. Manage., 158, 195 – 221.
- LARSEN J.B.; (1995); Ecological stability of forests and sustainable silviculture; For. Ecol. Manage., 73, 85 – 96.
- LEONHART R.; (2004); Lehrbuch Statistik – Einstieg und Vertiefung; Verlag Hans Huber, Hogrefe AG, Bern, CH.
- MOONEY H.A.; EHRLINGER J.R.; (1997); Photosynthesis; In: CRAWLEY M.J. (ed.); Plant Ecology; Blackwell Science, pp. 1 – 27.
- NARUKAWA Y.; YAMAMOTO S.; (2002); Effects of dwarf bamboo (*Sasa sp.*) and forest floor microsites on conifer seedling recruitment in a sub alpine forest, Japan; Forest Ecology and Management, 163, 61 – 70.
- OLIVER C.D., LARSON B.C.; (1996); Forest stand dynamics; Updated Ed.; John Wiley & Sons, New York, NY.
- OHSAWA M.; (1987); Vegetation zones in the Bhutan Himalaya; In: OHSAWA M. (ed.); Life Zone Ecology of the Bhutan Himalaya, Laboratory of Ecology, Chiba University, p 313.
- OHSAWA M.; (1995); Latitudinal comparisons of altitudinal changes in forest structure, leaf type and species richness in humid monsoon Asia; Vegetation, 121, 3 – 10.
- PACALA S.W.; (1997); Dynamics of plant communities; In: CRAWLEY M.J. (ed.); Plant Ecology; Blackwell Science, pp. 532 – 555.
- PICKETT S.T.A.; CADENASSO M.L.; (2005); Vegetation dynamics; In: VAN DER MAAREL (Ed.); (2005); Vegetation Ecology, Blackwell Science Ltd., Oxford, UK, 172 – 198.
- REES M.; (1997); Seed dormancy; In: CRAWLEY M.J. (ed.); Plant Ecology; Blackwell Science, pp. 214 – 238.
- RESCO DE DIOS V.; YOSHIDA T.; IGA Y.; (2005); Effects of topsoil removal by soil-scarification on regeneration dynamics of mixed forests in Hokkaido, Northern Japan; Forest Ecology and Management, 215, 138 – 148.
- RICH P.M.; (1989); A manual for analysis of hemispherical canopy photography; Los Alamos National Laboratory - 87545, Los Alamos, New Mexico.
- RICH P.M.; (1990); Characterizing plant canopies with hemispherical photographs; Remote Sensing Reviews, 5, 13 – 29; In: Goel N.S. and Norman J.M.(eds.); (1990); Instrumentation for Studying Vegetation Canopies for Remote Sensing in Optical and Thermal Infrared Regions, Remote Sensing Reviews Special Issue.

- SCHWEINFURTH U.; (1984); The Himalaya: complexity of a mountain system manifested by its vegetation; *Mountain Research and Development*, 4 (4), 339 – 344.
- SYDES C.; GRIMES J.P.; (1981a); Effects of tree leaf litter on herbaceous vegetation in deciduous woodland, field investigations; *Journal of Ecology*, 69, 237 – 248.
- SYDES C.; GRIMES J.P.; (1981b); Effects of tree leaf litter on herbaceous vegetation in deciduous woodland, an experimental investigation; *Journal of Ecology*, 69, 249 – 262.
- TILMAN D.; (1990); Constraints and tradeoffs: toward a predictive theory of competition and succession; *Oikos*, 58, 3 – 15. or (1982); *Resource competition and community structure*; Princeton University Press, Princeton, US.
- TILMAN D.; (1997); Mechanisms of plant competition; In: CRAWLEY M.J. (ed.); *Plant Ecology*; Blackwell Science, pp. 239 – 261.
- TSHERING P.; (2005); The interaction of grazing and competition in the conifer forest of Bhutan; M.Sc. thesis, University of Applied Life Sciences, Vienna, Austria.
- VAN ANDEL J.; (2005); Species interactions structuring plant communities; ; In: VAN DER MAAREL (Ed.); (2005); *Vegetation Ecology*, Blackwell Science Ltd., Oxford, UK, 238 – 264.
- VAN DER VALK A.G.; (1992); Establishment, colonization and persistence, in the plant succession: theory and prediction; In: GLENN-LEWIN D.C., PEET R.K., VEBLEN T.T. (Eds.); *Plant Succession*; Chapman and Hall, London, UK, pp. 60 – 102.
- VEBLEN T.T.; (1992); Regeneration dynamics; In: GLENN-LEWIN D.C., PEET R.K., VEBLEN T.T. (Eds.); *Plant Succession*; Chapman and Hall, London, UK, pp. 152 – 187.
- WANGCHUK K.; (2007); Natural regeneration ecology of mixed conifer forests in Western Bhutan; M.Sc. thesis, University of Applied Life Sciences, Vienna, Austria.
- WANGDA P.; OHSAWA M.; (2006); Structure and regeneration dynamics of dominant tree species along altitudinal gradient along in a dry valley slope of the Bhutan Himalaya; *Forest Ecology and Management*, 230, 136 – 150.
- WIEDENBECK M.; ZÜLL C.; (2001); Klassifikation mit Clusteranalyse: Grundlegende Techniken hierarchischer und K-means-Verfahren; Zentrum für Umfragen, Methoden und Analysen, Mannheim; ZUMA How to – Reihe, Nr. 10.
- YORK R.A.; BATTLES J.J.; HEALD R.C.; (2003); Edge effects in mixed conifer group selection openings: tree height response to resource gradients; *Forest Ecology and Management*, Vol 179, Issues 1-3, pp. 107 – 121.

11 Annex

Annex 1: Descriptive Statistics Selected Competing Herbs – Inventory Data

	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
N	470	470	470	470	470	470	470	470
Maximum	80	80	80	150	70	80	110	225
Minimum	0	0	0	0	0	0	0	0
Mean	3.75	4.88	2.76	3.79	1.91	6.81	14.84	88.00
Std. Error of Mean	0.55	0.51	0.45	0.65	0.32	0.56	1.24	1.47
Variance	143.69	124.37	96.64	197.33	49.08	148.39	718.38	1016.31
Kurtosis	18.47	12.46	27.66	39.81	38.16	7.95	2.31	1.97
Skewness	4.09	3.25	4.98	5.71	5.57	2.57	1.84	0.61
Sum	1762	2294	1295	1779	897	3202	6976	41362

Annex 2: Descriptive Statistics Selected Regeneration – Inventory Data

	<i>Abies densa</i>	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Picea spinulosa</i>	<i>Pinus wallichiana</i>	<i>Tsuga dumosa</i>	Total Regeneration
N	470	470	470	470	470	470	470
Maximum	107	40	35	34	21	433	519
Minimum	0	0	0	0	0	0	0
Mean	2.48	0.37	0.71	0.73	0.25	7.87	12.71
Std. Error of Mean	0.41	0.15	0.18	0.11	0.06	1.28	1.53
Variance	78.39	10.97	14.96	5.45	1.57	766.35	1096.18
Kurtosis	73.23	113.34	45.66	92.72	165.37	123.57	118.89
Skewness	7.70	10.47	6.58	7.86	11.11	9.27	8.76
Sum	1165	176	332	341	119	3700	5974

Annex 3: Descriptive Statistics Selected Competing Herbs – Plot Data

	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
N	90	90	90	90	90	90	90	90
Maximum	52	51	47	11	130	82	18	410
Minimum	0	0	0	0	0	0	0	38
Mean	5.43	8.11	3.67	0.72	19.61	2.96	2.34	185.31
Std. Error of Mean	1.27	1.19	0.73	0.21	2.84	1.07	0.40	9.06
Variance	145.55	127.40	48.13	3.82	726.91	103.57	14.54	7384.67
Kurtosis	5.63	3.65	17.52	12.23	3.51	42.74	3.97	-0.40
Skewness	2.55	1.93	3.58	3.42	1.91	6.05	1.98	0.56
Sum	489	730	330	65	1765	266	211	16678

Annex 4: Descriptive Statistics Selected Regeneration – Plot Data

	<i>Abies densa</i>	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Picea spinulosa</i>	<i>Tsuga dumosa</i>	Total Regeneration
N	90	90	90	90	90	90
Maximum	135	19	14	38	148	235
Minimum	0	0	0	0	0	0
Mean	17.93	0.99	0.82	1.61	9.19	30.54
Std. Error of Mean	2.71	0.25	0.24	0.49	2.68	4.52
Variance	733.84	6.17	5.81	23.90	717.26	2047.49
Kurtosis	4.53	31.90	14.31	37.58	18.24	6.28
Skewness	2.07	4.99	3.71	5.67	4.20	2.34
Sum	1614	89	74	145	827	2749

Annex 5: Correlations – Inventory Data

		Altitude (masl)	Gradient (deg)	Opening area	Aspect N (gon)	Aspect E (gon)	Aspect S (gon)	Aspect W (gon)	Aspect Flat (gon)	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Pinus wallichiana</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	Total Regeneration	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
Altitude (masl)	Pearson Correlation	1.00	0.06	-0.11(**)	-0.06	-0.25(**)	0.21(**)	0.17(**)	.(a)	-0.02	-0.05	-0.23(**)	0.12(**)	-0.05	-0.05	-0.03	0.11(*)	-0.07	-0.16(**)	-0.01	0.07	-0.04	-0.07	-0.09(**)
	Sig. (2-tailed)		0.24	0.02	0.21	0.00	0.00	0.00	0.00	0.69	0.28	0.00	0.01	0.26	0.25	0.49	0.02	0.13	0.00	0.79	0.16	0.43	0.15	0.05
	N	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Gradient (deg)	Pearson Correlation	0.06	1.00	0.02	-0.18(**)	-0.27(**)	0.38(**)	0.19(**)	.(a)	0.02	0.12(**)	0.00	-0.03	0.01	-0.05	0.01	-0.03	-0.09	0.00	-0.11(*)	-0.16(**)	0.00	0.10(*)	-0.04
	Sig. (2-tailed)	0.24		0.63	0.00	0.00	0.00	0.00	0.00	0.69	0.01	0.93	0.55	0.91	0.34	0.84	0.56	0.07	0.96	0.02	0.00	0.93	0.04	0.37
	N	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Opening area	Pearson Correlation	-0.11(*)	0.02	1.00	0.05	0.07	-0.07	-0.07	.(a)	-0.06	0.05	0.05	-0.05	-0.13(**)	-0.03	-0.13(**)	0.01	-0.05	0.10(*)	0.07	-0.07	-0.02	0.05	0.07
	Sig. (2-tailed)	0.02	0.63		0.34	0.12	0.12	0.12	0.00	0.21	0.26	0.30	0.26	0.00	0.57	0.01	0.83	0.29	0.03	0.15	0.16	0.74	0.30	0.16
	N	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450	450
Aspect N (gon)	Pearson Correlation	-0.06	-0.18(**)	0.05	1.00	-0.45(**)	-0.29(**)	-0.39(**)	-0.16(**)	0.00	0.02	0.03	0.12(**)	-0.03	0.06	0.01	0.17(**)	0.14(**)	0.12(**)	-0.04	0.04	0.00	-0.08	0.07
	Sig. (2-tailed)	0.21	0.00	0.34		0.00	0.00	0.00	0.00	0.92	0.67	0.51	0.01	0.52	0.19	0.76	0.00	0.00	0.01	0.38	0.44	0.98	0.08	0.12
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
Aspect E (gon)	Pearson Correlation	-0.25(**)	-0.27(**)	0.07	-0.45(**)	1.00	-0.22(**)	-0.29(**)	-0.12(**)	0.05	-0.02	0.06	0.00	0.07	0.01	0.07	-0.04	-0.06	0.00	0.00	0.10(*)	-0.05	-0.05	-0.08
	Sig. (2-tailed)	0.00	0.00	0.12	0.00		0.00	0.00	0.01	0.29	0.61	0.16	0.94	0.11	0.89	0.14	0.37	0.19	0.98	1.00	0.04	0.28	0.24	0.10
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
Aspect S (gon)	Pearson Correlation	0.21(**)	0.38(**)	-0.07	-0.29(**)	-0.22(**)	1.00	-0.19(**)	-0.08	0.00	-0.05	-0.06	-0.10(*)	-0.06	-0.04	-0.09(*)	-0.12(**)	-0.05	-0.10(*)	-0.10(*)	-0.10(*)	0.03	0.11(**)	-0.05
	Sig. (2-tailed)	0.00	0.00	0.12	0.00	0.00		0.00	0.08	0.97	0.25	0.18	0.04	0.18	0.42	0.05	0.01	0.32	0.03	0.03	0.02	0.47	0.01	0.30
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
Aspect W (gon)	Pearson Correlation	0.17(**)	0.19(**)	-0.07	-0.39(**)	-0.29(**)	-0.19(**)	1.00	-0.11(*)	-0.05	0.04	-0.04	-0.04	0.01	-0.04	-0.01	-0.04	-0.05	-0.04	0.16(**)	-0.07	0.05	0.04	0.06
	Sig. (2-tailed)	0.00	0.00	0.12	0.00	0.00	0.00		0.02	0.31	0.41	0.36	0.36	0.80	0.35	0.88	0.44	0.29	0.35	0.00	0.13	0.28	0.39	0.18
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
Aspect Flat (gon)	Pearson Correlation	.(a)	.(a)	.(a)	-0.16(**)	-0.12(**)	-0.08	-0.11(*)	1.00	-0.03	0.02	-0.03	-0.03	-0.01	-0.01	-0.02	-0.05	-0.03	-0.05	-0.06	0.01	-0.05	0.04	-0.05
	Sig. (2-tailed)	0.00	0.00	0.00	0.00	0.01	0.08	0.02		0.55	0.73	0.58	0.56	0.84	0.81	0.70	0.30	0.48	0.25	0.22	0.75	0.27	0.38	0.27
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
<i>Acer campbellii</i>	Pearson Correlation	-0.02	0.02	-0.06	0.00	0.05	0.00	-0.05	-0.03	1.00	0.07	0.04	-0.03	-0.01	0.03	0.11(*)	-0.04	-0.02	-0.02	-0.03	-0.03	-0.04	0.00	-0.06
	Sig. (2-tailed)	0.69	0.69	0.21	0.92	0.29	0.97	0.31	0.55		0.15	0.41	0.50	0.83	0.57	0.02	0.38	0.67	0.59	0.53	0.47	0.45	1.00	0.19
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
<i>Betula utilis</i>	Pearson Correlation	-0.05	0.12(**)	0.05	0.02	-0.02	-0.05	0.04	0.02	0.07	1.00	-0.03	-0.02	0.01	0.06	0.13(**)	-0.05	0.06	-0.03	-0.05	-0.05	0.04	-0.03	-0.04
	Sig. (2-tailed)	0.28	0.01	0.26	0.67	0.61	0.25	0.41	0.73	0.15		0.48	0.68	0.83	0.19	0.00	0.30	0.17	0.52	0.32	0.28	0.42	0.54	0.33
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
<i>Pinus wallichiana</i>	Pearson Correlation	-0.23(**)	0.00	0.05	0.03	0.06	-0.06	-0.04	-0.03	0.04	-0.03	1.00	-0.04	0.06	0.29(**)	0.10(*)	-0.02	0.03	-0.04	-0.05	-0.01	0.01	0.03	0.00
	Sig. (2-tailed)	0.00	0.93	0.30	0.51	0.16	0.18	0.36	0.58	0.41	0.48		0.42	0.22	0.00	0.04	0.74	0.52	0.39	0.33	0.85	0.88	0.46	0.98
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
<i>Abies densa</i>	Pearson Correlation	0.12(**)	-0.03	-0.05	0.12(**)	0.00	-0.10(*)	-0.04	-0.03	-0.03	-0.02	-0.04	1.00	0.37(**)	0.06	0.58(**)	-0.01	0.04	-0.06	-0.06	0.02	-0.04	-0.13(**)	-0.15(**)
	Sig. (2-tailed)	0.01	0.55	0.26	0.01	0.94	0.04	0.36	0.56	0.50	0.68	0.42		0.00	0.21	0.00	0.88	0.39	0.16	0.19	0.61	0.33	0.01	0.00
	N	450	450	450	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470	470
<i>Tsuga dumosa</i>	Pearson Correlation	-0.05	0.01	-0.13(**)	-0.03	0.07	-0.06	0.01	-0.01	-0.01	0.01	0.06	0.37(**)	1.00	0.14(**)	0.95(**)	-0.04	0.03	-0.08	-0.07	-0.01	0.01	-0.05	-0.10(*)
	Sig. (2-tailed)	0.26	0.91	0.00	0.52	0.11	0.18	0.80	0.84	0.83	0.83	0.22	0.00		0.00	0.00	0.39	0.50	0.09	0.13	0.85	0.90	0.24	0.03
	N	450	450	450	470	470	470	470	470	470	470</													

Annex 6: Correlations – Plot Data

		Altitude (masl)	Gradient (deg)	Opening area	Biomass dry (g)	GSF value	Aspect N (gon)	Aspect E (gon)	Aspect S (gon)	Aspect W (gon)	Aspect Flat (gon)	<i>Acer campbellii</i>	<i>Betula utilis</i>	<i>Abies densa</i>	<i>Tsuga dumosa</i>	<i>Picea spinulosa</i>	Total Regeneration	<i>Artemisia moorcroftiana</i>	<i>Osmunda sp.</i>	<i>Salvia sp.</i>	<i>Sambucus adnata</i>	<i>Senecio graciliflorus</i>	<i>Wulfenia abliqua</i>	<i>Yushania microphylla</i>	Total Herbs
Altitude (masl)	Pearson Correlation	1.00	-0.04	0.28(**)	0.07	0.07	-0.14	0.38(**)	0.02	-0.23(*)	-0.13	-0.23(*)	-0.01	0.21(*)	-0.01	0.23(*)	0.15	-0.10	-0.40(**)	-0.21(*)	0.13	-0.05	0.10	-0.15	-0.25(*)
	Sig. (2-tailed)		0.70	0.01	0.51	0.51	0.19	0.00	0.82	0.03	0.21	0.03	0.89	0.05	0.91	0.03	0.17	0.33	0.00	0.05	0.22	0.62	0.37	0.15	0.02
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Gradient (deg)	Pearson Correlation	-0.04	1.00	-0.31(**)	0.04	-0.10	0.10	-0.16	0.21(*)	0.14	-0.34(**)	0.17	0.00	0.05	0.19	0.03	0.12	0.10	-0.09	0.16	0.04	-0.05	-0.01	0.00	-0.01
	Sig. (2-tailed)	0.70		0.00	0.71	0.37	0.33	0.13	0.05	0.19	0.00	0.10	0.98	0.65	0.08	0.75	0.25	0.33	0.39	0.13	0.72	0.61	0.91	0.99	0.95
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Opening area	Pearson Correlation	0.28(**)	-0.31(**)	1.00	-0.12	0.16	-0.04	0.27(**)	0.06	-0.31(**)	-0.03	-0.25(*)	-0.05	0.03	-0.01	-0.04	-0.01	0.01	-0.21(*)	-0.28(**)	-0.16	-0.15	0.18	-0.02	-0.22(*)
	Sig. (2-tailed)	0.01	0.00		0.27	0.12	0.73	0.01	0.56	0.00	0.77	0.02	0.65	0.78	0.91	0.69	0.93	0.96	0.05	0.01	0.13	0.15	0.10	0.84	0.04
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Biomass dry (g)	Pearson Correlation	0.07	0.04	-0.12	1.00	0.28(**)	-0.12	0.03	0.12	0.14	-0.08	-0.11	-0.16	-0.27(**)	-0.15	-0.16	-0.29(**)	0.42(**)	-0.15	0.03	0.26(**)	-0.12	-0.03	-0.21(*)	-0.01
	Sig. (2-tailed)	0.51	0.71	0.27		0.01	0.27	0.78	0.25	0.19	0.43	0.29	0.13	0.01	0.15	0.14	0.01	0.00	0.15	0.77	0.01	0.26	0.75	0.05	0.91
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
GSF value	Pearson Correlation	0.07	-0.10	0.16	0.28(**)	1.00	-0.17	0.19	0.08	0.00	-0.05	-0.25(*)	-0.25(*)	-0.27(**)	-0.16	-0.17	-0.31(**)	0.12	0.00	-0.14	0.28(**)	0.11	-0.06	0.16	0.13
	Sig. (2-tailed)	0.51	0.37	0.12	0.01		0.11	0.07	0.45	0.97	0.64	0.02	0.02	0.01	0.14	0.11	0.00	0.25	0.97	0.18	0.01	0.31	0.60	0.12	0.23
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Aspect N (gon)	Pearson Correlation	-0.14	0.10	-0.04	-0.12	-0.17	1.00	-0.70(**)	-0.14	-0.46(**)	-0.20	0.04	-0.10	-0.03	-0.02	0.00	-0.03	0.06	0.08	-0.10	-0.16	-0.13	0.01	0.04	-0.08
	Sig. (2-tailed)	0.19	0.33	0.73	0.27	0.11		0.00	0.19	0.00	0.06	0.69	0.37	0.81	0.86	0.99	0.77	0.60	0.48	0.36	0.14	0.24	0.96	0.72	0.43
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Aspect E (gon)	Pearson Correlation	0.38(**)	-0.16	0.27(**)	0.03	0.19	-0.70(**)	1.00	-0.06	-0.19	-0.08	-0.09	0.08	0.12	0.08	0.07	0.12	-0.15	-0.25(*)	-0.01	0.20	-0.01	0.07	-0.07	-0.13
	Sig. (2-tailed)	0.00	0.13	0.01	0.78	0.07	0.00		0.60	0.07	0.45	0.39	0.46	0.28	0.46	0.50	0.26	0.16	0.02	0.93	0.06	0.91	0.49	0.51	0.22
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Aspect S (gon)	Pearson Correlation	0.02	0.21(*)	0.06	0.12	0.08	-0.14	-0.06	1.00	-0.04	-0.02	-0.03	-0.03	-0.04	-0.03	-0.02	-0.05	0.29(**)	-0.08	-0.03	-0.04	-0.08	-0.03	0.05	0.00
	Sig. (2-tailed)	0.82	0.05	0.56	0.25	0.45	0.19	0.60		0.73	0.88	0.80	0.77	0.73	0.78	0.83	0.67	0.01	0.47	0.81	0.71	0.47	0.77	0.66	0.97
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Aspect W (gon)	Pearson Correlation	-0.23(*)	0.14	-0.31(**)	0.14	0.00	-0.46(**)	-0.19	-0.04	1.00	-0.05	0.08	-0.10	-0.13	-0.10	-0.08	-0.14	0.05	0.17	0.21(*)	0.01	0.16	-0.08	0.01	0.24(*)
	Sig. (2-tailed)	0.03	0.19	0.00	0.19	0.97	0.00	0.07	0.73		0.62	0.44	0.33	0.24	0.35	0.48	0.20	0.67	0.10	0.05	0.89	0.12	0.46	0.89	0.02
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
Aspect Flat (gon)	Pearson Correlation	-0.13	-0.34(**)	-0.03	-0.08	-0.05	-0.20	-0.08	-0.02	-0.05	1.00	-0.04	0.34(**)	0.05	0.08	-0.03	0.09	-0.07	0.14	-0.08	-0.06	0.15	-0.04	0.01	0.12
	Sig. (2-tailed)	0.21	0.00	0.77	0.43	0.64	0.06	0.45	0.88	0.62		0.72	0.00	0.64	0.47	0.76	0.38	0.52	0.19	0.45	0.60	0.15	0.73	0.95	0.26
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
<i>Acer campbellii</i>	Pearson Correlation	-0.23(*)	0.17	-0.25(*)	-0.11	-0.25(*)	0.04	-0.09	-0.03	0.08	-0.04	1.00	0.32(**)	0.22(*)	0.30(**)	-0.02	0.38(**)	-0.10	0.14	0.44(**)	-0.08	-0.12	0.22(*)	-0.10	0.06
	Sig. (2-tailed)	0.03	0.10	0.02	0.29	0.02	0.69	0.39	0.80	0.44	0.72		0.00	0.04	0.00	0.83	0.00	0.35	0.20	0.00	0.43	0.25	0.03	0.35	0.58
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
<i>Betula utilis</i>	Pearson Correlation	-0.01	0.00	-0.05	-0.16	-0.25(*)	-0.10	0.08	-0.03	-0.10	0.34(**)	0.32(**)	1.00	0.42(**)	0.33(**)	0.04	0.55(**)	-0.13	0.07	-0.01	-0.03	0.04	0.38(**)	-0.17	0.11
	Sig. (2-tailed)	0.89	0.98	0.65	0.13	0.02	0.37	0.46	0.77	0.33	0.00	0.00		0.00	0.00	0.74	0.00	0.23	0.51	0.89	0.78	0.69	0.00	0.11	0.30
	N	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90	90
<i>Abies densa</i>	Pearson Correlation	0.21(*)	0.05	0.03	-0.27(**)	-0.27(**)	-0.03	0.12	-0.04	-0.13	0.05	0.22(*)	0.42(**)	1.00											

Annex 7: Total Variance Explained - Factor Analysis Inventory Data

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	1.52	12.64	12.64	0.87	7.29	7.29	0.83	6.92	6.92
2	1.43	11.93	24.56	0.77	6.38	13.67	0.58	4.80	11.72
3	1.13	9.45	34.01	0.42	3.51	17.18	0.50	4.19	15.91
4	1.13	9.41	43.43	0.34	2.82	20.00	0.47	3.95	19.86
5	1.07	8.92	52.34	0.26	2.14	22.14	0.27	2.28	22.14
6	0.99	8.27	60.62						
7	0.96	8.02	68.64						
8	0.89	7.42	76.06						
9	0.85	7.04	83.10						
10	0.77	6.40	89.49						
11	0.66	5.48	94.98						
12	0.60	5.02	100.00						

Extraction Method: Principal Axis Factoring.

Annex 8: Factor Analysis, Anti Image Covariance and Anti Image Correlation – Inventory Data

		Z-Value: <i>Abies densa</i>	Z-Value: <i>Picea spinulosa</i>	Z-Value: <i>Tsuga dumosa</i>	Z-Value: <i>Acer campbellii</i>	Z-Value: <i>Betula utilis</i>	Z-Value: <i>Artemisia moorcroftiana</i>	Z-Value: <i>Osmunda sp.</i>	Z-Value: <i>Salvia sp.</i>	Z-Value: <i>Sambucus adnata</i>	Z-Value: <i>Senecio graciliflorus</i>	Z-Value: <i>Wulfenia abliqua</i>	Z-Value: <i>Yushania microphylla</i>
Anti-image Covariance	Z-Value: <i>Abies densa</i>	0.84	-0.01	-0.30	0.03	0.03	0.00	-0.01	0.05	0.05	0.00	0.04	0.10
	Z-Value: <i>Picea spinulosa</i>	-0.01	0.97	-0.11	-0.02	-0.05	0.04	0.02	0.05	0.05	-0.01	-0.04	0.00
	Z-Value: <i>Tsuga dumosa</i>	-0.30	-0.11	0.84	0.01	0.00	0.03	-0.01	0.04	0.04	0.02	-0.01	0.03
	Z-Value: <i>Acer campbellii</i>	0.03	-0.02	0.01	0.99	-0.06	0.03	0.03	0.02	0.04	0.03	0.05	0.02
	Z-Value: <i>Betula utilis</i>	0.03	-0.05	0.00	-0.06	0.98	0.04	-0.06	0.02	0.04	0.05	-0.03	0.05
	Z-Value: <i>Artemisia moorcroftiana</i>	0.00	0.04	0.03	0.03	0.04	0.93	0.05	-0.16	0.05	-0.03	-0.02	0.14
	Z-Value: <i>Osmunda sp.</i>	-0.01	0.02	-0.01	0.03	-0.06	0.05	0.96	0.02	0.10	-0.02	0.05	0.12
	Z-Value: <i>Salvia sp.</i>	0.05	0.05	0.04	0.02	0.02	-0.16	0.02	0.93	0.02	0.09	0.03	0.12
	Z-Value: <i>Sambucus adnata</i>	0.05	0.05	0.04	0.04	0.04	0.05	0.10	0.02	0.95	0.07	0.09	0.13
	Z-Value: <i>Senecio graciliflorus</i>	0.00	-0.01	0.02	0.03	0.05	-0.03	-0.02	0.09	0.07	0.96	0.06	0.14
	Z-Value: <i>Wulfenia abliqua</i>	0.04	-0.04	-0.01	0.05	-0.03	-0.02	0.05	0.03	0.09	0.06	0.97	-0.05
	Z-Value: <i>Yushania microphylla</i>	0.10	0.00	0.03	0.02	0.05	0.14	0.12	0.12	0.13	0.14	-0.05	0.88
Anti-image Correlation	Z-Value: <i>Abies densa</i>	0.53(a)	-0.01	-0.36	0.03	0.03	0.01	-0.01	0.06	0.06	0.00	0.05	0.12
	Z-Value: <i>Picea spinulosa</i>	-0.01	0.62(a)	-0.12	-0.02	-0.05	0.04	0.02	0.05	0.05	-0.01	-0.04	0.00
	Z-Value: <i>Tsuga dumosa</i>	-0.36	-0.12	0.54(a)	0.01	0.00	0.03	-0.01	0.05	0.05	0.03	-0.01	0.03
	Z-Value: <i>Acer campbellii</i>	0.03	-0.02	0.01	0.48(a)	-0.06	0.04	0.03	0.02	0.04	0.04	0.05	0.02
	Z-Value: <i>Betula utilis</i>	0.03	-0.05	0.00	-0.06	0.51(a)	0.04	-0.06	0.03	0.04	0.06	-0.04	0.05
	Z-Value: <i>Artemisia moorcroftiana</i>	0.01	0.04	0.03	0.04	0.04	0.55(a)	0.06	-0.17	0.05	-0.03	-0.02	0.15
	Z-Value: <i>Osmunda sp.</i>	-0.01	0.02	-0.01	0.03	-0.06	0.06	0.48(a)	0.02	0.10	-0.02	0.05	0.13
	Z-Value: <i>Salvia sp.</i>	0.06	0.05	0.05	0.02	0.03	-0.17	0.02	0.55(a)	0.02	0.09	0.03	0.13
	Z-Value: <i>Sambucus adnata</i>	0.06	0.05	0.05	0.04	0.04	0.05	0.10	0.02	0.45(a)	0.07	0.09	0.14
	Z-Value: <i>Senecio graciliflorus</i>	0.00	-0.01	0.03	0.04	0.06	-0.03	-0.02	0.09	0.07	0.46(a)	0.06	0.15
	Z-Value: <i>Wulfenia abliqua</i>	0.05	-0.04	-0.01	0.05	-0.04	-0.02	0.05	0.03	0.09	0.06	0.55(a)	-0.06
	Z-Value: <i>Yushania microphylla</i>	0.12	0.00	0.03	0.02	0.05	0.15	0.13	0.13	0.14	0.15	-0.06	0.50(a)

a Measures of Sampling Adequacy(MSA)

Annex 9: Total Variance Explained - Factor Analysis Plot Data

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.29	19.07	19.07	1.94	16.15	16.15	1.38	11.53	11.53
2	1.70	14.14	33.21	1.25	10.40	26.55	1.29	10.75	22.28
3	1.60	13.34	46.55	1.04	8.64	35.20	1.25	10.45	32.73
4	1.27	10.55	57.10	0.74	6.20	41.40	0.96	8.03	40.76
5	1.10	9.17	66.27	0.47	3.95	45.35	0.55	4.59	45.35
6	0.94	7.82	74.09						
7	0.84	7.01	81.10						
8	0.63	5.28	86.38						
9	0.57	4.76	91.14						
10	0.46	3.83	94.97						
11	0.39	3.25	98.22						
12	0.21	1.78	100.00						

Extraction Method: Principal Axis Factoring.

Annex 10: Factor Analysis, Anti Image Covariance and Anti Image Correlation – Inventory Data

		Z-Value: <i>Abies densa</i>	Z-Value: <i>Tsuga dumosa</i>	Z-Value: <i>Picea spinulosa</i>	Z-Value: <i>Acer campbellii</i>	Z-Value: <i>Betula utilis</i>	Z-Value: <i>Artemisia moorcroftiana</i>	Z-Value: <i>Osmunda sp.</i>	Z-Value: <i>Salvia sp.</i>	Z-Value: <i>Sambucus adnata</i>	Z-Value: <i>Senecio graciliflorus</i>	Z-Value: <i>Wulfenia abliqua</i>	Z-Value: <i>Yushania microphylla</i>
Anti-image Covariance	Z-Value: <i>Abies densa</i>	0.40	-0.06	-0.31	-0.14	-0.18	0.03	0.08	0.16	-0.04	0.01	0.03	-0.02
	Z-Value: <i>Tsuga dumosa</i>	-0.06	0.74	0.06	-0.10	-0.17	0.07	0.08	-0.09	-0.04	0.01	0.20	0.04
	Z-Value: <i>Picea spinulosa</i>	-0.31	0.06	0.51	0.13	0.12	0.04	-0.03	-0.14	0.09	-0.01	0.01	0.07
	Z-Value: <i>Acer campbellii</i>	-0.14	-0.10	0.13	0.58	-0.03	0.02	-0.13	-0.29	0.11	0.04	-0.12	0.00
	Z-Value: <i>Betula utilis</i>	-0.18	-0.17	0.12	-0.03	0.56	0.02	-0.12	0.03	0.04	-0.05	-0.24	0.12
	Z-Value: <i>Artemisia moorcroftiana</i>	0.03	0.07	0.04	0.02	0.02	0.84	0.00	0.06	0.10	0.19	0.08	0.14
	Z-Value: <i>Osmunda sp.</i>	0.08	0.08	-0.03	-0.13	-0.12	0.00	0.82	-0.02	-0.04	-0.15	0.12	-0.17
	Z-Value: <i>Salvia sp.</i>	0.16	-0.09	-0.14	-0.29	0.03	0.06	-0.02	0.63	-0.11	0.11	0.04	0.09
	Z-Value: <i>Sambucus adnata</i>	-0.04	-0.04	0.09	0.11	0.04	0.10	-0.04	-0.11	0.89	-0.15	0.01	0.11
	Z-Value: <i>Senecio graciliflorus</i>	0.01	0.01	-0.01	0.04	-0.05	0.19	-0.15	0.11	-0.15	0.78	0.07	-0.11
	Z-Value: <i>Wulfenia abliqua</i>	0.03	0.20	0.01	-0.12	-0.24	0.08	0.12	0.04	0.01	0.07	0.74	0.01
	Z-Value: <i>Yushania microphylla</i>	-0.02	0.04	0.07	0.00	0.12	0.14	-0.17	0.09	0.11	-0.11	0.01	0.80
Anti-image Correlation	Z-Value: <i>Abies densa</i>	0.46(a)	-0.11	-0.68	-0.29	-0.37	0.05	0.14	0.33	-0.07	0.01	0.05	-0.03
	Z-Value: <i>Tsuga dumosa</i>	-0.11	0.59(a)	0.10	-0.15	-0.27	0.09	0.10	-0.14	-0.05	0.02	0.28	0.06
	Z-Value: <i>Picea spinulosa</i>	-0.68	0.10	0.38(a)	0.23	0.22	0.06	-0.05	-0.25	0.13	-0.02	0.02	0.11
	Z-Value: <i>Acer campbellii</i>	-0.29	-0.15	0.23	0.53(a)	-0.06	0.03	-0.18	-0.48	0.15	0.06	-0.18	0.00
	Z-Value: <i>Betula utilis</i>	-0.37	-0.27	0.22	-0.06	0.55(a)	0.03	-0.18	0.05	0.06	-0.08	-0.38	0.17
	Z-Value: <i>Artemisia moorcroftiana</i>	0.05	0.09	0.06	0.03	0.03	0.62(a)	0.00	0.08	0.12	0.23	0.11	0.17
	Z-Value: <i>Osmunda sp.</i>	0.14	0.10	-0.05	-0.18	-0.18	0.00	0.47(a)	-0.03	-0.05	-0.19	0.16	-0.21
	Z-Value: <i>Salvia sp.</i>	0.33	-0.14	-0.25	-0.48	0.05	0.08	-0.03	0.41(a)	-0.15	0.15	0.05	0.12
	Z-Value: <i>Sambucus adnata</i>	-0.07	-0.05	0.13	0.15	0.06	0.12	-0.05	-0.15	0.41(a)	-0.18	0.02	0.13
	Z-Value: <i>Senecio graciliflorus</i>	0.01	0.02	-0.02	0.06	-0.08	0.23	-0.19	0.15	-0.18	0.61(a)	0.10	-0.14
	Z-Value: <i>Wulfenia abliqua</i>	0.05	0.28	0.02	-0.18	-0.38	0.11	0.16	0.05	0.02	0.10	0.46(a)	0.01
	Z-Value: <i>Yushania microphylla</i>	-0.03	0.06	0.11	0.00	0.17	0.17	-0.21	0.12	0.13	-0.14	0.01	0.61(a)

a Measures of Sampling Adequacy(MSA)

Annex 11: Test of Equality of Group Means - Discriminant Analysis Inventory Data

	Wilks' Lambda	F	df1	df2	Sig.
Z-Value: Altitude	0.44	61.49	9	438	0.00
Z-Value: Gradient	0.46	56.42	9	438	0.00
Z-Value: Opening area	0.43	63.58	9	438	0.00
Z-Value: <i>Abies densa</i>	0.37	84.30	9	438	0.00
Z-Value: <i>Picea spinulosa</i>	0.28	128.36	9	438	0.00
Z-Value: <i>Tsuga dumosa</i>	0.34	95.61	9	438	0.00
Z-Value: <i>Acer campbellii</i>	0.11	415.66	9	438	0.00
Z-Value: <i>Betula utilis</i>	0.13	341.21	9	438	0.00
Z-Value: <i>Artemisia moorcroftiana</i>	0.90	5.50	9	438	0.00
Z-Value: <i>Salvia sp.</i>	0.93	3.76	9	438	0.00
Z-Value: <i>Sambucus adnata</i>	0.94	2.90	9	438	0.00
Z-Value: <i>Senecio graciliflorus</i>	0.96	1.95	9	438	0.04
Z-Value: <i>Yushania microphylla</i>	0.95	2.53	9	438	0.01
Aspect N	0.66	25.07	9	438	0.00
Aspect E	0.83	10.11	9	438	0.00
Aspect S	0.68	22.53	9	438	0.00
Aspect W	0.87	7.54	9	438	0.00
Aspect Flat	.(a)				
Z-Value: <i>Osmunda sp.</i>	0.97	1.31	9	438	0.23
Z-Value: <i>Wulfenia abliqua</i>	0.99	0.72	9	438	0.69

a Cannot be computed because this variable is a constant.

Annex 12: Eigenvalues - Discriminant Analysis Inventory Data

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	8.94(a)	31.70	31.70	0.95
2	7.32(a)	26.00	57.70	0.94
3	3.23(a)	11.50	69.20	0.87
4	2.42(a)	8.60	77.70	0.84
5	1.92(a)	6.80	84.60	0.81
6	1.66(a)	5.90	90.40	0.79
7	1.53(a)	5.40	95.90	0.78
8	0.80(a)	2.90	98.70	0.67
9	0.36(a)	1.30	100.00	0.52

a First 9 canonical discriminant functions were used in the analysis.

Annex 13: Wilk's Lambda Test - Discriminant Analysis Inventory Data

Test of Function(s)	Wilks' Lambda	Chi- square	df	Sig.
1 through 9	0.00	4785.35	99	0.00
2 through 9	0.00	3782.95	80	0.00
3 through 9	0.00	2858.09	63	0.00
4 through 9	0.01	2228.18	48	0.00
5 through 9	0.02	1691.78	35	0.00
6 through 9	0.06	1223.61	24	0.00
7 through 9	0.16	796.84	15	0.00
8 through 9	0.41	392.01	8	0.00
9	0.74	134.58	3	0.00

Annex 14: Structure Matrix - Discriminant Analysis Inventory Data

	Function								
	1	2	3	4	5	6	7	8	9
Z-Value: <i>Acer campbellii</i>	0.96(*)	-0.16	0.12	-0.09	0.11	0.03	0.03	0.08	0.00
Z-Value: <i>Betula utilis</i>	0.19	0.95(*)	0.00	-0.08	0.04	-0.17	0.13	0.06	0.05
Z-Value: <i>Picea spinulosa</i>	-0.03	-0.01	0.82(*)	0.01	0.33	-0.01	0.29	-0.35	-0.02
Z-Value: <i>Tsuga dumosa</i>	-0.03	0.00	-0.07	-0.75(*)	0.18	0.29	0.45	-0.32	0.11
Z-Value: <i>Abies densa</i>	-0.01	-0.03	-0.31	0.27	0.64(*)	-0.16	0.41	-0.43	0.19
Z-Value: Altitude	-0.04	-0.01	-0.08	-0.03	0.62(*)	0.21	-0.24	0.59	-0.33
Aspect E	0.01	-0.02	0.02	-0.04	-0.20(*)	-0.20	0.15	-0.10	-0.18
Z-Value: <i>Yushania microphylla (a)</i>	0.01	0.04	0.05	0.07	-0.12(*)	0.09	-0.01	0.01	-0.07
Z-Value: <i>Salvia sp. (a)</i>	0.02	-0.01	-0.02	0.04	-0.11(*)	-0.03	-0.03	0.05	0.04
Z-Value: <i>Artemisia moorcroftiana (a)</i>	0.00	0.01	-0.04	0.02	-0.08(*)	-0.02	-0.07	0.07	0.04
Z-Value: Gradient	0.03	0.11	-0.03	0.03	0.10	0.52(*)	-0.49	-0.48	0.39
Z-Value: <i>Senecio graciliflorus (a)</i>	-0.03	-0.04	0.04	-0.08	0.03	-0.14(*)	0.02	0.04	0.02
Z-Value: <i>Sambucus adnata (a)</i>	0.00	-0.03	-0.02	-0.03	0.01	-0.08(*)	-0.07	0.05	-0.05
Aspect S	0.01	0.01	-0.01	-0.01	0.11	0.18	-0.46(*)	-0.22	-0.26
Z-Value: <i>Osmunda sp. (a)</i>	-0.02	0.05	0.05	-0.01	-0.05	-0.02	0.07	0.09(*)	0.06
Z-Value: <i>Wulfenia abliqua (a)</i>	-0.01	0.01	-0.01	0.01	-0.05	0.04	0.01	-0.06(*)	-0.06
Aspect N	0.00	0.00	0.01	0.15	0.02	0.13	0.34	0.38	0.63(*)
Z-Value: Opening area	-0.01	0.07	-0.02	0.38	-0.27	0.52	0.36	-0.06	-0.60(*)
Aspect W (a)	-0.02	0.02	-0.03	-0.11	0.11	-0.06	-0.17	-0.12	-0.28(*)

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions

Variables ordered by absolute size of correlation within function.

* Largest absolute correlation between each variable and any discriminant function

a This variable not used in the analysis.

Annex 15: Classification Function Coefficients - Discriminant Analysis Inventory Data

Group	Ward Method									
	1	2	3	4	5	6	7	8	9	10
Z-Value: Altitude	2.23	-4.98	2.68	1.78	-2.70	0.18	-0.14	1.69	-0.07	1.11
Z-Value: Gradient	1.66	0.19	1.16	3.90	1.74	3.63	-0.97	0.09	0.70	-1.81
Z-Value: Opening area	-0.03	1.52	0.99	0.73	1.80	3.46	-1.35	-0.44	11.01	3.37
Z-Value: <i>Abies densa</i>	-5.24	2.13	0.02	-0.97	-0.91	-1.32	-0.59	-2.40	-0.22	37.37
Z-Value: <i>Picea spinulosa</i>	26.26	-5.85	0.13	-0.44	-1.46	-0.96	-0.49	-2.88	-2.33	-11.97
Z-Value: <i>Tsuga dumosa</i>	-4.42	-4.24	-0.51	-1.33	-1.58	-2.32	-0.77	18.07	-0.39	-9.09
Z-Value: <i>Acer campbellii</i>	-4.58	83.57	-1.61	-0.90	0.22	2.79	-1.26	-1.09	0.16	2.66
Z-Value: <i>Betula utilis</i>	-0.38	-4.43	-1.37	1.33	-1.41	55.37	-1.38	-0.82	-0.70	-2.22
Aspect N	10.16	5.61	11.12	5.84	9.71	8.74	4.01	4.27	12.75	-2.45
Aspect E	8.42	3.19	7.56	4.92	8.83	7.27	5.41	4.15	9.62	-3.65
Aspect S	1.73	11.11	2.75	7.66	3.75	12.53	2.87	2.16	5.23	3.51
Constant	-55.82	-386.62	-7.38	-7.81	-9.72	-201.92	-3.83	-30.06	-34.20	-208.43

Fisher's linear discriminant functions

Annex 16: Classification Results (a) - Discriminant Analysis Inventory Data

Ward Method	Predicted Group Membership											Total
	Group	1	2	3	4	5	6	7	8	9	10	
Original Count	1	13	0	0	0	0	0	0	0	0	0	13
	2	0	5	0	0	0	0	0	0	0	0	5
	3	0	0	105	3	0	0	1	2	0	0	111
	4	0	0	2	64	0	1	7	0	0	0	74
	5	0	0	3	0	64	0	0	1	0	0	68
	6	0	0	0	0	0	8	0	0	0	0	8
	7	0	0	2	0	2	0	137	0	0	0	141
	8	0	0	0	0	0	0	1	16	0	0	17
	9	0	0	0	0	0	0	0	0	9	0	9
	10	0	0	0	0	0	0	0	0	0	2	2
Original %	1	100	0	0	0	0	0	0	0	0	0	100
	2	0	100	0	0	0	0	0	0	0	0	100
	3	0	0	94.6	2.7	0	0	0.9	1.8	0	0	100
	4	0	0	2.7	86.5	0	1.4	9.5	0	0	0	100
	5	0	0	4.4	0	94.1	0	0	1.5	0	0	100
	6	0	0	0	0	0	100	0	0	0	0	100
	7	0	0	1.4	0	1.4	0	97.2	0	0	0	100
	8	0	0	0	0	0	0	5.9	94.1	0	0	100
	9	0	0	0	0	0	0	0	0	100	0	100
	10	0	0	0	0	0	0	0	0	0	100	100

a 94.4% of original grouped cases correctly classified.

Annex 17: Overview Important Variables - Clusteranalysis/Discriminant Analysis Inventory Data

Group	N	% of N total	Important Positive Variables	Important Negative Variables
1	13	2.90%	<i>Tsuga dumosa</i> <i>Picea spinulosa</i> <i>Yushania microphylla</i>	
2	5	1.10%	<i>Picea spinulosa</i> <i>Acer campbellii</i> <i>Yushania microphylla</i>	
3	111	24.80%	Altitude <i>Abies densa</i> <i>Artemisia moorcroftiana</i> <i>Salvia sp.</i>	
4	74	16.50%	Altitude Gradient	
5	68	15.20%		Altitude
6	8	1.80%	<i>Betula utilis</i>	
7	141	31.50%		Gradient
8	17	3.80%	<i>Abies densa</i> <i>Tsuga dumosa</i> <i>Picea spinulosa</i>	
9	9	2.00%	Opening area <i>Sambucus adnata</i> <i>Senecio graciliflorus</i>	Gradient <i>Wulfenia abliqua</i> <i>Yushania microphylla</i>
10	2	0.40%	Altitude <i>Abies densa</i> <i>Osmunda sp.</i>	<i>Wulfenia abliqua</i> <i>Yushania microphylla</i>
Sum	448	100.00%		

Annex 18: Test of Equality of Group Means - Discriminant Analysis Plot Data

	Wilks' Lambda	F	df1	df2	Sig.
Z-Value: Altitude	0.38	14.44	9	80	0.00
Z-Value: Gradient	0.68	4.18	9	80	0.00
Z-Value: Opening area	0.60	6.05	9	80	0.00
Z-Value: Biomass	0.52	8.33	9	80	0.00
Z-Value: GSF value	0.77	2.71	9	80	0.01
Z-Value: <i>Abies densa</i>	0.53	7.79	9	80	0.00
Z-Value: <i>Tsuga dumosa</i>	0.48	9.47	9	80	0.00
Z-Value: <i>Picea spinulosa</i>	0.13	60.70	9	80	0.00
Z-Value: <i>Acer campbellii</i>	0.14	54.25	9	80	0.00
Z-Value: <i>Betula utilis</i>	0.41	12.66	9	80	0.00
Z-Value: Total Regeneration	0.32	18.61	9	80	0.00
Z-Value: <i>Artemisia moorcroftiana</i>	0.23	29.48	9	80	0.00
Z-Value: <i>Osmunda sp.</i>	0.68	4.10	9	80	0.00
Z-Value: <i>Salvia sp.</i>	0.59	6.14	9	80	0.00
Z-Value: <i>Sambucus adnata</i>	0.33	17.75	9	80	0.00
Z-Value: <i>Senecio graciliflorus</i>	0.69	4.04	9	80	0.00
Z-Value: <i>Wulfenia abliqua</i>	0.28	22.72	9	80	0.00
Z-Value: <i>Yushania microphylla</i>	0.38	14.37	9	80	0.00
Z-Value: Total Herbs	0.72	3.44	9	80	0.00
Aspect N	0.92	0.79	9	80	0.62
Aspect E	0.81	2.13	9	80	0.04
Aspect S	0.89	1.16	9	80	0.33
Aspect W	0.87	1.31	9	80	0.25
Aspect Flat	0.96	0.38	9	80	0.94

Annex 19: Eigenvalues - Discriminant Analysis Plot Data

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	12.92(a)	37.30	37.30	0.96
2	7.32(a)	21.10	58.40	0.94
3	3.94(a)	11.40	69.70	0.89
4	3.32(a)	9.60	79.30	0.88
5	2.72(a)	7.80	87.10	0.86
6	2.01(a)	5.80	92.90	0.82
7	1.09(a)	3.10	96.10	0.72
8	1.04(a)	3.00	99.10	0.71
9	0.32(a)	0.90	100.00	0.49

a First 9 canonical discriminant functions were used in the analysis.

Annex 20: Wilk's Lambda Test - Discriminant Analysis Plot Data

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 9	0.00	938.42	99	0.00
2 through 9	0.00	731.68	80	0.00
3 through 9	0.00	565.41	63	0.00
4 through 9	0.00	440.09	48	0.00
5 through 9	0.02	325.32	35	0.00
6 through 9	0.06	222.19	24	0.00
7 through 9	0.18	135.63	15	0.00
8 through 9	0.37	77.82	8	0.00
9	0.76	21.85	3	0.00

Annex 21: Classification Results (a) - Discriminant Analysis Plot Data

Ward Method		Predicted Group Membership										Total
	Group	1	2	3	4	5	6	7	8	9	10	
Original Count	1	11	0	0	0	1	0	1	1	0	0	14
	2	0	7	0	0	0	0	0	0	1	0	8
	3	0	0	2	0	0	0	0	0	0	0	2
	4	0	0	0	5	0	0	0	0	0	0	5
	5	0	0	0	0	22	0	0	0	0	0	22
	6	0	0	0	0	0	3	0	0	0	0	3
	7	0	0	0	0	0	0	6	0	0	0	6
	8	0	0	0	0	1	0	0	9	0	0	10
	9	0	1	0	0	3	0	0	0	15	0	19
	10	0	0	0	0	0	0	0	0	0	1	1
Original %	1	78.6	0	0	0	7.1	0	7.1	7.1	0	0	100
	2	0	87.5	0	0	0	0	0	0	12.5	0	100
	3	0	0	100	0	0	0	0	0	0	0	100
	4	0	0	0	100	0	0	0	0	0	0	100
	5	0	0	0	0	100	0	0	0	0	0	100
	6	0	0	0	0	0	100	0	0	0	0	100
	7	0	0	0	0	0	0	100	0	0	0	100
	8	0	0	0	0	10	0	0	90	0	0	100
	9	0	5.3	0	0	15.8	0	0	0	78.9	0	100
	10	0	0	0	0	0	0	0	0	0	100	100

a 90,0% of original grouped cases correctly classified.

Annex 22: Structure Matrix - Discriminant Analysis Plot Data

	Function								
	1	2	3	4	5	6	7	8	9
Z-Value: <i>Acer campbellii</i>	0.58(*)	0.43	-0.07	0.07	-0.14	-0.40	-0.03	0.07	-0.03
Aspect Flat (a)	0.35(*)	0.00	-0.08	0.07	0.23	0.21	0.05	-0.06	-0.27
Z-Value: <i>Picea spinulosa</i>	-0.35	0.83(*)	0.10	0.05	0.01	0.30	0.15	-0.17	-0.17
Z-Value: Opening area (a)	-0.12	-0.26(*)	0.04	-0.04	0.21	-0.06	0.03	-0.02	-0.06
Z-Value: <i>Wulfenia abliqua</i>	0.15	0.07	0.55(*)	-0.22	0.47	-0.29	0.17	-0.32	-0.04
Aspect E (a)	-0.09	0.07	0.19(*)	-0.06	0.17	-0.07	0.03	0.17	-0.04
Z-Value: <i>Artemisia moorcroftiana</i>	-0.05	-0.16	0.45	0.74(*)	-0.40	-0.07	0.16	0.15	-0.11
Z-Value: <i>Sambucus adnata</i>	0.00	-0.06	0.10	-0.54(*)	-0.49	0.15	0.26	0.41	-0.27
Aspect W (a)	-0.15	-0.07	-0.05	0.17(*)	0.02	0.01	-0.04	-0.08	0.13
Aspect N (a)	0.06	-0.02	-0.09	-0.09	-0.24(*)	-0.03	-0.04	-0.10	0.00
Z-Value: Total Regeneration	0.13	0.36	0.06	0.03	0.19	0.59(*)	-0.03	0.10	-0.55
Z-Value: <i>Betula utilis</i>	0.23	0.10	0.21	-0.07	0.24	0.38(*)	0.17	-0.12	-0.23
Z-Value: <i>Tsuga dumosa</i> (a)	0.12	-0.25	-0.06	-0.06	-0.04	0.27(*)	-0.15	0.04	-0.17
Z-Value: GSF value (a)	-0.03	-0.09	0.08	-0.04	-0.09	-0.21(*)	-0.02	0.06	-0.09
Z-Value: Biomass (a)	0.02	-0.12	0.02	-0.04	-0.03	-0.17(*)	-0.02	-0.08	-0.07
Z-Value: <i>Yushania microphylla</i>	-0.04	-0.08	-0.35	0.05	0.29	-0.17	0.81(*)	0.25	0.04
Z-Value: <i>Osmunda sp.</i> (a)	0.15	-0.02	0.07	-0.09	-0.02	-0.01	0.21(*)	0.09	-0.08
Z-Value: Altitude	-0.13	0.10	0.23	-0.15	0.28	0.04	-0.39	0.80(*)	0.11
Z-Value: Gradient	0.06	0.03	0.09	0.03	-0.10	0.25	0.18	0.06	0.77(*)
Z-Value: <i>Abies densa</i> (a)	0.04	0.44	0.07	0.07	0.21	0.46	0.02	0.11	-0.47(*)
Z-Value: <i>Salvia sp.</i>	0.15	0.15	-0.11	0.05	-0.22	-0.03	-0.12	-0.07	0.35(*)
Z-Value: Total Herbs (a)	0.11	0.13	-0.10	-0.09	0.08	0.06	0.17	-0.01	-0.19(*)
Z-Value: <i>Senecio graciliflorus</i> (a)	-0.04	-0.13	0.00	-0.16	0.07	0.07	-0.16	0.05	-0.18(*)
Aspect S (a)	0.02	0.01	-0.01	0.01	0.07	0.08	0.13	0.13	0.18(*)

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.

* Largest absolute correlation between each variable and any discriminant function

a This variable not used in the analysis.

Annex 23: Classification Function Coefficients - Discriminant Analysis Plot Data

Group	Ward Method									
	1	2	3	4	5	6	7	8	9	10
Z-Value: Altitude (masl)	-4.27	0.00	-1.47	0.49	1.12	5.23	0.10	1.17	0.24	3.19
Z-Value: Gradient (deg)	0.72	0.66	-1.24	1.36	0.32	-2.12	2.89	-0.81	-1.81	4.80
Z-Value: <i>Picea spinulosa</i>	-2.17	-0.79	-9.30	2.46	0.15	45.78	-11.06	-0.47	-0.75	-12.35
Z-Value: <i>Acer campbellii</i>	-1.18	-2.41	42.76	0.36	-1.99	-3.48	6.29	-1.87	-2.17	24.88
Z-Value: <i>Betula utilis</i>	0.69	-0.31	9.79	-0.17	-0.92	-6.47	7.27	-0.73	-2.09	17.10
Z-Value: Total Regeneration	0.02	-0.15	4.08	-5.09	-1.00	-8.69	10.90	-0.11	-0.04	2.76
Z-Value: <i>Artemisia moorcroftiana</i>	-1.54	10.71	-1.45	-1.79	-0.67	-0.99	-0.63	-1.46	-1.00	2.84
Z-Value: <i>Salvia sp.</i>	0.08	-0.61	13.01	-3.46	-0.68	-0.99	5.63	-0.19	-1.10	1.87
Z-Value: <i>Sambucus adnata</i>	1.52	-0.58	-0.42	10.69	-0.69	-0.73	-1.26	-2.34	-1.26	3.08
Z-Value: <i>Wulfenia abliqua</i>	-1.31	0.77	-4.62	0.98	0.94	-0.66	-1.64	-1.66	-0.09	25.91
Z-Value: <i>Yushania microphylla</i>	-0.58	-0.84	1.94	-3.21	-1.43	0.40	0.39	5.46	0.14	-2.24
Constant	-6.06	-18.12	-150.05	-22.65	-2.87	-113.46	-28.37	-9.36	-3.68	-187.45

Fisher's linear discriminant functions

Annex 24: Overview Important Variables - Clusteranalysis/Discriminant Analysis Plot Data

Group	N	% of N total	Important Positive Variables	Important Negative Variables
1	14	15.60%	<i>Osmunda sp.</i> <i>Senecio graciliflorus</i> Aspect W	Altitude Opening area
2	8	8.90%	Biomass <i>Artemisia moorcroftiana</i> Aspect N	Total Herbs
3	2	2.20%	<i>Tsuga dumosa</i> <i>Acer campbellii</i> Total Regeneration <i>Osmunda sp.</i> <i>Salvia sp.</i> Aspect W	Altitude Opening area GSF value
4	5	5.60%	Altitude Biomass GSF value <i>Sambucus adnata</i> <i>Senecio graciliflorus</i> Aspect E	Total Herbs
5	22	24.40%	Aspect N	<i>Senecio graciliflorus</i> Total Herbs
6	3	3.30%	Altitude <i>Abies densa</i> <i>Picea spinulosa</i> Total Regeneration Total Herbs Aspect N	GSF value
7	6	6.70%	Gradient <i>Abies densa</i> <i>Tsuga dumosa</i> <i>Betula utilis</i> Total Regeneration	GSF value Total Herbs
8	10	11.10%	GSF value <i>Senecio graciliflorus</i> <i>Yushania microphylla</i> Aspect N	
9	19	21.10%	Opening area	Gradient <i>Senecio graciliflorus</i>
10	1	1.10%	<i>Abies densa</i> <i>Acer campbellii</i> <i>Betula utilis</i> Total Regeneration <i>Wulfenia abliqua</i> Total Herbs Aspect N	GSF value
Sum	90	100.00%		

Annex 25: Site Information for Hemiphoto Analysis

Site information for hemiphotos	
Site name	Gidakom
Longitude	89.40 E
Latitude	27.20 N
Magnetic declination	0.10 E
Altitude	3100 masl
Lens name	Linear 180
Lens view	180,0
Lens coefficients	0,636620
Solar Model	
Model name	Hemiview Default Simple Model
Model type	Simple
Diffuse distribution	UOC (uniform overcast sky model)
External solar flux - solar constant	1370 W/m2
Solar Transmission	0,80
Diffuse radiation	0,10

Annex 26: Recorded Parameters – Inventory Data

Recorded Parameters - Inventory Data
species
height class
microsite
seedling number
cover percentage
subplot (north, east, south, west, centre)
aspect
altitude
slope
slope position
topography
opening size
grazing intensity
cover percentage of overstorey
soil moisture
soil nutrients

Annex 27: Recorded Parameters – Plot Data

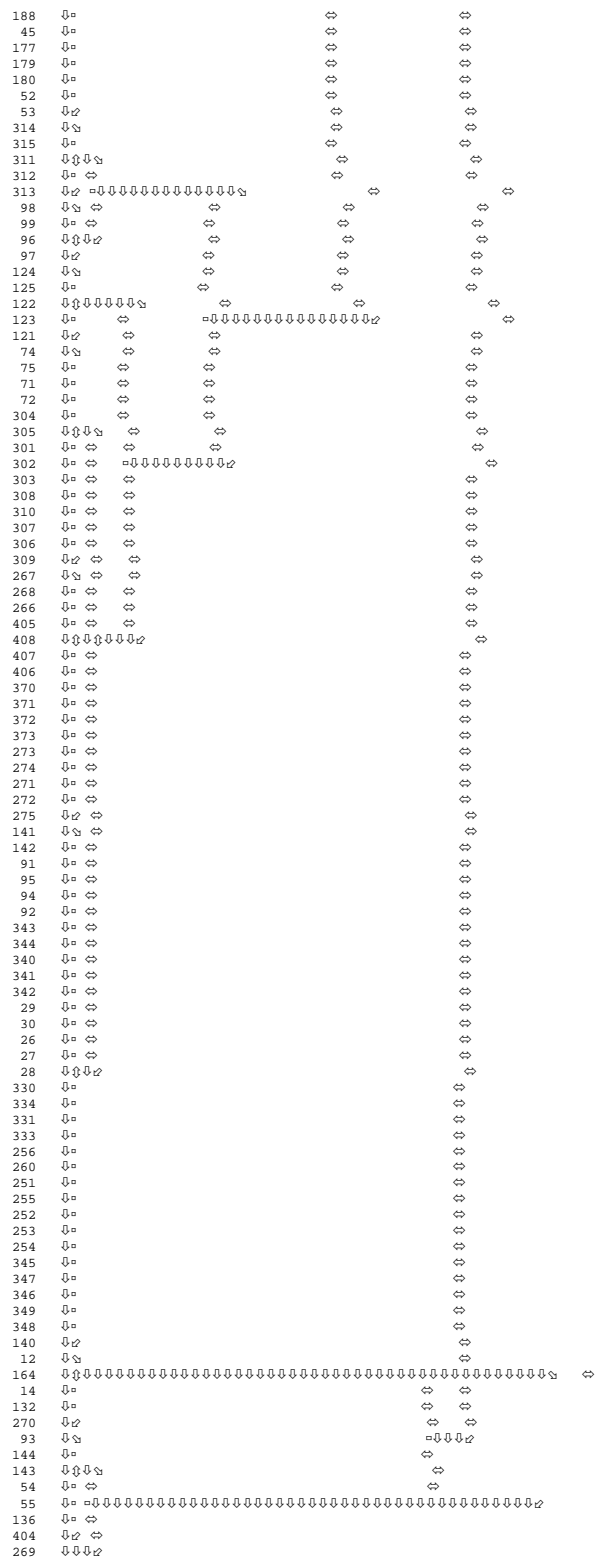
Recorded Parameters - Plot Data

gsf
isf
dsf
subplot (north, east, south, west, centre)
species
number of individuals (cover percentage)
aspect
altitude
slope
slope position
topography
opening size
grazing intensity
cover percentage of overstorey
soil moisture
soil nutrients
opening size (EW)
next tree species
next tree distance
next tree direction
biomass wet
biomass dry
site conditions (homogenous, inhomogenous)
macromorphology (basin, terrace, upper slope, mid slope, lower slope, flat, steep, ridge, top of hillock)
micromorphology (smooth, small creek, undulated, boulders)
human impact (felling, grazing cattle, burning, tracks in the area)
nr of cable line
logging date
seedling height
number of seedling whorls
length of green crown
collar diameter
length of terminal shoot
microsite (moss, nurse log, litter, bare soil, boulder)

C A S E	0	5	10	15	20	25
Label Num						
467	0					
468	0					
464	0					
466	0					
194	0					
195	0					
191	0					
193	0					
462	0					
463	0					
459	0					
461	0					
59	0					
465	0					
192	0					
247	0 0					
209	0					
210	0					
206	0					
207	0					
208	0					
248	0					
250	0					
246	0					
58	0					
60	0					
56	0					
57	0					
249	0 2					
221	0					
229	0					
227	0					
230	0					
226	0					
228	0					
84	0					
85	0					
223	0					
225	0 0 2					
129	0					
130	0					
128	0					
126	0					
133	0					
135	0					
131	0					
134	0					
127	0 2					
158	0					
159	0					
182	0					
289	0					
290	0					
286	0					
287	0					
288	0					
434	0					
435	0					
436	0					
156	0					
437	0					
438	0					
293	0					
294	0					
291	0					
292	0					
279	0					
280	0					
276	0					
277	0 0 0 0 2					
278	0					
325	0					
295	0					
429	0					
430	0					
163	0					
165	0					
161	0					
162	0					
432	0					
433	0					
185	0					
431	0					
326	0					
327	0					
329	0					
328	0					
318	0 2					
154	0					
155	0					
151	0					
153	0					
152	0					
446	0 0 0 0 0					
447	0					
445	0					
378	0					
379	0					
377	0 2					
149	0					
150	0					
147	0					
148	0					
68	0					
70	0					
66	0					
67	0					
69	0					
323	0 0 0					
324	0					
320	0					
321	0					
322	0					

262	0a 00	
263	0a 00	
261	0a 00	
264	0a 00	
265	02 00	
297	0a 00	
298	0a 00	
316	0a 00	
332	0a 00	
374	0a 00	
299	0a 00	
300	0a 00	
296	02 00	
237	0a 00	
239	0a 00	
238	0a 00	
231	0a 00	
235	0a 00	
234	0a 00	
319	0a 00	
284	0a 00	
285	0a 00	
281	0a 00	
282	0a 00	
146	0a 00	
375	0a 00	
236	0a 00	
283	02 00	
457	0a 00	
458	0a 00	
454	0a 00	
455	0a 00	
456	0a 00	
112	0a 00	
115	0a 00	
113	0a 00	
422	0a 00	
423	0a 00	
419	0a 00	
421	02 00	
366	0a 00	
367	0a 00	
368	0a 00	
369	0a 00	
365	0a 00	
363	0a 00	
364	0a 00	
360	0a 00	
362	0a 00	
427	0a 00	
428	0a 00	
425	0a 00	
424	02 00	
356	0a 00	
359	0a 00	
355	0a 00	
64	0a 00	
65	0a 00	
61	0a 00	
62	0a 00	
63	0a 00	
358	02 00	
196	0a 00	
200	0a 00	
197	0a 00	
199	0a 00	
198	02 00	
106	0a 00	
109	02 00	
108	0a 00	
351	0a 00	
381	02 00	
317	0a 00	
448	02 00	
397	0a 00	
417	0a 00	
338	0a 00	
114	0a 00	
402	0a 00	
400	0a 00	
361	02 00	
444	0a 00	
352	0a 00	
354	0a 00	
410	0a 00	
411	0a 00	
46	0a 00	
392	0a 00	
118	02 00	
48	0a 00	
111	0a 00	
420	02 00	
104	0a 00	
105	0a 00	
190	02 00	
399	0a 00	
401	0a 00	
403	0a 00	
119	0a 00	
120	0a 00	
47	0a 00	
50	0a 00	
116	0a 00	
117	0a 00	
395	0a 00	
398	0a 00	
396	0a 00	
394	0a 00	
390	0a 00	
391	0a 00	
389	0a 00	
440	0a 00	
442	0a 00	
439	02 00	
387	0a 00	
388	0a 00	
385	0a 00	
386	0a 00	
412	0a 00	

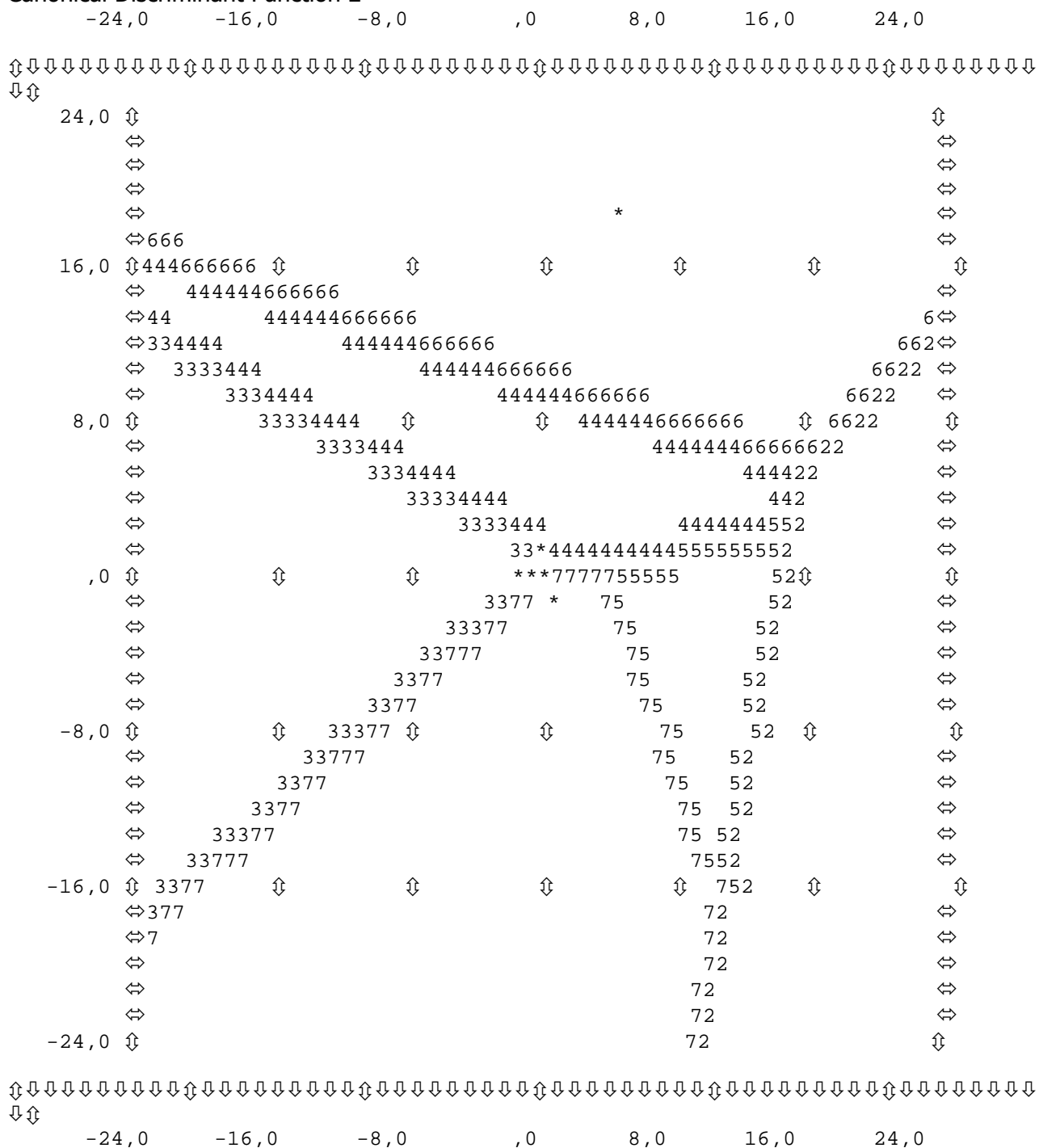
[illegible]



Dendrogram using Ward Method
Rescaled Distance Cluster Combine

Figure Annex 1: Dendrogramm – Cluster Analysis Inventory Data

Canonical Discriminant Function 2



Canonical Discriminant Function 1

Symbols used in territorial map – the numbers are equal to the group numbers, “*” indicate group centroids.

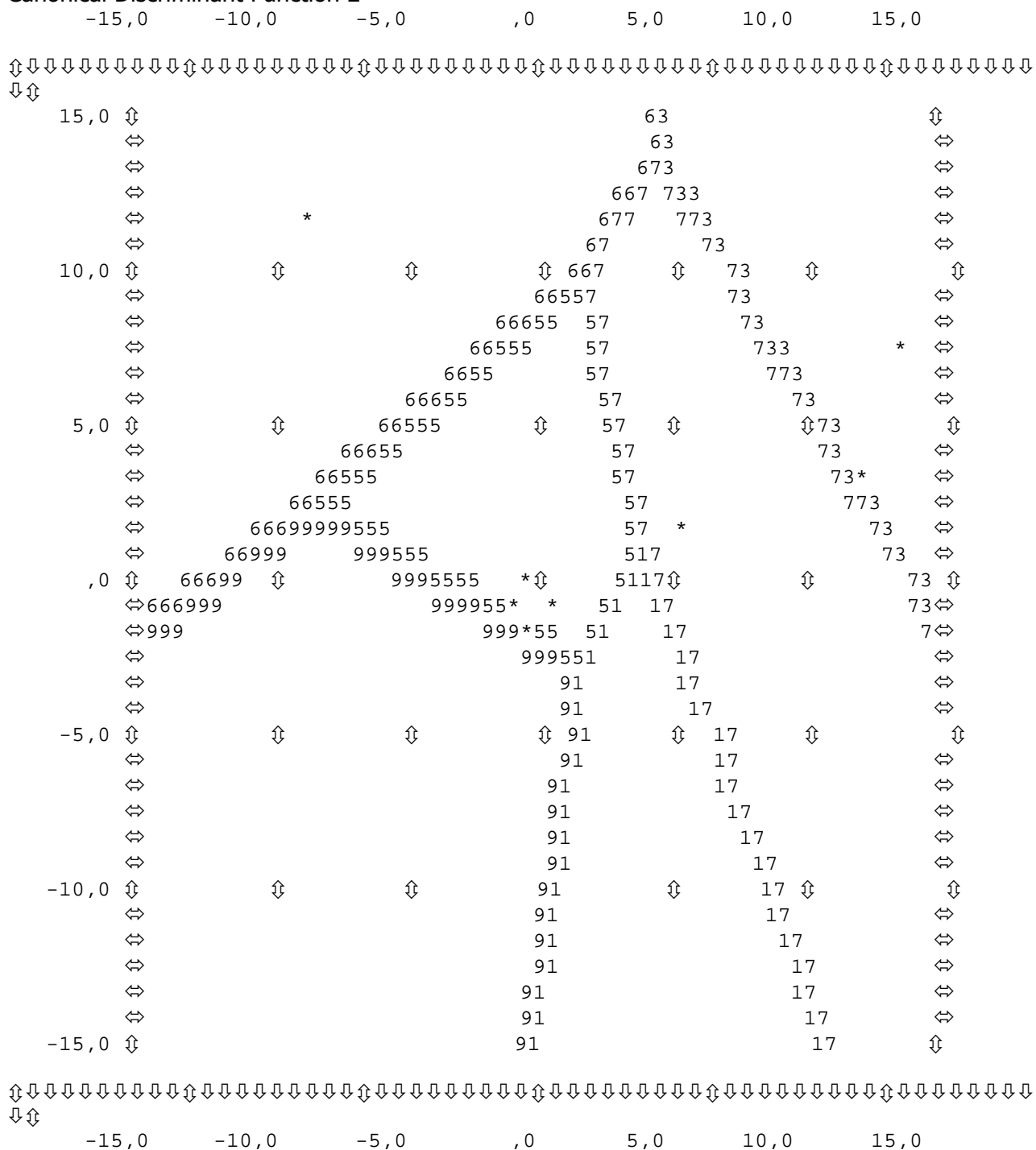
Figure Annex 2: Territorial Map - Cluster Analysis Inventory Data

C A S E	0	5	10	15	20	25
Label	Num					
60	0 0 0					
76	0 0					
41	0 0					
61	0 0 0 0 0 0					
20	0 0					
24	0 0 0					
29	0 0 0					
34	0 0					
44	0 0 0 0 0 0 0 0					
45	0 0 0 0 0 0					
31	0 0 0 0 0 0					
28	0 0 0 0 0 0					
78	0 0 0 0 0 0					
43	0 0 0 0 0 0					
38	0 0 0 0 0 0 0 0 0 0					
74	0 0 0 0 0 0					
39	0 0 0 0 0 0					
17	0 0 0 0 0 0					
18	0 0 0 0 0 0					
73	0 0 0 0 0 0					
55	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
59	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
58	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
69	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
47	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
51	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
53	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
63	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
52	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
83	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
57	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
64	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
65	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
87	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
81	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
86	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
88	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
89	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
85	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
82	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
84	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
71	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0					
75	0 0					
16	0 0					
25	0 0					
21	0 0					
42	0 0					
79	0 0					
46	0 0					
56	0 0					
33	0 0					
35	0 0					
6	0 0					
32	0 0					
67	0 0					
72	0 0					
66	0 0					
90	0 0					
40	0 0					
70	0 0					
37	0 0					
48	0 0					
54	0 0					
49	0 0					
8	0 0					
11	0 0					
4	0 0					
2	0 0					
5	0 0					
3	0 0					
9	0 0					
1	0 0					
27	0 0					
14	0 0					
15	0 0					
50	0 0					
13	0 0					
12	0 0					
19	0 0					
62	0 0					
68	0 0					
7	0 0					
10	0 0					
36	0 0					
80	0 0					
22	0 0					
26	0 0					
23	0 0					
30	0 0					
77	0 0					

Dendrogram using Ward Method
Rescaled Distance Cluster Combine

Figure Annex 3: Dendrogram - Cluster Analysis Plot Data

Canonical Discriminant Function 2



Canonical Discriminant Function 1

Symbols used in territorial map – the numbers are equal to the group numbers, “*” indicate group centroids.

Figure Annex 4: Territorial Map - Cluster Analysis Plot Data

