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# Long term monitoring of natural regeneration in natural forest reserves in Austria - results from the ELENA project

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## Abstract

Research in natural forest reserves (NWR) provides insights into the dynamics of natural forests that can serve as a basis for a targeted oriented management of forests. In this context, the research project ELENA has studied the natural regeneration in unmanaged mountain forests in Austria. A comparative analysis of the natural regeneration was done in seven natural reserves (Goldeck, Laaser Berg, Schiffwald, Hutterwald I and II, Kronawettgrube, Krimpenbachkessel) by establishing 197 permanent sample plots for a long-term monitoring. The study focused on seven different forest associations, where as the main focus was put on the *Homogyno alpinae-Piceetum*, *Athyrio alpestris-Piceetum* and *Adenostylo glabrae-Piceetum*. This contribution presents the study design and the results of the first investigation of the natural regeneration in these natural forest reserves. The results allow an evaluation of the dynamics of the natural forest reserves and the establishment of natural regeneration in mountain forests. The numbers of individuals in the natural regeneration and their distribution among different categories vary greatly between the natural forest reserves (between 766 n*ha$^{-1}$ in the Hutterwald and 15869 n*ha$^{-1}$ in Krimpenbachkessel). The growing stock lies between 334 and 725 m$^3$*ha$^{-1}$ and the coarse woody debris volume (lying and standing dead wood) summaries up to 44.2 and 73.2 m$^3$*ha$^{-1}$ (10-20% of the growing stock). The analysis focuses on the relation between the occurrence of natural regeneration and the availability of coarse woody debris. It is shown that the number of seedlings established and saplings depend on the amount, type and distribution of coarse woody debris strongly.

## Keywords

natural regeneration, natural forest reserves, Norway-spruce, long-term monitoring, coarse woody debris

## Introduction

Undisturbed forests are valuable objects to study vegetation structure and dynamics (Mayer et al. 1987; Leibundgut 1982). The Austrian "Natural Forest Reserves Program" was launched in 1995 to support the in-situ conservation of rare and endangered forest types and the study of natural dynamic processes, including the effect of natural disturbances and catastrophes (Frank & Müller 2003). The natural forest reserves also serve as references for biodiversity assessments and ecological monitoring, as they are not subject to any human activities (Frank & Koch 1999; Frank & Müller 2003). Research in natural forest reserves aims at identifying the structure and dynamics of forest ecosystems. While the structure of a forest may be described rather easily at a certain moment, the dynamics results from a temporal development of the structure and can only be identified by repeated surveys on permanent sample plots. The initiative for the establishment of such a network has its origin in the signing of the Helsinki Resolutions (H2 - General Guidelines for the Conservation of the Biodiversity of European Forests; MCPFE 2000) and the COST-Action E4 Forest Reserves Research. Until 2012 a number of 200 natural forest reserves with a size of 8603 ha have been established (BMLFUW 2010). Due to its location at the interface of alpine, subcontinental and subatlantic climatic influences Austria comprises around 125 different forest communities. The aim of the network is to reach a representation by at least one reserve per eco-region and forest community of all typical forest communities occurring in those 22 eco-regions (Kilian et al. 1994). Currently 0.15 % of the total forested area in Austria is represented with natural reserves.

In this context, the research project ELENA has studied the natural regeneration in selected natural reserves of mountain forests in Austria (Ruprecht et al. 2012). The dependence of seedling recruitment on deadwood has been reported from various studies (Lonsdale et al. 2008; Zielonka 2006). It was also reported that decaying logs form a major seedbed for trees in European subalpine *Picea abies* forests (Bače et al. 2012). Therefore a comparative analysis of the stand and site characteristics as well as the natural regeneration dynamics was initiated to analyse the implications of site and stand characteristics on regeneration success. This contribution presents the study design of the long-term monitoring research and the results of the first investigation of the natural regeneration in the studied natural forest reserves. The results allow an evaluation of the dynamics of the natural forest reserves and the establishment of natural regeneration in mountain forests.

## Study site and methods

The study sites of the spruce-dominated natural forest reserves (Goldeck, Hutterwald I, Hutterwald II, Krimpenbachkessel, Kronawettgrube, Laaser Berg, Schiffwald) are located in the eco region 1.3 „Interior Alps – eastern part“, 3.3 „Southern Intermediate“, 4.2 „Northern Rim Alps – eastern part“ and eco region 5.2 „Foothills“ (figure 1 and table 1). The study analysed different forest associations, where as the main focus was put on the *Homogyno alpinae-Piceetum, Athyrio alpestris-Piceetum* and *Adenostylo glabrae-Piceetum*. The classification follows the taxonomie of WILLNER & GRABHERR (2007).

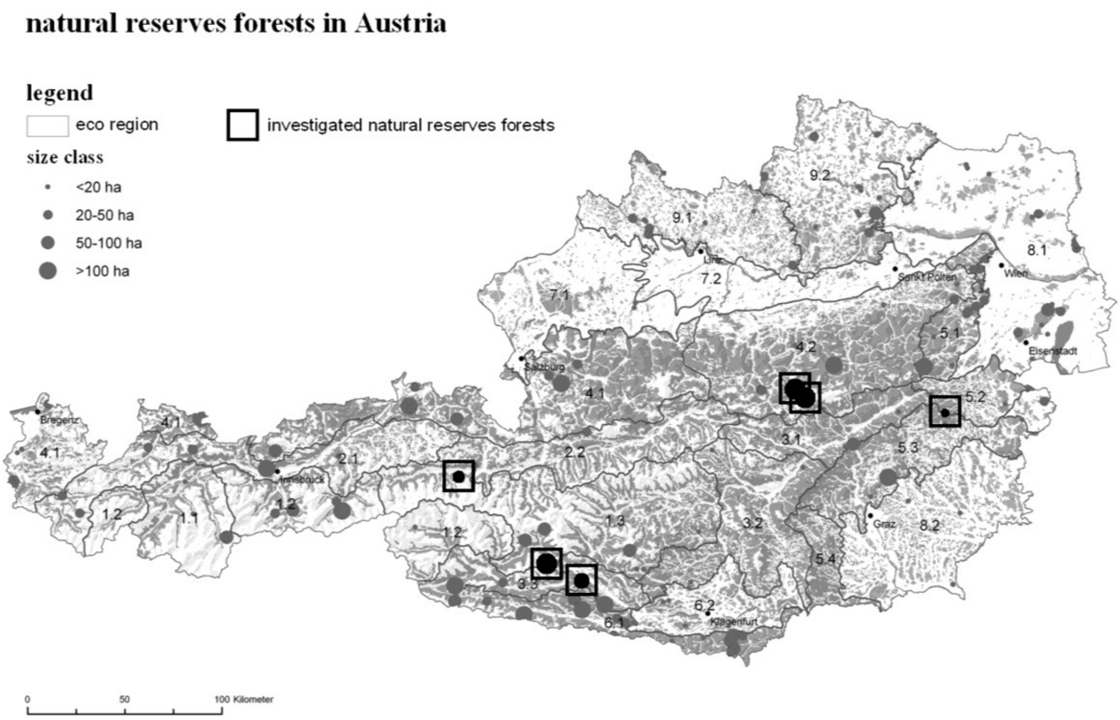


Figure 1: Location of Natural Forest Reserves in Austria and the observed study sites

The reserves at the study sites range from 840 to 2080 m above sea level, whereas the sample plots are mainly situated in the montan and subalpine altitudinal zone. The bedrock is mainly from silicate origin, whereas in the reserves Schiffwald and Krimpenbachkessel the bedrock is calceaus. The average daily mean temperature ranges between 3.6 and 5.9°C and the mean precipitation between 1054 and 1532 mm (period 1960-2009). A short characterisation of the natural reserves can been found in table 1. Detailed information on the study sites are published in RUPRECHT et al. (2012) as well.

Table 1: Characteristics of the observed natural forest reserves

| reserve | eco region | forest association | sea level [m] | bedrock | slope [%] | aspect | temp. [°C] | precip. [mm] | area [ha] | established | points [n] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Goldeck | 3.3 | *Adenostylo alliariae-Piceetum*<br>*Athyrio alpestris-Piceetum*<br>*Calamagrostio villosae-Fagetum*<br>*Homogyno alpinae-Piceetum*<br>*Saxifrago rotundifolae-Fagetum* | 1040-1620 | silicate | 40-**80**-110 | W-**N**-E | 4.7 | 1107 | 58.3 | 1997 | 30 |
| Hutterwald I | 1.3 | *Calamagrostio villosae-Piceetum*<br>*Homogyno alpinae-Piceetum*<br>*Sphagno-Piceetum*<br>*Vaccinio-Pinetum cembrae* | 1500-1700 | silicate | 10-**50**-80 | W-**N**-E | 3.6 | 1354 | 18.3 | 1997 | 18 |
| Hutterwald II | 1.3 | *Athyrio alpestris-Piceetum*<br>*Homogyno alpinae-Piceetum* | 1550-1700 | silicate | 10-**50**-80 | W-**N**-E | 3.6 | 1354 | 11.1 | 1999 | 11 |
| Krimpen-bachkessel | 4.2 | *Adenostylo glabrae-Fagetum*<br>*Adenostylo glabrae-Abietetum* | 840-1330 | carbonate | 20-**50**-80 | W-**N**-E | 5.9 | 1332 | 151.2 | 1997 | 25 |
| Kronawett-grube | 5.2 | *Athyrio alpestris-Piceetum* | 1400-1540 | silicate | 10-**40**-80 | N-**E**-S | 4.2 | 1532 | 7.5 | 1997 | 20 |
| Laaser Berg | 1.3 | *Homogyno alpinae-Piceetum*<br>*Adenostylo alliariae-Piceetum*<br>*Vaccinio-Pinetum cembrae* | 1500-2080 | silicate | 20-**70**-90 | **S**-W-N | 4.9 | 1054 | 63.2 | 1998 | 26 |
| Schiffwald | 4.2 | *Saxifrago rotundifolae-Fagetum*<br>*Adenostylo glabrae-Piceetum*<br>*Rhodothamno-Laricetum* | 960-1500 | carbonate | 0-**20**-110 | all | 4.6 | 1477 | 692.5 | 1999 | 67 |

In the context of the given size of the studied reserves a regular grid of sampling plots with a distance between 75 to 200 m has been established. Each sample plot has a size of 300 m² (radius 9.77 m) and the measurements have been investigated according to six strata (natural regeneration, dead wood, site and stand attributes, hemispherical photographs and angel count (Bitterlich) sampling). Plots for sampling natural regeneration are located in each of the four main expositions (figure 2). Each regeneration plot was composed of 7 subplots whereas individuals up to a tree height of 1.30 m have been investigated. The seedlings have been sampled on 16 subplots with a size of 0.25 m² (figure 2: VI) and samplings older one year up to a tree height of <30 cm have been sampled on the 16 subplots with 0.25 m² and on the 12 subplots with a size of 1.0 m² (figure 2: VII). Larger individuals (tree height ≥30 cm) have been sampled on the whole sample plot. For all individual larger then ≥15 cm tree height a detailed investigation of tree characteristics and damages was done (compare figure 2). Additionally the regeneration on the lying deadwood (having a mean diameter ≥10 cm) was sampled.

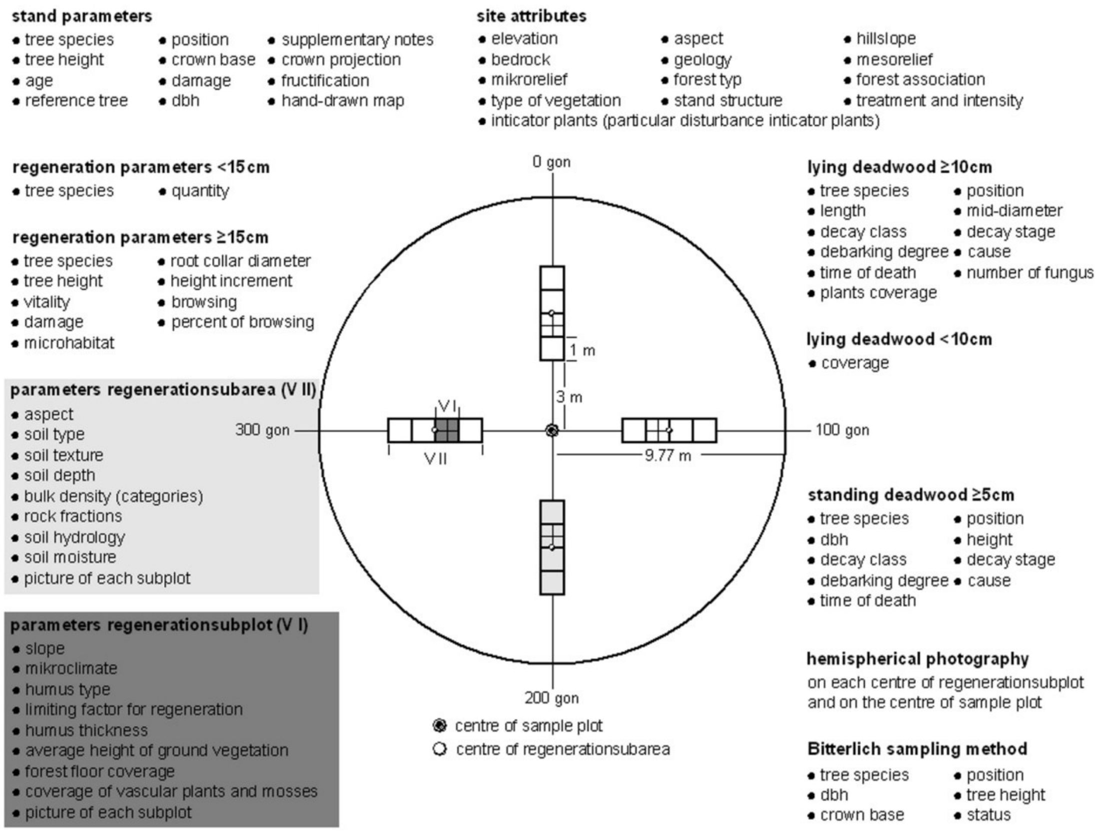


Figure 2: Sampling design and measurement parameter

Logistic regression has been used in this study to analyse the influence of lying deadwood on the occurrence of natural regeneration, since we found it to be a useful instrument to model several phenomena and to predict the presence or absence of a particular characteristic based on the values of a group of predictive variables. Model phenomena with binary or dichotomous variables – such as recruitment and natural regeneration - are described best by means of logistic regression. Moreover logistic regression proves to be relatively flexible, since it accepts a combination of continuous, categorical and non-normally distributed variables (BELLGARDT 1997).

Table 2: Mean values and standard error for the volume of deadwood classified by categories and its share of the growing stock of the living trees (≥1.30 m height)

| reserve | standing dead wood [≥5 cm] | | lying dead wood [≥10 cm] | | stumps [≥5 cm] | | ∑ dead wood | living trees | ratio dead wood / living tree |
|---|---|---|---|---|---|---|---|---|---|
| | Vfm*ha$^{-1}$ | % | m$^3$*ha$^{-1}$ | % | m$^3$*ha$^{-1}$ | % | m$^3$*ha$^{-1}$ | Vfm*ha$^{-1}$ | % |
| Goldeck | 18.3 ±9.4 | 26 | 46.5 ±9.6 | 67 | 4.3 ±0.9 | 7 | 69.3 ±14.5 | 724.8 ±56.8 | 10 |
| Hutterwald | 23.1 ±5.5 | 32 | 45.6 ±18.2 | 61 | 5.6 ±1.1 | 7 | 73.2 ±19.4 | 361.7 ±40.3 | 20 |
| Krimpen-bachkessel | 13.7 ±4.0 | 21 | 48.4 ±14.4 | 72 | 4.9 ±1.0 | 7 | 67.0 ±15.8 | 334.4 ±32.4 | 20 |
| Kronawett-grube | 45.3 ±10.6 | 64 | 24.5 ±13.8 | 35 | 0.4 ±0.4 | 1 | 70.2 ±19.6 | 477.9 ±44.7 | 15 |
| Laaser Berg | 15.6 ±4.3 | 26 | 33.2 ±5.5 | 56 | 10.4 ±3.1 | 18 | 59.2 ±7.5 | 537.7 ±59.1 | 11 |
| Schiffwald | 36.3 ±7.8 | 82 | 7.1 ±1.6 | 16 | 0.8 ±0.7 | 2 | 44.2 ±8.1 | 345.2 ±20.8 | 13 |
| all | 27.0 ±3.4 | 45 | 29.2 ±4.1 | 49 | 3.8 ±0.6 | 6 | 60.0 ±5.4 | 443.0 ±18.7 | 14 |

## Results

Characteristics of the natural reserves

The amount of the stand volume varies between 334 and 725 Vfm*ha$^{-1}$ in the studied reserves (table 2). The coarse woody debris volume (lying and standing dead wood) summaries up to 44.2 and 73.2 m$^3$*ha$^{-1}$ (10-20% of the stand volume). The reserve Goldeck has the highest total volume (724.8 Vfm*ha-1), whereas the reserves Hutterwald and Krimpenbachkessel have the highest share of deadwood (20%) in relation to the total volume (table 2). In total 1050 individual logs respectively stumps have been sampled. The size, decay stage and number of fungi varied strongly. The differences between the reserves are mainly based on the existence of different development stages within the forest communities and the time that has passed since the last human intervention (table 1).

Amount of Regeneration

The numbers of individuals in the natural regeneration and their distribution among different categories vary to a high degree between the natural forest reserves (table 3). The total number of seedlings found on the lying coarse woody debris is 5799. It was found that there is strong relationship between the amount of deadwood sampled on a plot and the regeneration found on the sample plots. Plots with no lying deadwood had a significant lower number of individuals in the regeneration than plots with lying deadwood (respectively logs and stumps). There were no significant differences found between the different classes of deadwood (1=to 50 m$^2$*ha$^{-1}$; 2=to 150 m$^2$*ha$^{-1}$; 3=to 250 m$^2$*ha$^{-1}$; 4=to 350 m$^2$*ha$^{-1}$, 5= >350 m$^2$*ha$^{-1}$).

Table 3: Mean number of individuals and standard error of the natural regeneration classified by regeneration type and natural forest reserve

| reserve | category of regeneration | | | |
|---|---|---|---|---|
| | seedling | <15 cm height | 15 to <30 cm | 30 to <130 cm |
| | n*ha$^{-1}$ | n*ha-1 | n*ha-1 | n*ha-1 |
| Goldeck | 16286 ±2970 | 12288 ±4237 | 303 ±157 | 394 ±142 |
| Hutterwald | 661531 ±162812 | 766 ±256 | 683 ±287 | 543 ±200 |
| Krimpenbachkessel | 19235 ±3785 | 15869 ±4018 | 2065 ±598 | 2222 ±579 |
| Kronawettgrube | 139565 ±21071 | 8123 ±2085 | 55 ±29 | 183 ±61 |
| Laaser Berg | 39221 ±5592 | 1242 ±332 | 238 ±136 | 413 ±85 |
| Schiffwald | 6574 ±1757 | 6911 ±1164 | 436 ±120 | 587 ±96 |
| all | 123888 ±28726 | 7337 ±990 | 581 ±106 | 696 ±98 |

Logistic regression model

A total of 907 logs were used to study the relationship between the occurrence of natural regeneration and coarse woody debris. 379 logs had no regeneration and 528 logs had natural regeneration. All parameters from lying deadwood and stumps that have been investigated in the field have been used for the model building process. In order to eliminate multicollinearity between the variables selected for this study, the Pearson correlation has been conducted for the whole datasets independently. All variables with a correlation higher than 0.7 were not further considered for the model building procedure.

Table 4: Significant variables of the logistic regression model and outcomes of the Wald-statistic

| variable | estimate | std. error | z value | Pr(>\|z\|) | signif. |
|---|---|---|---|---|---|
| (intercept) | -2.0009E+00 | 3.34E-01 | -5.990 | <0.001 | *** |
| projected area | 2.2366E-01 | 7.05E-02 | 3.172 | 1.51E-03 | ** |
| moss coverage | 5.3565E-02 | 1.09E-02 | 4.933 | <0.001 | *** |
| moss coverage ^2 | -4.0930E-04 | 1.35E-04 | -3.022 | 2.51E-03 | ** |
| spruce | 9.4117E-01 | 2.30E-01 | 4.090 | <0.001 | *** |
| non-determinable tree species | 1.4505E+00 | 2.57E-01 | 5.638 | <0.001 | *** |
| no exposition | 9.0078E-01 | 2.17E-01 | 4.145 | <0.001 | *** |
| decay class 8 | 1.5825E+00 | 8.04E-01 | 1.969 | 4.90E-02 | * |
| decay stage 3 | -4.6279E-01 | 1.66E-01 | -2.783 | 5.38E-03 | ** |
| no fungus | 6.6396E-01 | 2.24E-01 | 2.965 | 3.03E-03 | ** |

signif. codes: 0 ‘***’, 0.001 ‘**’, 0.01 ‘*’, 0.05 ‘.’, 0.1 ‘ ’

Various methods were tested examining the level of significance through which the variables were introduced and removed from the equation. Variables were introduced into the model according to a significance of $p < 0.05$ (Wald significance) and removed from the model with a $p > 0.1$ (Wald significance). The variables “projected area of deadwood”, “moss coverage”, “non-determinable or spruce as tree species”, “deadwood with no orientation”, “deadwood with decay class 8 (root plate with trunk)” and “no fungus available” showed a positive significant effect for regeneration whereas the “decay stage 3 of the deadwood (advanced decomposition)” was found to have a negative significant effect on regeneration (table 4). The Nagelkerke´s $R^2$ test, ROC (receiver operating characteristic) value and the Hosmer & Lemeshow goodness-of-fit test was used to estimate goodness of fit. 2 x 2 classification tables of observed and predicted responses were calculated in order to test the predictive capability of the models. For that purpose the logs were categorised with a probability threshold of 0.5.

The selected model includes nine variables (table 4) predicting regeneration on deadwood correctly with a percentage of 73%. “No regeneration” is modelled with 66% and the total percentage of correctly predicted cases is 70%. The model has a quite acceptable goodness of fit with a Nagelkerke´s $R^2$ of 0.280, a ROC of 0.768 and a Hosmer & Lemeshow goodness-of-fit test with a significance level of 0.90. It was found, that an increasing coverage of moss on the lying trunk has a positive effect on the seeding establishment. When the coverage exceeds 65%, the probability for a successful regeneration decreases again. Figure 3 shows the probability for successful regeneration based on the logistic regression model for the parameters moss coverage and projected area of deadwood.

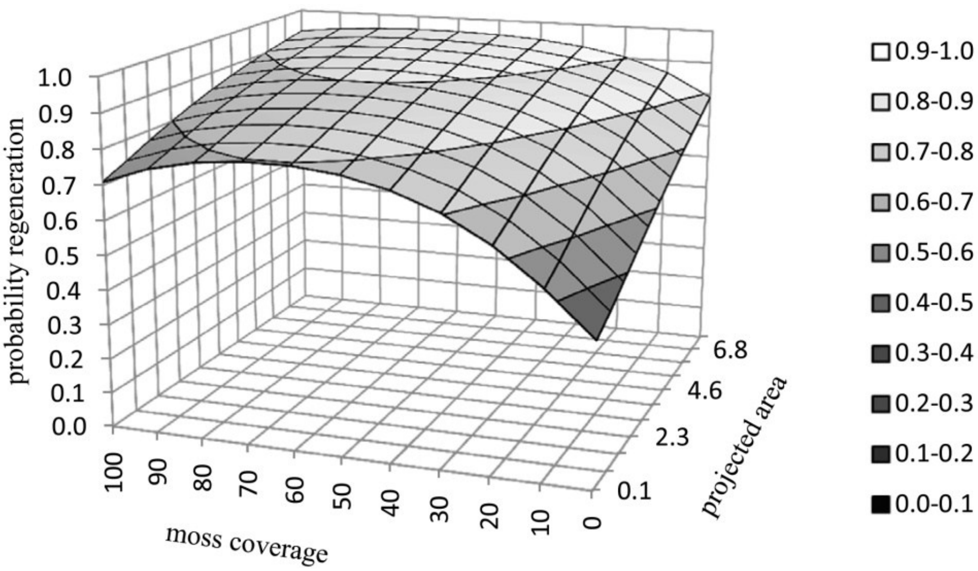


Figure 3: Probability for successful regeneration based on the logistic regression model for the parameters moss coverage and projected area of deadwood (for all other parameters median values are used)

## Discussion and Conclusions

One of the main objectives of establishing natural forest reserves is to monitor natural vegetation processes, which will be used as a reference value in near-to-nature management of the same forest types.

The role of deadwood for a successful natural regeneration has been described by several authors (e.g. HUNZIKER & BRANG 2005; ZIELONKA 2006; LONSDALE et al. 2008; BAČE et al. 2012). In this context several parameters have been found to have a significant effect on the recruitment. BAČE et al. (2012) have shown, that similar to this study the diameter has a significant effect on a successful regeneration. The decay process seems to have mostly a variable effect (BAČE et al. 2012; ZIELONKA 2006), this could be confirmed in this study as well, as the decay stage 3 and other decay stages have a different effect. Surrounding vegetation was found by BAČE et al. (2012) has a positive effect on recruiment, but descreases with a high percentage again. This finding is in line with our results, as the moss coverage shows a similar trend and also IIJIMA et al. (2007) shows that moss have a positive effect for regeneration. Other authors have demonstrated the positive effect of special fungi species, this finding could not be confirmed with this study in each respect, as the availability of a fruiting body was found to have a negative effect.

Most of the studies have used different size classes for studying natural regeneration. In this study the whole population ranging from seedlings to individuals with a height less than 130cm have been used to model the effect of deadwood on regeneration success. Further analysis for different size classes of the natural regeneration could help to differentiate between the different parameters.

The long term monitoring network established in the context of this study has shown already some interesting insights in natural regeneration from its first sampling period. Further investigations will increase the importance of the sample plots for future studies (c.f. BUGMANN & BRANG 2009; BRANG et al. 2011). Although the sample plots are influenced by man to some extent, the study sites can serve as a good proxy to study natural dynamics. The set of parameters chosen for data investigation allows comparison with other national and international studies in protected natural reserves.

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