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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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Introduction

The Austrian "Natural Forest Reserves Program" was launched in 1995 to support the in-situ conservation of rare and endangered forest types in Austria. Natural forest reserves allow to study natural dynamics and serve as reference 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 describing the structure and dynamics of forest ecosystems from repeated observations on permanent sample plots. Until recently some 200 natural forest reserves with a size of in total 8603 ha have been established covering 0.15 % of the total forested area in Austria (BMLFUW 2010). In this context, the research project ELENA has studied the natural regeneration processes in selected natural reserves of mountain forests in Austria (Ruprecht et al. 2012). A comparative analysis of stand and site characteristics was initiated to analyse their implications on regeneration success. We present the study design of the long-term monitoring research and 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 support the silvicultural planning of natural regeneration in mountain forests.

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

Study site and methods

The seven spruce-dominated natural forest reserves studied 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). 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*. A characterisation of the natural reserves can been found in table 1. A regular grid of sampling plots with a distance between 75 to 200 m has been established in each reserve. Each sample plot has a size of 300 m² and the measurements have been investigated according to six strata (natural regeneration, dead wood, site and stand attributes, hemispherical photographs and angel count 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 all individuals up to a tree height of 1.30 m have been investigated. The seedlings and samplings have been sampled on the 16 subplots with a size of 0.25 m² and on the 12 subplots with a size of 1.0 m² respectively (figure 2). For all individuals larger then ≥15 cm tree height a detailed investigation of tree characteristics and damages was done. Additionally the regeneration on the lying deadwood (having a mean diameter ≥10 cm) was sampled. Logistic regression technique has been used to analyse the influence of lying deadwood on the occurrence of natural regeneration. It was seen as useful to predict the presence or absence of natural regeneration based on a group of predictive variables.

Table 1: Characteristics of the observed natural forest reserves

reserve	eco region	sea level [m]	bedrock	slope [%]	aspect	temp. [°C]	precip. [mm]	area [ha]	established	points [n]
Goldeck	3.3	1040-1620	silicate	40-**80**-110	W-**N**-E	4.7	1107	58.3	1997	30
Hutterwald I	1.3	1500-1700	silicate	10-**50**-80	W-**N**-E	3.6	1354	18.3	1997	18
Hutterwald II	1.3	1550-1700	silicate	10-**50**-80	W-**N**-E	3.6	1354	11.1	1999	11
Krimpen-bachkessel	4.2	840-1330	carbonate	20-**50**-80	W-**N**-E	5.9	1332	151.2	1997	25
Krona-wettgrube	5.2	1400-1540	silicate	10-**40**-80	N-**E**-S	4.2	1532	7.5	1997	20
Laaser Berg	1.3	1500-2080	silicate	20-**70**-90	**S**-W-N	4.9	1054	63.2	1998	26
Schiffwald	4.2	960-1500	carbonate	0-**20**-110	all	4.6	1477	692.5	1999	67

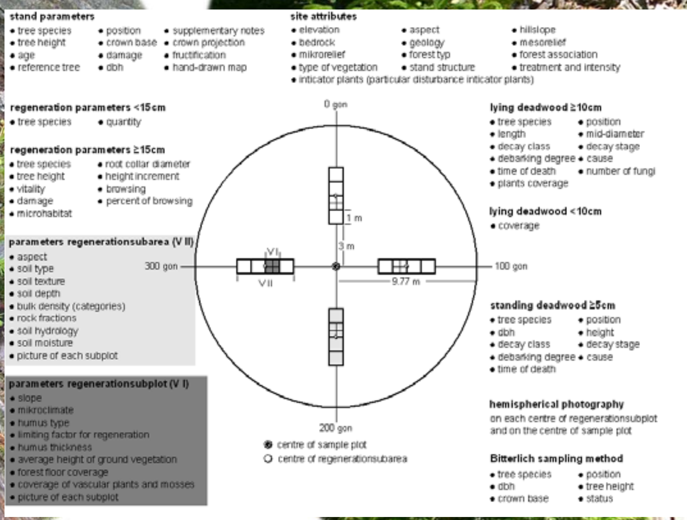

Figure 2: Sampling design and measurement parameter

Table 2: Deadwood classified by categories and its share of the growing stock of the living trees

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 (i)

The amount of stand volume varies between 334 and 725 $Vfm*ha^{-1}$ in the studied reserves (table 2). The coarse woody debris volume summaries up to 44.2 and 73.2 m^3*ha^{-1} (10-20% of the stand volume). 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). The numbers of individuals in the natural regeneration and their distribution among different categories vary to a high degree (table 3). The total number of seedlings found on the lying deadwood is 5799. A strong relationship was found between the amount of deadwood sampled on a plot and the amount of regeneration found. 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: Natural regeneration classified by regeneration type

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
Krimpen-bachkessel	19235 ±3785	15869 ±4018	2065 ±598	2222 ±579
Kronawett-grube	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

Results (ii)

A total of 907 logs were used to study the relationship between the occurrence of natural regeneration and coarse woody debris by means of logistic regression models (379 logs without regeneration and 528 logs with natural regeneration). In order to eliminate multi-collinearity between the variables, 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 model building. 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. The selected model includes nine variables predicting the occurrence of regeneration on deadwood with a percentage of 73%. The variables "projected area of deadwood", "moss coverage", "root plate with trunk", "deadwood with no orientation", and "no fungus available" showed a positive effect. The "decay class advanced decomposition" was found to have a negative effect on regeneration.

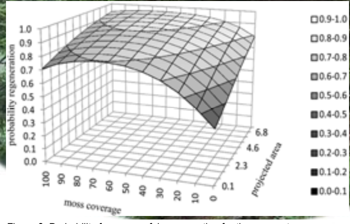

Figure 3: Probability for successful regeneration for the parameters moss coverage and projected area of deadwood

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.

Discussion and Conclusions

One of the main objectives of establishing natural forest reserves is to observe natural dynamics, which can serve as a reference for near-to-nature management. 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). 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 a variable effect in many studies (Bače et al. 2012; Zielonka 2006), similar to this study. Surrounding vegetation was found by Bače et al. (2012) has a positive effect on recruitment, but decreases with a high percentage again. This finding is in line with our results, as the moss coverage shows a similar trend. 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 dynamics. Further investigations in the future will increase the relevance of the sample plots (c.f. Bugmann & Brang 2009; Brang et al. 2011) although some influence by man can be observed. The set of parameters chosen for data investigation allows comparison with other national and international studies in protected natural reserves.

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