Natural regeneration of pine following a large scale bark beetle infestation in the Mountain Pine Ridge Forest Reserve, Belize

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Abstract

The Mountain Pine Ridge Forest Reserve is located 40 km southwest of Belmopan, the capital of Belize. The Forest Reserve has an area of approximately 40,000 ha of which 30,000 ha are natural pine forest with *Pinus caribaea* Morelet var. *hondurensis* (Barr. et Golf.) and *Pinus patula* Schiede et Deppe ssp. *tecunmanii* (Eguiluz et Perry), whereby *Pinus caribaea* dominates in the lower ranges and *Pinus patula* in elevation higher than 700m above sea level. The remainder of the forest reserve is covered by hardwood forest which is mostly in swampy areas and along the water ways.

Between 2000 and 2002 over 90% of the pine forest was destroyed by a massive bark beetle infestation of *Dendroctonus frontalis* (Zimmermann). The explosion of the bark beetle population was probably triggered by extended drought periods in previous years. A first assessment in December 2000 revealed that in the southern half of the reserve more than 90% of the trees were already dead. In the following year the infestation proceeded north affecting the entire reserve. In 2001 an attempt was made to contain the spreading of the infestation through the establishment of containment lines, 200m wide strips cleared with bulldozers, but that was not successful. By the end of 2002 the bark beetle populations collapsed naturally.

In February and March 2004 a sample based inventory of the natural pine regeneration was conducted to assess the progress of natural regeneration. The collected data were analysed with regard to the spatial distribution and the mean density of pine seedlings in the sampled areas, as well as regarding the possible influence that certain site factors have on the establishment of natural regeneration.

On average, 64% of every management unit (compartment) were found to have a regeneration cover of at least 200 seedlings/ha. However, the natural regeneration is distributed rather heterogeneously, which requires adaptive strategies of forest management in the different sub-units of the reserve.

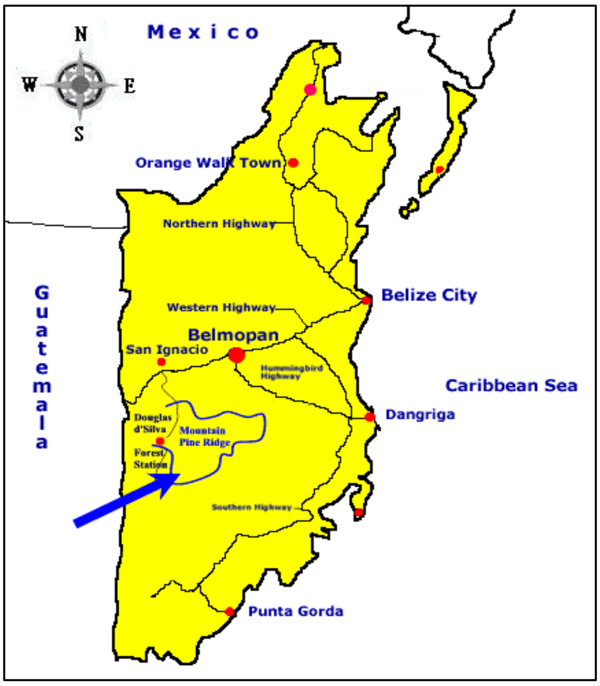
Based on the findings of the regeneration inventory the paper discusses four different silvicultural management options for the rehabilitation of the devastated forest reserve and recommends: ‘artificial reforestation’ on 13% of the area, ‘natural succession’ on 13% of the area, and ‘natural regeneration-based forestry’ on 74%. The fourth option of fires induced natural regenerations was not recommended for none of the 23 analysed sub-compartments.

Keywords: Natural regeneration, *Pinus caribaea, Pinus patula*, pine bark beetle

Introduction

The Mountain Pine Ridge Forest Reserve (MPRFR) is located 40km southwest of Belmopan, the capital of Belize. The Forest Reserve has an area of approximately 40,000 ha of which 30,000 ha are natural pine forest with *Pinus caribaea* Morelet var. *hondurensis* (Barr. et Golf.) and *Pinus patula* Schiede et Deppe ssp. *tecunmanii* (Eguiluz et Perry), whereby *Pinus* caribaea dominates in the lower ranges and *Pinus patula* in elevation higher than 700m above sea level. The remainder of the forest reserve is covered by hardwood forest which occurs mostly in swampy areas and along the water ways. The pine forest is associated with rather poor and acid granite. The surrounding lime stone areas are covered with dense tropical broad leaf forest and there is no pine forest on lime stone bedrock soils. Between 2000 and 2002 most of the pine forest died following a devastating bark beetle infestation.

Map 1: Location of the Mountain Pine Ridge Forest Reserve in Belize



Scope of the Regeneration Study

The main objective of the study is to assess the status of the natural pine regeneration approximately two years after most of the pine overstory died. The knowledge of the average density and the spatial distribution or pine regeneration will assist in answering the main management question; whether the forest has to be replanted or if there will be sufficient natural regeneration to bring the forest back into production. In addition to the above, the study attempts to analyse the ecological site factors that possibly influence the establishment of natural regeneration in order to draw conclusions or recommendations on how to encourage natural regeneration. The results presented in this paper are based on a Bachelor thesis prepared by Johannes Horstmann of the Faculty of Forestry, in Eberswalde Germany.

Pine forests in the Mountain Pine Ridge Forest Reserve (MPRFR)

Pine forest dominated by *Pinus* caribaea Morelet var. hondurensis Barr. et Golf.

A wide range of stand ages and densities of Caribbean pine forest formed the main type of vegetation before the outbreak of the bark beetle infestation in 2000. While the overstory was clearly dominated by pine with a few broadleaf trees in between, the understory was and still is composed mainly with oaks (*Quercus spp*.), Craboo (*Brysonima crassifolia*), Polewood (*Xylopia rutescens*) and shrubs from the Melastomataceae family, e.g. *Miconia albicans*, other shrubs such as *Hypericum terrae-firmae*, as well as plants from the Palmae family, e.g. *Acoelarraphe wrightii*. The latter occurs preferably in moist and swampy areas, where a fern called ‘Tiger bush’ (*Dicanopteris pectinata*) and a grass called ‘dumb cane’ (*Tripsacum latifolium*) can form extremely dense patches. Here, other species, e.g. the natural regeneration of pines, are locally excluded.

Pine forest dominated by *Pinus patula Schiede et Deppe ssp. tecunmanii Eguiluz et Perry*

Generally this forest is similar to the preceding vegetation type, but with some typical differences: stands are rather dense and there are no broadleaved species in the main canopy. A dense and mixed broad leaf understorey vegetation with a similar plant composition as in *P.caribaea* forests is only found where the canopy closure is light. The large distribution of dense patches of tiger bush and dumb cane associated with *Pinus patula* is specially mentioned by Gray (1995).

In the past, *Pinus patula* trees were also referred to as *Pinus oocarpa* or *Pinus tecunmanii*. Meanwhile taxonomists have identified two distinct species and since then, the Belizean pines were addressed to as '*Pinus patula*', the vernacular name remained 'Oocarpa'. For further taxonomic details, please check A.GREAVES (1980), J.P. PERRY (1991), D.M. RICHARDSON et al. (1998)

Pine forests after the of bark beetle infestation

Between 2000 and 2002 over 90% of the pine forest was destroyed by a massive bark beetle infestation of *Dendroctonus frontalis (Zimmermann)*. The explosion of the bark beetle population was probably triggered by extended drought periods in previous years. A first assessment in December 2000 revealed that in the southern half of the reserve more than 90 % of the trees were already dead. In the following year the infestation proceeded north affecting the entire reserve. In 2001 an attempt was made to contain the spreading of the infestation through the establishment of containment lines, 200 m wide strips cleared with bulldozers, but that was not successful. By the end of 2002 most of the bark beetle populations collapsed naturally.

In the remote areas east of Cooma Cairn towards Baldy Beacon, the impact of the infestation of 2000-2002 was less disastrous than in western parts of the reserve. However, active bark beetle breeding herds were identified in 2004. Within one year after the infestation the pine trees lost the needles and the thinner branches. After 3 years most of the trees were completely branchless, in an advanced rotten state and about to break and fall to the ground. In early 2004, the general image of the forests was dominated by standing dead branchless pines.

However some pine trees survived, most of them stand isolated and scattered over the area but some occur in small patches. These survivors will be important seed trees for the reestablishment of pine forests.

Especially in the early stages of the devastation the dying forest was prone to forest fires. If these dry trees would have been ignited by lightning the whole forest would have gone up in flames. With the dying of the pine trees the broad leaf understory vegetation with herbaceous plants, shrubs and broadleaved trees became more vigorous. As the broadleaf trees grow larger and pine trees decompose and fall to the ground the risk of fire is likely to decrease. The increased broadleaf cover appears to be an impediment for the pine regeneration but on the other hand it also protects the soil against erosion. Therefore massive dying of the pine trees does not lead automatically to soil degradation.

Climate

Two distinct seasons characterize the climate regime of Belize. A relatively dry season prevails between February and May, and a rainy season from June to January, with increased lightning during the weeks of transition. Thus, this period is also referred to as “fire season” with increased risk and frequency of forest fire incidences. The ‘fire season’ starts from mid February and goes throughout July.

Only incomplete meteorological data from recent years are available, taken at the Divisional Forestry Station at Douglas D’Silva (500m altitude a.s.l.) and at Cooma Cairn (920 m a.s.l.) Belize Defence Forces military camp. Referring to King et al. (1992), average annual rainfall of 1559mm at Douglas D’Silva and 2101mm at Cooma Cairn were recorded. According to the seasons, monthly rainfall can vary between 100mm in dry months and a maximum of 250mm around October.

Temperature recordings give mean annual maxima of 29°C for the Douglas D’Silva Forest Station and 26°C for Cooma Cairn. Mean annual minima vary between 19°C and 17°C, while extreme temperatures of 39°C and 6°C and 36°C and 7°C respectively have been recorded. January and May are referred to as the coolest and hottest months respectively.

Geology and soils

The MPRFR can be roughly divided into a granite basin with a mean elevation of 400-700m in the North West, and a mountainous ridge of metasedimentic bedrock with steep slopes descending towards the Macal River in the southern and eastern parts. Due to their foundation on granite bedrock or heavily weathered metamorphosed sediments, the soils of the MPRFR are rather poor. The poor soil appears to be the main reason for the isolated presence of a relative monotonous pine forest, which is surrounded by dense subtropical broadleaved forests on limestone just south of the Macal River and on the banks of the Eastern Branch.

According to the parent material, soils have been classified into two major soil suites: the ‘Stopper’ suite, with granitic parent material, and the ‘Ossory’ suite, which is derived from metasediments (metamorphosed sediments), slates and shale.

Soils of the Stopper suite consist of sandy loams or sandy clay loam and are generally acid and leached. Base and nutrient deficiency is typical, especially the contents of phosphorus is extremely low. This soil type is predominantly found in the granite basin area. Some soils deriving from granite parent material contain a visible proportion of coarse quartz sand and larger quartz fragments

The Ossory suit is described as a sandy to sandy clay soil, characterized as highly susceptible to erosion and is poor in nutrients and bases.

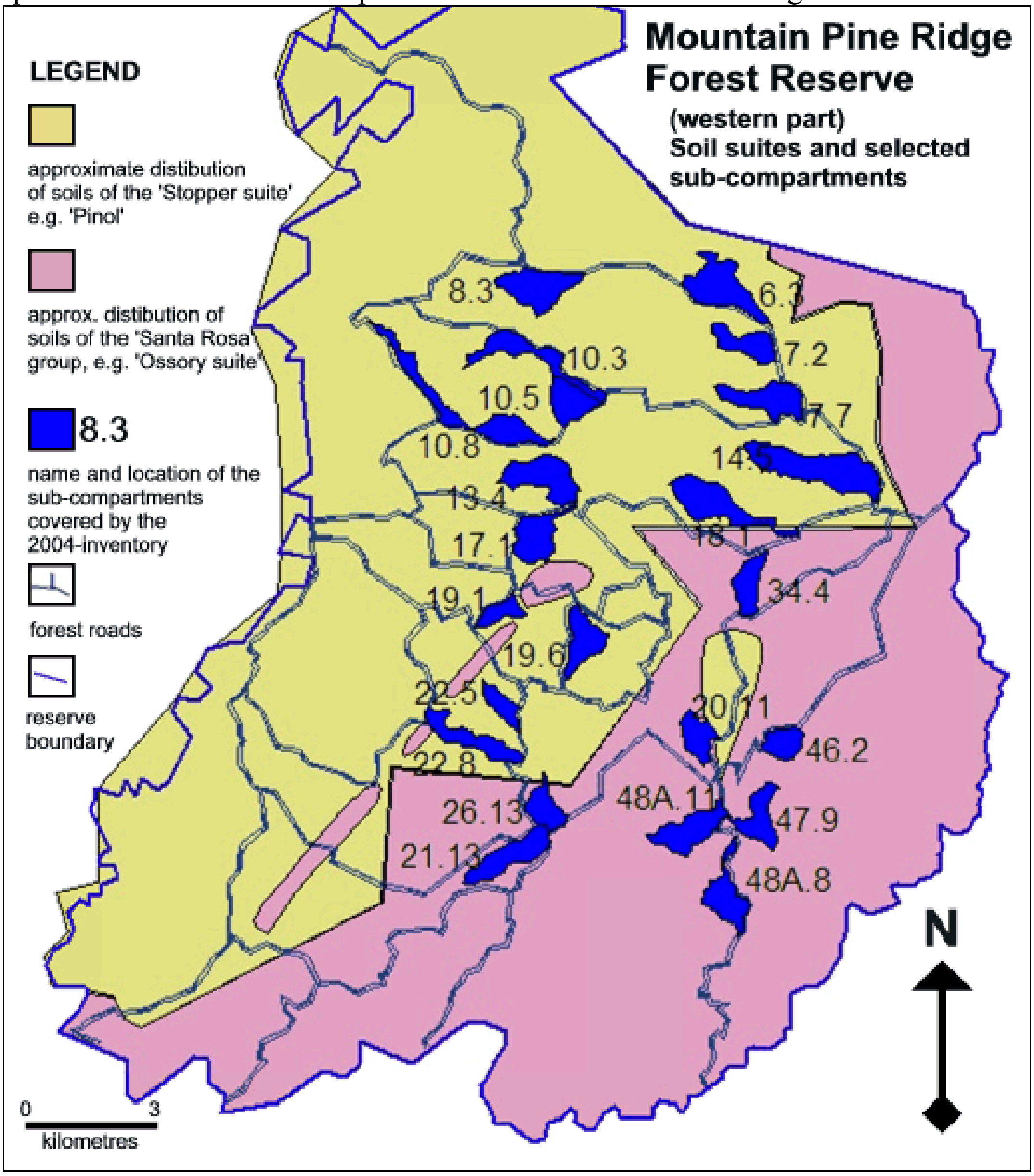
Birchhall (1973) refers to pH-findings of Darcel with ph values ranging from 4,0 to 5,3 in both suites. Subsoils were found to be slightly more acid than the topsoil layers.

Methods

To assess the regeneration density and distribution a simple sampling system was designed. The total time for the field inventory was limited to 8 weeks working with one inventory crew.

The MPRFR is divided into 140 compartments, subdivided into a total of 522 sub-compartments as management units, each between 20 and 100 ha . Due to the limited time, the assessment could not cover the total area but had to focus on a number of selected sub-compartments. Approximately one third of the forest reserve is excluded from timber production because of the slope gradient, this area was excluded from the inventory. Some sub compartments were replanted with pine in 2001/2002 and the plantation success was evaluated by the Forestry Division. Any planted compartments were excluded from the regeneration assessment. The eastern and north western part of the reserve is leased under long term concessions and is privately managed, these areas were also excluded.

Map 2: Soil suites and sub compartments covered in the natural regeneration assessment



As the regeneration assessment should not only provide average regeneration density data for the entire area but also management information for selected compartments, the sample technique had to be compartment based. In order to systematically select the compartments to be included in the inventory, two major transect lines running from north to south across the forest reserve were established. These transect lines allow for analysis of the regeneration results along different ecological gradients: In total the regeneration inventory covered 23 sub-compartments, 18 of these are dominated by *Pinus caribaea* and 5 by *Pinus patula*. 17 sub-compartments belong to the 'Stopper suite', the remaining 6 are based on soils of the 'Ossory suite' (Map 2)

Transect lines

In each of the sub-compartments, sample plots were established along a stratified transect line. On the basis of the vegetation map (Sandom & Sollis, 1990), the transect lines were run through areas classified as pine stands, avoiding areas classified as hardwood stands along creeks and valleys. Following geographical directions taken from the compartment map, the transect lines were laid out in the field. The plot centres were set in regular distance of 50 meters along the transect line. This inventory approach can be classified as a pre-stratified, systematic random sampling.

Sample Plots and recordings

In each compartment a fixed number of 30 sample plots per sub-compartment were set up along the 1500 meters transect line. Within the 23 sub-compartments a total of 690 sample plots were recorded.

The number of sample plots was not adapted according to the total surface of the sub-compartments. Therefore the sampling intensity varies disproportional to the area of the inventoried management unit.

Each sample plot consists of three concentric circular plots.

1. The regeneration was measured within a inner circle of r = 5,64 m (A = 100 m²). The height of all pine regeneration plants was recorded and assigned to four height classes between 0,1m and 3m and one class for regeneration plants higher than 3m, up to a diameter at breast height (d.b.h.) of 4.9cm. The regeneration of broadleaved tree species was only counted and the density of competing vegetation was estimated visually in 10% ground cover classes. The density of competing vegetation includes areas covered with grasses, ferns and different broadleaved herbaceous plants and shrubs.

2. The d.b.h. of pine saplings and young trees was measured within the circular plot of r = 10,30m (A = 333m²). Here all trees between 5cm and 19cm d.b.h. were recorded. All broadleaved trees of equal size were rapidly counted but not measured in d.b.h. All species were summarized.

3. Within the third concentric plot of r = 17,84m (A = 1000 m²), only living pine trees with d.b.h. > 20cm were recorded in order to assess the density of surviving trees and the presence of potential seed trees. Broadleaved tree species of this d.b.h class were counted again and summarized regardless of their species, while the d.b.h. was not recorded.

The stand structure of the dead, former pine forest was recorded by a rough optical estimation. The stands were classified according to the classification system developed by J.H. Sandom in 1990, which combines five mean diameter classes with percentage of canopy closure.

The complete recording of one sample plot (without soil sampling) took between 5 and 15 minutes, depending on the regeneration abundance, density of the understory and steepness of the slope.

Slope correction

According to the inclination of the slope at every plot centre, the radii of the concentric plots were modified by the correction factor $1: \sqrt{\cos \alpha}$ in order to avoid a systematic error concerning the plot surface on slopes.

Soil samples

Two soil samples were collected at the centre of three plots of every sub-compartment for an ex-situ determination of soil type and pH-value, samples were taken from the upper and lower soil layer.

A pH-meter HI-98127 by HANNA-instruments was used to determine the soil acidity in distilled H_2O and KCl-solution.

Recording and data analysis

The field data were copied into a MS-Excel database file. For the analyses of correlations the following statistical tools have been used:
In the figures showing correlations of dependant regeneration/seedling density (y-axis) with various site factors, either independent single values or mean values of a class of independent single values have been used on the x-axis. Mean values are calculated as the arithmetic average $ñ = \sum(x1; xn) / N$
The coefficient of correlation is calculated as the PEARSON coefficient r which can vary between $-1 < r < +1$, indicating strictly negative (-1), neutral (0) or strictly positive (+1) dependency of y-values from a series of independent x-values. It is obtained by the formula $r = n(\sum XY) - (\sum X)(\sum Y) / \sqrt{\{[n\sum X^2 - (\sum X)^2][n\sum Y^2 - (\sum Y)^2]\}}$
The trend of correlation is visualized as a linear trend line with the equation $y = mx + b$.
As a measure for the proportion of variance of y-values which is caused by the variance of x-values, the coefficient of determination R^2 is calculated as the square of the PEARSON's coefficient of correlation: $R^2 = r*r$.

Results of the Pine Regeneration assessment

Overall regeneration density

Approximately one third of all sample plots indicated very poor regeneration of 100 or less seedlings/ha. About 30% of the sampled area was covered with 200 - 800 seedlings/ha, and another 34% of all plots showed dense regeneration of more than 900 seedlings/ha (with peaks of more than 13.000 plants/ha).

On the basis of this plot-wise summary, about 64% of the MPRFR pine forest area could be considered as sufficiently covered with regeneration, according to the ‘natural regeneration criterion’ (200 seedlings per ha). However, only 0,02% of the reserve’s total surface were covered with sample plots and because of the large variation this information alone is not appropriate in the forest planning process. Therefore further analysis will focus on the management-unit level.

Regeneration density per sub-compartment (management unit)

The mean value of all 30 sample plots of a series represents the average regeneration density/ha of a certain sub-compartment. However, the regeneration is distributed unevenly throughout the area. Therefore the standard deviation of the series is rather high in most of the sub-compartment. For operational planning, it is important to know the spatial distribution of regeneration and to evaluate, how much area of the sub-compartment is sufficiently regenerated.

While there are two proposed definitions of what can be considered sufficient, the spatial patchiness of regeneration was calculated by the proportion of plots fulfilling the criterion against those failing it (e.g. 15 of 30 plots = 50% of the area is sufficiently covered with regeneration).

<u>Criteria for sufficient regeneration density</u>

- <u>Plantation-criterion</u>

To evaluate the success of the reforestation conducted by Silviculture Belize, a private company, which was commissioned to replant parts of the MPRFR, the Forestry Department defined that 350 pine seedlings per acre were considered sufficient regeneration. This is equal to 865 seedlings per ha. (The criterion is based on a 3*3 m planting pattern which leads to 1100 plants per ha, and tolerating a seedling mortality of approximately 250 plants per ha.) Applying the plantation criterion, only 8 out of 23 sub-compartments are covered sufficiently on at least 50% of the area. There are only 2 sub-compartments with more than 70% sufficiently covered. (26.13, 46.2 > 70 %; 13.4, 18.1, 22.8, 7.2, 48A..8, 20.11 > 50%)

- <u>Natural regeneration criterion (NR criterion</u>)

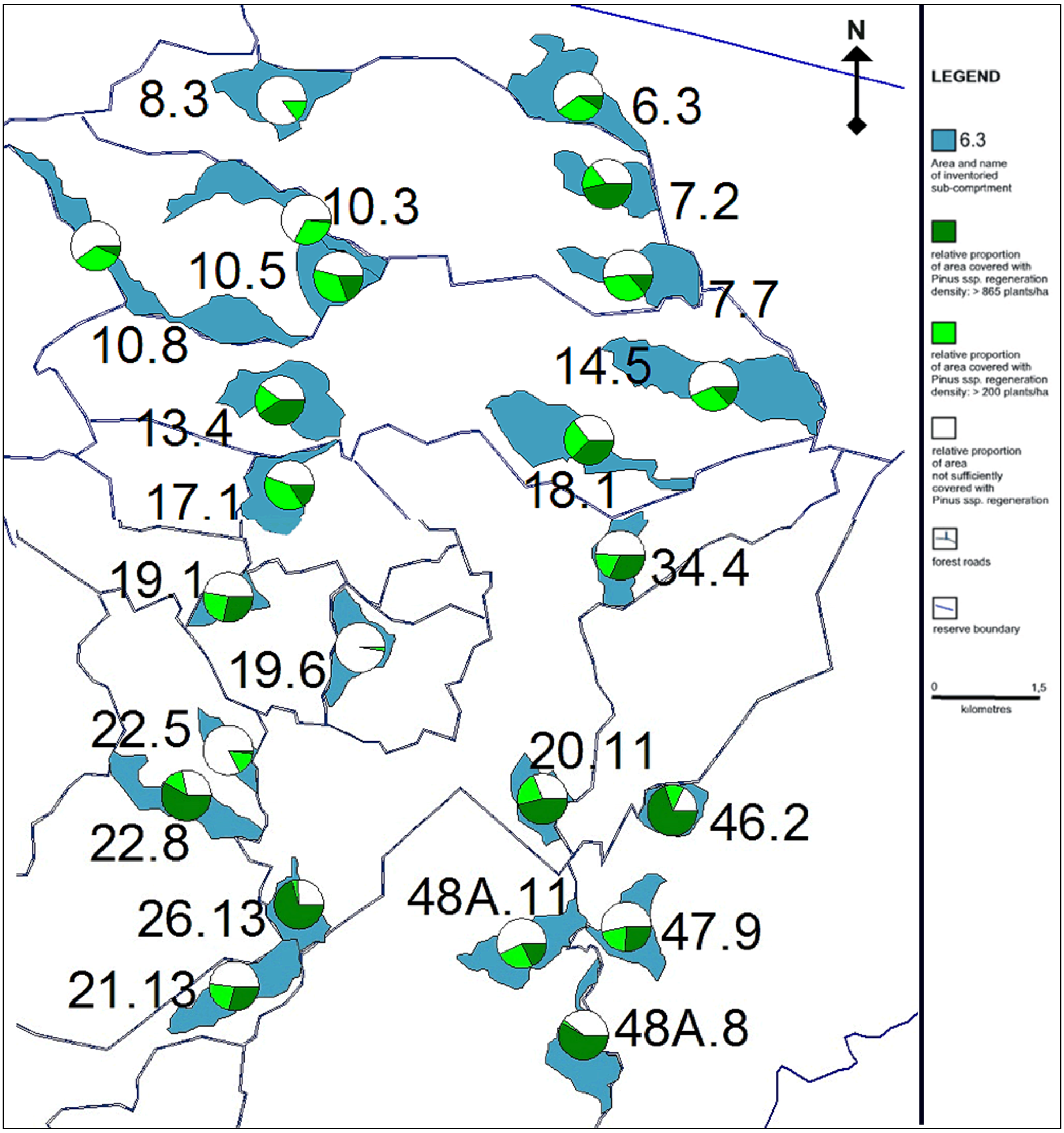
Assuming that a pine stand with 100 trees per ha or with one mature pine tree every 10 m by 10 m can be considered sufficiently stocked the natural regeneration criterion was defined as 200 seedlings per ha or two seedlings per 100 m^2 making an allowance for 50% mortality until the trees reach maturity. So even if only one of two pine seedlings per 100 m^2 will survive it would still lead to a sufficiently stocked pine stand with 100 crop trees per ha .

Among the 23 sub-compartments, there are 19 where more than 50% of the area is covered with at least 200 plants/ha. Out of these, 11 areas are covered “sufficiently” on even more than 70% of the sub-compartment. (26.13, 13.4, 18.1, 19.1, 10.5, 17.1, 7.7; 22.8, 7.2; 46.2, 20.11 > 70%; 14.5, 6.3, 10.8; 34.4, 21.13; 48A.8, 47.9, 48A.11 > 50%)

Summary of the regeneration inventory results
<u>Regeneration Density and horizontal distribution</u>

Table 1 presents a summary of the main results of the assessment of natural regeneration in the MPRFR. For each of the inventoried sub-compartments, it provides quantitative information about the natural regeneration found in February and March 2004. The table includes data on living pine trees that survived the bark beetle infestation in 2000/2001 and which may serve as a seed source for further regeneration and reestablishment of the pine forest.

Map 3: Map showing the sub compartments covered in the regeneration assessment and the percentage of the area covered with natural regeneration according to two regeneration criteria.



The acreage of the sub-compartment given in [ha] refers the areas classified as pine forest. Column 4 provides the average seedling density/ha in the sub-compartment, based on a series of 30 samples. The standard deviation of regeneration samples is given in column 5 as the variance relative to the average value, evaluating the spatial heterogeneity of the regeneration density.

Table 1: Summary of the regeneration inventory results. The inventory results are grouped according to their stand composition of pine species: PC *Pinus caribaea* pure stands (PC pure), *Pinus caribaea* mixed stands (PC mix) and *Pinus patula* mixed stands (PP-mix) according to the most frequent pine species in the regeneration. Within each group the sub-compartments are ranked according to pine seedling density. In addition to the regenerations the table also lists the pine trees which survived the bark beetle attack.

Sub-compartment			regeneration				survivors			
			Prevailing *Pinus ssp.*		Area-% sufficiently covered					
N°	Pine forest Area [ha]	stand composition	average seedlings / ha	relative variance	Plantation criterion: "more than 865 seedlings/ha"	NR criterion: "more than 200 seedlings/ha "	*P.caribaea* poles dbh ≤19cm /ha	*P.caribaea* seed trees dbh ≥20cm /ha	*P.patula* poles dbh ≤19cm /ha	*P.patula* seed trees dbh ≥20cm /ha
26.13	60	PC pure	4570	(+/-) 35 %	73%	77%	76	1	1	0
13.4	83,4	PC pure	1781	(+/-) 32 %	50%	77%	91	9	0	0
18.1	118,8	PC pure	1544	(+/-) 44 %	50%	87%	175	6	0	0
10.5	67,8	PC pure	894	(+/-) 18 %	30%	83%	104	5	0	0
17.1	74,9	PC pure	794	(+/-) 51 %	27%	93%	290	2	0	0
19.1	33,5	PC pure	697	(+/-) 26 %	37%	70%	23	14	0	0
7.7	90,5	PC pure	690	(+/-) 25 %	20%	73%	271	8	1	0
14.5	198,1	PC pure	497	(+/-) 28 %	20%	63%	219	10	0	0
10.8	126,4	PC pure	344	(+/-) 52 %	10%	60%	177	5	0	0
6.3	116,6	PC pure	307	(+/-) 7 %	13%	57%	170	4	0	0
10.3	79,3	PC pure	223	(+/-) 27 %	3%	47%	56	6	0	0
22.5	31,9	PC pure	87	(+/-) 70 %	3%	20%	32	1	0	0
8.3	110,6	PC pure	73	(+/-) 21 %	0%	17%	151	14	1	0
19.6	60,1	PC pure	30	(+/-) 88 %	0%	3%	45	3	0	0
7.2	75,4	PC mix	1588	(+/-) 35 %	57%	77%	79	9	1	0
22.8	69,4	PC mix	1581	(+/-) 20 %	67%	83%	35	4	1	0
21.13	54,4	PC mix	1298	(+/-) 47 %	37%	67%	63	0	0	0
34.4	48,1	PC mix	977	(+/-) 40 %	40%	63%	134	1	17	0
48A.8	66,2	PP mix	2895	(+/-) 9 %	60%	63%	47	2	2	1
46.2	45	PP mix	2652	(+/-) 27 %	80%	93%	19	2	9	1
20.11	38,8	PP mix	2395	(+/-) 17 %	60%	90%	4	1	81	1
47.9	86,4	PP mix	1137	(+/-) 7 %	33%	60%	36	2	0	1
48A.11	69,4	PP mix	1081	(+/-) 36 %	23%	57%	7	0	7	0

More important than the average seedling density is the spatial distribution of the seedlings. Very high density of seedling in only a few sample plots and very few seedlings in the remaining plots could still indicate an acceptable seeding density unfortunately in an unfavourable distribution. Very different seeding densities in neighbouring sample plots reveal a heterogeneous, clustered distribution of pine seedlings. As a response to this, columns 6 and 7 give an approximate percentage of the area that is sufficiently covered by pine regeneration, applying two criteria: “at least 865 seedlings/ha (350/acre)” or the natural regeneration criterion with a “minimum of 200 seedlings/ha (81/acre)”.

The two Pine species occurring in the MPRFR have quite distinct distribution areas. However, in some areas *Pinus caribaea* (PC) and *Pinus patula* (PP) can coexist in variable densities. According to the most frequent pine species in the regeneration the selected sub-compartments have been assigned to the prevailing species, with the additional attribute “pure” or “mixed” if both species were present in the stand. In mixed stands, regeneration density/ha of secondary *Pinus ssp.* is between 0.2% and 4% of the prevailing pine regeneration, with only up to 117 seedlings/ha.

Surviving pine trees are listed separately for both pine species in two diameter classes: “5-19 cm” and “20 cm and bigger”. It is interesting to note that a rather high number of pole size trees or older regenerations survived the beetle attack. Although the density of potential seed trees (dbh >20cm) is generally low as most trees died due to the bark beetle infestation, these “survivors” will be important seed sources for the reestablishment of pine forests.

It was observed that in some cases there is purely one species’ regeneration whereas both species were present in the canopy layer. In single cases, the distribution of the regeneration in mixed stands is obviously related to the exposition of the slope. *Piuns caribaea* seedlings and saplings were found on southerly exposed slopes with relative low competing vegetation, whereas *Pinus patula* regeneration was almost exclusively found on the northerly exposed slopes with abundant *Quercus ssp.* regeneration and dense cover competing vegetation.

It is also quite obvious that in *Pinus patula* stands in the south east of the reserve, where the bark beetle breakout started, there are hardly any pine with dbh >20cm that survived the infestation.

Height classes and age of Pinus caribaea regeneration

It is assumed that each height class corresponds to a certain age of the seedling. Height classes for the classification of pine regeneration were set as presented in Table. 2. While the age indicated in the fifth column is based on estimations and observations made in the field in 2004, columns 3 and 4 show the approximate age of *Pinus caribaea* and *Pinus patula* respectively according to international provenience trials published by Greaves (1980).

Figure 1 reveals that two third of all Caribbean Pine regeneration inventoried during February and March 2004 fall into the height class H3.

Less than 1% of the seedlings fall in height class being smaller than 10 cm. This is mainly due to the fact that *Pinus caribaea* releases its mature seeds in June/July, germinating and growing it reaches height class H2 during the first 6 months. This means that seed germinated last year were already higher than 10 cm.
However, seedlings of height class H2 constitute only 6% of the total suggesting that in 2003 the seed fall and germination of Caribbean pine was less abundant and successful than in the preceding years. This is fairly obvious as only a few seed trees were alive and the competing vegetation developed rapidly as the pine overstory died two to three years ago.

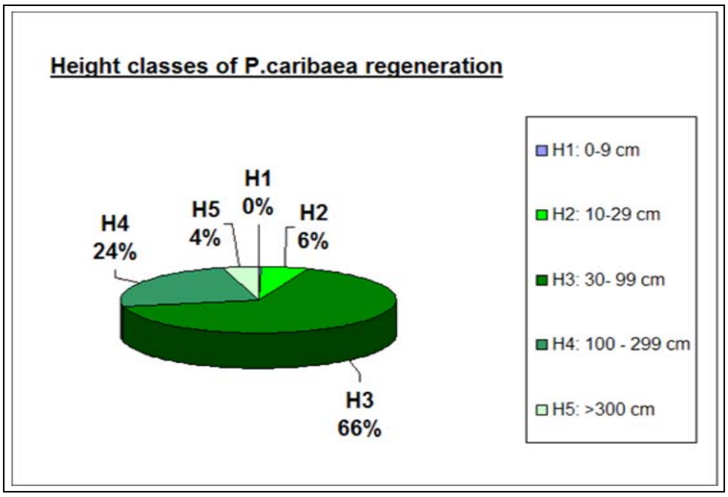
According to its height and estimated age, about 90% of the present regeneration of *Pinus caribaea*, assigned to the height classes H3 and H4, originate from the seeds released in

June/July 2001 and in the years before. These seedlings could develop and compete successfully against the shrubs and herbaceous plants of the understory, which must have been less abundant as they were still shaded by the 'dying' pine canopy.

Table 2: Limits of height classes and corresponding age of *Pinus* ssp.

height class	class limits	**estimated** approx. **age** (years)	approx. **age** (years) (according to *Greaves*, 1980)	
			P.caribaea	***P.patula***
H1	< 10 cm	0 - 0,5	(0,125)	0,125
H2	10 – 30 cm	0,6 – 1,5	0,125 - 0,5	0,125 - 0,25
H3	30 – 100 cm	1,5 – 3	0,55 - 1,5	0,3 – 1,5
H4	100 – 300 cm	3,1 – 5	1,55 - 2,5	1,55 - 2,5
H5	> 300 cm	5 plus	2,6 plus	2,6 plus

Figure 1: Relative frequency of *Pinus caribaea* seedlings in 5 height classes



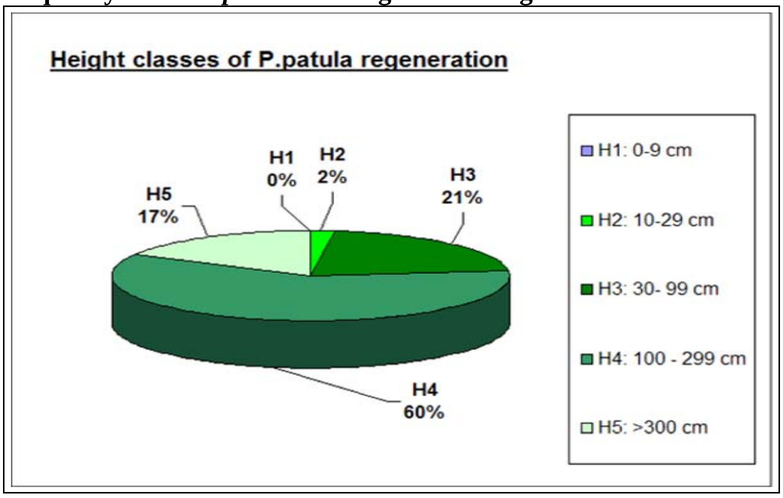
Only 4% of the Caribbean pine seedlings were higher than 3 m suggesting that these trees origin from seed germination prior to the bark-beetle attack under rather dense forest conditions. Some of the older regeneration would have been counted as poles as their dbh is above 5 cm.

Alternatively, based on the height/age relation found by Greaves, which assumes a faster growth rate of the pine seedlings the seedlings in age class 3 should have originated from germination in 2002 and 2003. However, in view of the small number of seed trees that actually survived the infestation and could have fructified in 2002 and 2003, the high abundance of H3 seedlings (66%) appears hardly possible, because the majority of mature trees were already dead at that time. With reference to Greaves, the seedlings found in H4 and H5 (28%) would have been about 1.5 to 3 years old in early 2004, mainly originating during 2000 and 2001, when the bark beetle infestation took place. As it is unlikely that regeneration increases after the overstory died this suggests that the Caribbean pine seedlings in natural regenerations grows slower than observed by Greaves in the plantation trial. Nevertheless, it is possible that some of the seeds released in 2000/01 only started germinating one or two years later. After all, the height/age relation found by Greaves (1980) is based on plantation trials conducted in open sunlight, natural regeneration under broken canopy and competing with herbal vegetation is expected to grow slower. In any case both height/age relationship suggest that the majority of present Caribbean pine seedlings developed from seeds that germinated the same time or after the overstory died, either from seeds of the dying pine trees or from "dormant" pine seeds in the soil.

Height classes and age of *Pinus patula* regeneration

The relative frequency of *Pinus patula* seedlings in five height classes differs slightly from Caribbean Pine. *Pinus patula* is more dominant in higher elevations with higher rainfall and the seedlings appear to grow faster than Caribbean pine on the lower and dryer sites. 60% of the *Pinus patula* regenerations falls in the height class 100 cm to 299cm (figure 2).

Figure 2. Relative Frequency of *Pinus patula* seedlings in five height classes



Only a few seedlings are smaller than 30 cm. One-year-old regeneration plants of *Pinus patula* already exceeded this limit and belong to height class H3 (21%). These relative young seedlings are either regeneration from the few remaining *Pinus patula* seed trees or they developed from dormant seeds in the soil.

The majority of *Pinus patula* seedlings belonged to H4 (100 - 300 cm), estimated to represent three to five-year-old plants. They appear to come from the last seeds released from the partially infested stands between 1999 and 2001. Considerably more seedlings of *Pinus patula* than of *Pinus caribaea* exceeded 300 cm height, while the d.b.h. was still inferior to 5 cm. This observation confirms the fast-growing character of *Pinus patula*.

Hardly any young regeneration (smaller than 30 cm) was found. Only 2% of *Pinus patula* regeneration fell into the height classes H1 or H2. Based on the above all *Pinus patula* seedlings of height class H1 to H4 must have germinated during or after the bark beetle infestation.

In view of the height structure of the regeneration and the estimated corresponding age, it was found that the majority of the present pine seedlings are younger than or as old as the bark beetle infestation, originating from the last seeds of the dying overstory or from dormant seeds in the soil.

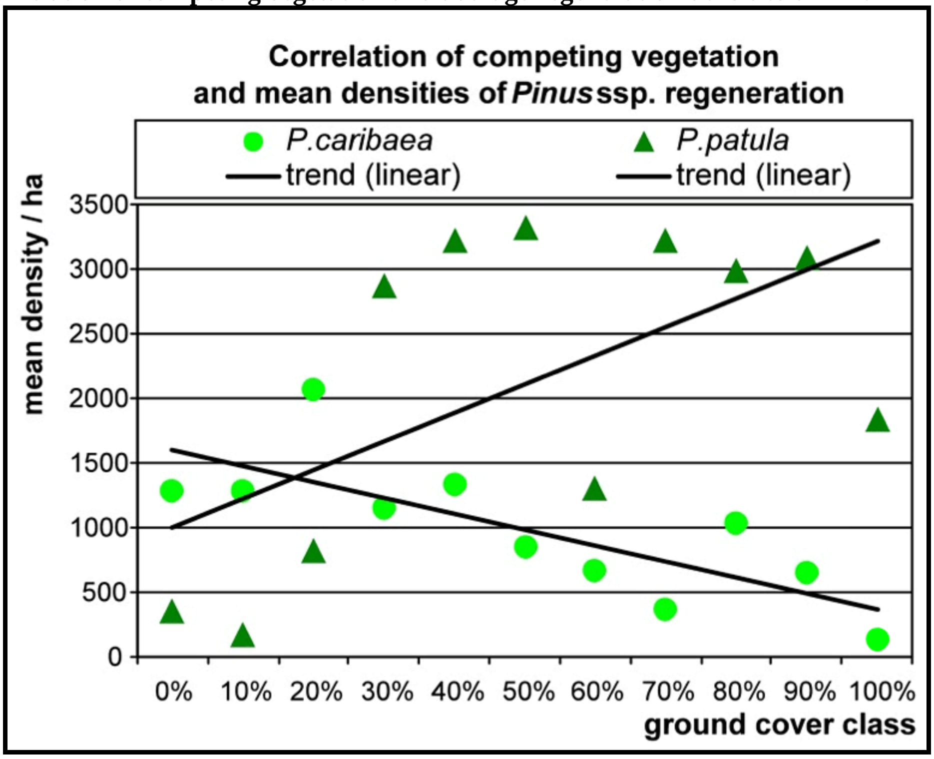
Analysis of vegetation cover and regeneration density

Based on the assumption that the growing space available to pine seedlings is limited by the abundance of herbaceous plants, it is expected that a higher vegetation cover will have a negative impact on germination and survival of pine seedlings which are considered to be a light-demanding regeneration.

The ground cover percentage of competing vegetation refers to the total ground cover of "grasses", "ferns" and different "broadleaved" herbaceous plants and shrubs in 50 cm height above ground.

The trend analysis compares the vegetation cover with the density of pine seedlings in 540 sample plots for *Pinus caribaea* and 150 plots for *Pinus patula*. The analysis in Figure 3 appears to support the above mentioned negative correlation for *Pinus caribaea*, while for *Pinus patula* regenerations increases simultaneously with the vegetation cover. However, in both cases the correlations coefficients are below 0.6. Therefore we can conclude that pine regeneration is not necessarily adversely influenced by higher degrees of ground cover from competing herbaceous and broadleaved vegetation.

Figure 3: Correlation of competing vegetation and average regeneration densities of Pine



A closer look at the findings for *Pinus caribaea* (table 3) seems to confirm the above mentioned correlation . Higher regeneration densities of P.caribaea are more frequently observed with ground covers between 0% to 50%. However, almost 6,000 seedlings per ha can also be found in plots with 80% herbaceous ground cover. Therefore higher ground cover does not automatically exclude higher regeneration densities.

In contrast to the hypothesis stated above, the mean regeneration density of *Pinus patula* increases with more competing vegetation (Table 4). Very little regeneration is found on sites with less than 30% herbaceous ground cover, while ground cover of 30 to 90% seems to have no strict correlation with the density of *Pinus patula* regeneration. Both poor and abundant regeneration can be found in these areas. In this range of ground cover the average regeneration densities of about 3,000 seedlings per hectare also suggest that successful pine regeneration is not automatically excluded by dense competing vegetation.

Table 3: Mean *Pinus caribaea* regeneration density per ground cover class

average *Pinus .caribaea* regeneration density per ground cover class											
Ground cover	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
P.c. reg./ha	1282	1291	2073	1154	1339	853	661	367	1028	650	141

Especially on *Pinus patula* sites, very low mean regeneration densities are observed in association with low herbaceous ground cover (0% to 20%). This might indicate that the specific site qualities apparently hinder the development of pine regeneration and herbaceous layers alike, even though single samples contained plenty pine seedlings.

Table 4. Average *Pinus patula* regeneration density per ground cover class

average *Pinus patula* regeneration density per ground cover class											
Ground cover	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
P.p reg./ha	347	172	821	2862	3219	3322	1301	3222	2990	3080	1826

Based on the above observation it appears as if both pine species are able to establish viable regeneration under conditions of increased competing herbaceous and broadleaved vegetation (up to 80 - 90% ground coverage). While it is obvious in the MPR that pine regeneration is locally excluded by very dense patches of fern (*Dicranopteris ssp*.), dumb cane (*Tripsacum ssp*.) and also cutting grass (*Rhynchospora ssp*.), the absence of pine regeneration cannot automatically be attributed to rather high ground cover of supposingly competing vegetation.

Impact of forest fires on natural regeneration

Generally, forest fires in the Mountain Pine Ridge occur more or less regularly due to drought, lightning, and military activities. A closer look at 540 sample plots covered predominantly by *Pinus caribaea* indicates the importance of forest fires for the establishment of regeneration. Out of 540 sample plots, 120 showed indices of forest fire in recent years; e.g. burnt bark layers. It is estimated that traces of fire can be visible for a time span of about 10-15 years. From fire recordings it is known that some traces originate from forest fires in 1996 or before. As in most cases it was not possible to determine the exact year of the last forest fire. The analysis simply compares areas with visible fire traces with those areas where no indices were found.

The mean regeneration density for burnt areas is about 1,886 seedlings/ha, whereas the average for non-burnt areas is only 740 seedlings/ha. Although competing vegetation was definitely reduced by recent forest fires, its mean ground cover (50%) on burnt areas is as dense as on non-burnt areas.

Observations from areas predominantly covered with *Pinus patula* (on 150 sample plots) tend to confirm these findings. The mean density on areas with fire traces exceeds 2,030 seedlings/ha. Ground coverage of competing vegetation is slightly lower (47%) than on *Pinus caribaea* sites, and most fires appeared to have occurred approximately 5 to 7 years ago. Though control areas without fire traces are missing, the general high density of seedling density confirmed that pine tends to regenerate well on previously burnt areas. Only 19% out of 150 sample plots did not have any pine regeneration.

If forest fires and pine seed release coincide well,seedlings of *Pinus caribaea* and *Pinus patula* can win the race against herbaceous plants and broadleaved shrubs. They develop as fast as the latter, become established and can outgrow the understory plants from the seedling phase onwards. The impact of forest fires on pine regeneration is positive as it favours the germination and establishment, but disastrous for young pine plants until the pines are high and thick enough to be able to survive a ground fire. The critical diameter appears to be between 10 and 20 cm d.b.h.

In case that competing vegetation in the understory is already thriving, pine seedlings start to develop with a disadvantage in the competition for light. Therefore they are less likely to survive and thus the average density of established regeneration in these areas is below the average on recently burnt areas.

In poorly regenerated stands with high ground coverage, natural fires can contribute to the initiation of abundant new regeneration, as long as seed sources are available. In order to enhance growing conditions for pine seedlings, well scheduled prescribed burning may be justified.

Analysis of the regeneration of pine with regard to the former stand structure

The 2004-assessment of natural regeneration included field observations about the structure of the former pine forest, recorded at every sample plot and based on a rough estimation at sight. The classification of the former stand structure was based on the classification system of the 1990-inventory (Sandom, 1990), which classifies pine forests in five maturity classes according to their d.b.h. and three canopy classes as listed in Table 5.

About two years after the severe bark beetle infestation, most pine trees remained standing as dead, branchless stems, upright, some with broken tops and increasingly falling down. Therefore the recording of the former stand structure is based on some kind of imagination of what the canopy closure possibly looked like before the infestation. The classification in the field was based on the vegetation map from 1990 and this was adjusted based on the judgement of field foresters. In this context, the following results and trends have to be understood as approximate values based on rough optical estimations in the field.

Despite a rather subjective judgement in the field, a comparison of former stand structure and current regeneration densities shows some interesting results. As presented in table 6, highest seedling densities in *Pinus caribaea* occurred in former stands with a higher density of thinner trees with diameter classes between 15 to 25 cm dbh. Older stands with larger trees appeared to have less regeneration, however there was only one plot classified as maturity class 5. Today, the former dense stands also host a rather high number of saplings which are potential seed trees for the future. In comparison to *Pinus caribaea*, highest seedling and sapling densities of *Pinus patula* are found in stands with diameters above 25 cm dbh, (former old pole and mature stands).

Table 5: Classification of the former stand structure (interpretation key)

interpretation key *(J.H. Sandom, 1990)*				
maturity class	d.b.h. [cm]		canopy closure class	canopy closure
sapling 1	> 5		class a high	70 % or more
young pole 2	5 – 14		class b medium	30 % - 69 %
medium pole 3	15 – 24		class c low	29 % or less
old pole 4	25 – 34		PC – *Pinus caribaea*	
mature 5	35 +		PP – *Pinus patula*	

Table 6: Mean densities of *P.caribaea* and *P.patula* in different stand structure classes

maturity classes		2	3	4	5	canopy closure classes		a	b	c
Mean regeneration density	PC	1106	1118	829	--		PC	1093	1180	786
per ha	PP	534	1281	2594	1418		PP	2834	2596	1125
Mean sapling density /**ha**	PC	168	258	102	--		PC	147	141	93
	PP	0	12	26	0		PP	7	9	37
PC saplings on PP sites	*PC*	*35*	*38*	*15*	*5*		*PC*	*26*	*10*	*36*
Mean seed tree density /**ha**	PC	3	7	7	--		PC	7	5	6
	PP	0	0	1	0		PP	0	1	1

For both *Pinus caribaea* and *Pinus pat*ula there is significantly less regeneration as soon as the canopy closure in the former stand was below 30%. This may be because there are too few seed trees in these light pine forest areas. In both cases the ground cover of competing vegetation cover was more or less similar between 40 to 50%.

The amount of seed trees that survived the bark beetle attack appeared to be the same regardless of the previous stand structure. In general there are far less survivors of *Pinus patula* than for *Pinus caribaea*.

Soil characteristics and regeneration density

The soils of the MRPFR are derived from lime-poor parent material of granitic or metasedimentary origin. As summarized by Birchall (1973), former soil investigations identified nutrient deficiencies, low fertility and a high susceptibility to erosion in most soils of the area.

A direct impact of the soil acidity on pine regeneration cannot be confirmed on the basis of the available number of soil samples which show a rather narrow range of pH-values between 6.2 to 6.4, indicating moderate to weak acid soils.

When compared with Birchall (1973) reporting pH values as low as 4.0 – 5.3, today's pH-values increased during the last decades indicating less acid soil conditions than 30 years ago.

In the same period, decomposed organic matter may have contributed to higher soil fertility in the upper stratum. Thus, the establishment of less acidophilus plants (e.g. broadleaved species) in the understory has been possible. These are likely to form the new overstory at least in some parts of the reserve, where mature pine trees died and natural regeneration is widely absent. In the course of natural succession, the former even-aged, almost pure pine stands might be replaced by a young, mixed-species forest with only a few persisting pines.

In view of the present abundance of pine regeneration on soils of the Ossory suite, the development of the forest towards a more broadleaf dominated forest appears to be limited to poorly regenerated former *P.caribaea* stands on the granite 'Stopper suite'.

Summary of findings

Summarizing the quantitative results of the inventoried areas, we can state that there is obviously pine regeneration widely spread across the reserve, however in an equally broad range of densities.

Even though one third of the sample-plots were almost free from pine regeneration, there is still about 64% of the area with a minimum of 200 seedlings/ha, projecting a substantial renewal of the pine forest in large parts of the MPRFR. In some areas, the mean regeneration density is even superior to 1,500 seedlings/ha. However, it is probable that the total extension of pine-dominated forests will finally be less than before the year 2000.

Considering the young pine trees that survived the infestation, some sub-compartments provide pines in the sapling stage in non-negligible quantities. Based on the above it appears that both *Pinus caribaea* and *Pinus patula* are capable of establishing a new generation of regeneration under increasing influence of competing vegetation in the understory.

It is interesting to note that the two pine species have different ecological preferences. Although overlapping in some areas, *Pinus caribaea* regeneration occupies generally lower sites, up to a relative optimum at 700 m , while *Pinus patula* is exclusively found in altitudes of 640 m and above, and almost exclusively on metasedimentary soils of the Ossory suite. Both pine species, *Pinus caribaea* and *Pinus patula*, are capable of establishing regeneration on moderate to weak acid soils.

The assessments shows a low density of surviving seed trees not exceeding 7 trees per hectare, although on single plots up to 90 survivors/ha were calculated. These figures underline the degree of devastation of the reserve, and emphasize the necessity of protection from fire for natural regeneration, because in case of losing the seed trees, there would be even less seed sources available for the pine regeneration.

As a final statement, it can be summarized that the pine forest resource of the reserve is naturally rehabilitating, but not as a whole. Partly, the former pine-dominated forests will be naturally replaced by mixed-species hardwood forests with only single pine trees scattered throughout the area.

In consideration of the management objectives of the MPRFR, it is now essential to develop silvicultural strategies for future management based on the above findings.

Recommendations for silvicultural treatments

Management objectives

Despite the huge economic lost through the bark beetle infestation the general management objective of MPRFR is expected to continue to be the same as indicated in the "Management Plan for the MPRFR 1992-1997" (Hawkes, 1992).

1. sustainable production of pine round wood, appropriate stumpage rates and export sales of pine seed
2. To ensure full protection of water catchments
3. To maintain and enhance habitats for natural flora and fauna
4. To maintain and enhance quality of the forest reserve for tourism and recreational usage

Based on the above objectives and taking into consideration the observation from the regeneration analysis four main management options can be presented :

Option 1: reforestation after prescribed burning

The option of planting pine seems appropriate only for areas where timber production is envisaged, which show very poor regeneration of pine in 2004 and low densities of surviving seed trees. Planting should be limited where no natural regeneration can be expected within the coming years. The investment in plantations is justifiable, as long as long-term benefits can be expected from sustainable harvesting. However the investment should be confined to the most productive sites of the production working cycle. In order to enhance the growing conditions and to facilitate the reforestation, prescribed burning of the area can be employed with caution.

It is suggested that this option is applied on sub-compartments where less than 50% of the area is covered with sufficient regeneration. Table 1 mentions two different criteria for what is considered sufficient regeneration. For natural forest management purposes it is suggested to consider 200 seedlings/ha as sufficient to develop the regeneration into a productive pine stand. This option is suggested for 13% of the analysed sub-compartments.

Option 2: favour natural regeneration through prescribed burning

In order to avoid additional costs for reforestation, areas with a low regeneration density (less than 200 seedings/ha) can be excluded from reforestation measures, if there is a natural potential for rehabilitation. This potential can either be found in surviving mature pines that are vigorous and present in a promising density (minimum 50/ha), serving as a seed source for natural regeneration, or the soil contains a stock of viable pine seeds. However, the latter is likely to have declined over the last 4 years as many seeds in the "seed bank" of the soil are likely to lose their germination capacity.

The common understanding is that controlled burning would increase the chance for the establishment of new pine seedlings. Fire reduces the amount of competing vegetation and the organic layers of the soil. This is expected to facilitate the germination and establishment of pine.

Although it was observed that rather high coverage of herbaceous vegetations does not seem to exclude natural pine vegetation, it appears that pine seedlings are more likely to establish themselves on sites with less litter and competing vegetation. With controlled burning, the chances of pine regeneration can be improved. If practised, prescribed burning should be scheduled precisely with regard to: a) the seed release period, b) favourable growing conditions after germination, and c) with regard to the amount of established regeneration that is likely to be destroyed. Even elder saplings (trees with a d.b.h. of 5 to 10 cm) are likely to be killed in a ground fire. Prescribed burning must be understood as a trade-off between certain losses of established regeneration and probable advantages for an expected increase in new regeneration. As long as seed sources for new regeneration are questionable, it is recommended to preserve the existing regeneration, even if only present in low density.

Based on the above mentioned limitations this option is not recommended in any of the 23 analysed sub-compartments.

<u>Option 3: no silvicultural activities - leaving the stand to natural succession</u>

This option does not consider active reforestation measures for the rehabilitation of the forest. While this strategy will probably not lead to maximised financial returns, it neither consumes any financial resources. However, this approach still fulfils the more protective management objectives 2), 3) and 4).This option would be recommended for steep slopes and other areas where protection is more important than timber production.

The present situation in these areas does not suggest an increased risk of erosion after the bark beetle infestation. As most of the pine trees are dead, their root system can no longer hold the soil, but broadleaved trees and shrubs of the understory are generally numerous enough to fulfil this function. After the overstory died, the understory is now developing rapidly and is protecting the soil against possible erosion. Day et al. (2002) discuss increased erosion as a consequence of the bark beetle infestation and coherent loss vegetation cover, but they see the risk mitigated by deciduous species and grasses as well. Under these circumstances, either wild forest fires or prescribed burnings could lead to severe erosion. Therefore it is recommended to leave these areas to natural succession. Here it is especially important to prevent forest fires and to limit their spread in case of wild fire, otherwise the risk of erosion will increase. Option 3 is suggested for 13% of analysed sub compartments.

<u>Option 4: natural regeneration based forestry</u>

After the devastating impacts of the recent bark beetle attack and the substantial loss of older pine resources, the assessment of natural regeneration indicates that the forest is regenerating naturally. Option 4 is suggested for the sub-compartments of the production forest area, where a promising quantity of pine seedlings has been found. These are expected to grow into harvestable sizes within the next three or four decades and will create economic benefits.

In the meantime thinning measures would assist the diameter growth of the crop especially during the early juvenile stage of regeneration. As long as the seedlings are not yet resistant to forest fires, areas with regeneration must be protected from forest fire. From a mean diameter of 25 cm d.b.h. onwards, prescribed burning can be carefully used as a tool to reduce the fuel load of the area. Wild fires can be tolerated as a natural agent in the forest ecosystem, as long as their spread to neighbouring areas can be controlled. This way additional successful natural regeneration can be induced.

It is suggested that all sub-compartments with 30 to 50% of the area covered by natural regeneration in sufficient density (according to the plantation-criterion (865 seedlings/ha)) can be treated as described above. Even if 70% of the sub-compartment area show lower regeneration densities, approximately half of these sub-compartments show an average seedling density of more than 890 seedlings/ha, indicating the patchy distribution of very high densities, and as indicated in Map 3 considerable areas of these compartments still have more than 200 regeneration plants per ha. All areas with regeneration are to be preserved. Limited additional planting may be justified but should be limited to areas without any pine regeneration. Option 4 is suggested for 74% of analysed sub compartments.

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