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A COMPARISON OF STRUCTURAL CHARACTERISTICS AND ECOLOGICAL FACTORS BETWEEN FOREST RESERVES AND MANAGED SILVER FIR – NORWAY SPRUCE FORESTS IN SLOVENIA

ALEKSANDER MARINŠEK, JURIJ DIACI

Institute of Biology, Scientific Research Centre of the Slovenian Academy of Sciences and Arts, Novi trg 2, P. O. Box 306, 1001 Ljubljana, Slovenia; e-mail: marinsek@zrc-sazu.si (corresponding author)
Department of Forestry and Renewable Forest Resources, University of Ljubljana, Večna pot 83, 1000 Ljubljana, Slovenia

Abstract

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In order to examine ecological, floristic and structural differences between the forest stands of managed and unmanaged silver fir – Norway spruce forests (*Bazzanio trilobatae-Abietetum albae*), twelve sample plots (25x25 m) were established in forest reserves and managed forests. Within the plots, subplots and microplots we conducted phytosociological and pedological surveys, analyses of the stand structure, natural regeneration and estimation of solar radiation. We determined that there are no significant differences in floristic composition and ecological factors between managed forest and forest reserve stands. The only variables that were significantly different were the solar radiation variables (ISF; TSF; DSF), vertical structure (cover indexes (CI)) and stand basal area. Small differences in the composition and the structure of the vegetation indicate that, as far as ecosystematic changes are concerned, managing these forests is not as significant as the soil conditions.
Solar radiation had a major influence on natural regeneration. Indirect solar radiation seemed to be more important than direct solar radiation. We found a statistically significant positive correlation between silver fir and Norway spruce regeneration and indirect solar radiation and confirmed that the management of light is a significant factor in the management of regeneration. Another trend that was detected was an increase in the number of beech, which will have quite a large proportion in the upper tree layer of the next generation, especially in forest reserves.

Key words: selection forest, silviculture, stand structure, natural regeneration, solar radiation

Introduction

As in most forests, the stand structure and natural regeneration dynamic in silver fir (*Abies alba* Mill.), Norway spruce (*Picea abies* L.) and beech (*Fagus sylvatica* L.) forests is the result of natural ecological factors, anthropogenic influences, and interactions and synergies between them. With a history that has been deeply affected by both natural and anthropogenic influences ever since 9000 B.C. (Wick, Möhl, 2006), silver fir (*Abies alba* Mill.) is a particularly interesting species in the European region.

Many studies have dealt with differences in the structure, natural regeneration and light conditions in managed and non-managed forests (Dubravac et al., 2005, 2007; Diaci et al., 2005; Anič et al., 2006; Anić, Mikac, 2008), where silver fir has an important role in the stands, but there is a lack of knowledge about the natural dynamics of silver fir-Norway spruce type of forest, particularly in terms of a comparison between managed and non-managed forests. Studies on silver fir stand structure, dynamics and regeneration on silicate soils have examined managed forests (Kotar, 2002; Bončina et al., 2002; Grassi et al., 2003; Gärtner, Reif, 2005; Paluch, 2005; Hunziker, Brang, 2005; Stancioiu, O´Hara, 2006), in which it is difficult to separate natural processes from management influences (Peterken, 1996). Only a few studies of such forests have been performed solely in forest reserves (Szymura, 2007). While some studies have successfully demonstrated methods for regenerating silver fir (Schütz, 2001; Bončina et al., 2002), quantitative measurements of the optimal light levels are scarce, all the more striking in its absence, since light is one of the principal environmental factors that foresters can influence (Brunner, 1994; Dohrenbusch, 1995; Robakowski et al., 2003; Albanesi et al., 2005; Diaci, Roženbergar, 2002).

In Slovenia, where silver fir grows on both calcareous and non-calcareous substrates in climax communities, we assume that another process is taking place – species reciprocal replacement, whereby silver fir is being replaced by beech (*Fagus sylvatica* L.) and vice versa (Bončina et al. 2003). This process has been quite extensively investigated in silver fir-beech communities on carbonate substrate (Gašperšič, 1974; Hartman, 1987; Dubravac et al., 2007) but not to the same extent in silver fir communities on silicate soils. The phenomenon of reciprocal replacement is known in Europe and America alike, but produces controversial opinions and study results (Dobrowolska, 1998; Fox, 1977; Gürth, 1988).

The goal of this study was to examine the influence of the interaction between anthropogenic and environmental factors in managed and unmanaged silver fir – Norway spruce forests on silicate soils.

Specifically, we were interested in the following research questions: (1) Does the management regime (irregular shelterwood) significantly alter the environmental factors, vascular plant composition and forest stand structure and dynamics compared to forest reserves? (2) What are the interactions among forest structure, light climate and natural regeneration? (3) What will be the future structure and composition of non-managed stands in forest reserves?

Methods

Study area

Four forest reserves (Udin Boršt (46°31´ N, 14°31´ E), Zminec (46°138´ N, 14°31´ E), Eržiša – Veliki vrh, Zagoriški hrib (46° 19´ N, 14° 30´ E)) and the nearby managed forests, all in northwest Slovenia, were selected for data collection, which was done in 2005. The size of the forest reserves ranges from 7.98 ha to 40.17 ha. The research plots

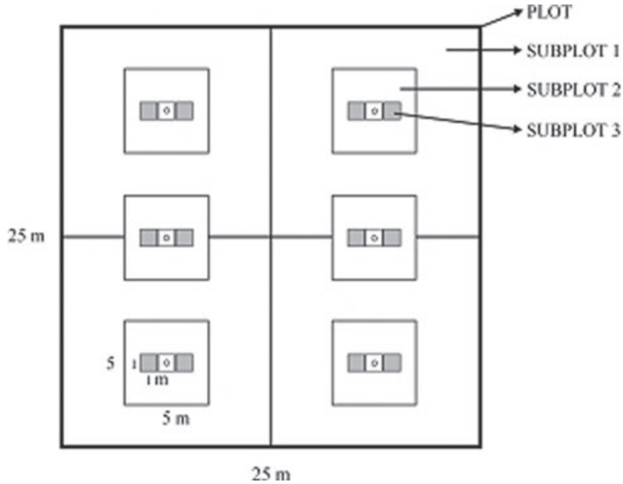

Fig. 1. Size and arrangement of a research plot and subplots within it.

in the managed forests were selected near to the forest reserves, with the same site conditions and with a record of selection or irregular shelterwood management. Forests disturbed by large windthrow were excluded. Regeneration in the managed forest stands under study is exclusively of natural origin. Elevations of the plots range from 430 m to 540 m. Slopes average 19°, with a range of 0 to 30°. Expositions vary from NW to N and NE. The climate is predominately subcontinental. Annual precipitation reaches 1539 mm, with 849 mm during the vegetation period (Zupančič, 1995). The mean annual temperature is 8.4 °C, with a mean temperature in the growing season of 14.4 °C (Mekinda-Majaron, 1995). The primary bedrock formations are schist and sandstone. The soil in the research area is Dystric Cambisol (Prus, 2002).

The principal overstory tree species are *Abies alba*, *Picea abies* and *Fagus sylvatica*. The major understory species are *Abies alba*, *Picea abies*, *Castanea sativa*, *Fagus sylvatica* and *Acer pseudoplatanus*.

The forests we studied were managed by traditional farmer selection systems (Bončina et al., 2002) until the late 1950's, when the irregular shelterwood system was introduced. The regeneration coups still remained relatively small. With a decree issued at the end of the 1970s, certain forests were classified as forest reserves in order to study the ecological factors, successional development of the vegetation and human influences on the ecosystem (Mlinšek et al., 1980). Only small traces of the past management were detected in the investigated forest reserves.

Field sampling

Silver fir–Norway spruce forests on silicaceous soils in Slovenia are generally found only in small fragmented areas and special sites, for example on acidic, waterlogged, heavy clayish soils (Mucina et al., 1993). Due to the heterogeneity of the sites, the stands were selected based on Braun-Blanquet (1964) selection criteria: homogeneous site, mature stand, same phytosociological unit – in this case, *Bazzanio trilobatae-Abietetum albae* (Ellenberg, Klötzli, 1972) – and similar exposition. Because our research focuses on a comparison of mature stands, we deliberately excluded from our investigation larger regenerated surfaces in managed forest.

Twelve plots (PLOT) of size 25x25 m were selected for investigation (6 in managed forest and 6 in forest reserves). We conducted phytosociological and pedological analyses in each PLOT (Fig. 1), including:

- 48 subplots (SUBPLOT 1) of size 12.5x12.5 m, in which we identified tree species and their number, and measured the dbh and height of all trees > 5 cm dbh),

- 72 subplots (SUBPLOT 2) of size 5x5 m (we counted tree saplings taller than 1.3 m and less than 5 cm dbh) and
- for the purpose of analysing microsites, each SUBPLOT 2 contained 3 nested 1x1 m microplots (MICROPLOT). On the two lateral microplots, we counted tree seedlings less than 1.3 m in height. On the central microplots, we recorded herbaceous and moss layers, counted one-year-old seedlings and measured understorey solar radiation.

We recorded the vegetation in each of the plots according to Braun-Blanquet (1964). Mean cover values for a constant combination of the species of the association were calculated according to Braun-Blanquet (1964). The nomenclature of vascular plant species followed Ehrendorfer (1973), and Martinčič (2003) for mosses.

Pedological analyses

Within each PLOT, we systematically extracted ten pedological samples at a depth of 0–10 cm following the ISO/DIS 10381-4 (1995) method. We analysed soil reaction (pH), the proportion of dry matter, organic matter, total nitrogen, total phosphorous, exchange capacity, and soil base saturation level.

Solar radiation analysis

In order to understand the contribution of light to the growing space, our research focused on direct (DSF), diffuse (ISF) and total (TSF) solar radiation in forest stands. In all central MICROPLOTS, we estimated the proportions of direct and diffuse components of solar radiation relative to the outside conditions, using hemispheric photography. We used a digital camera and lens – fisheye converter (Nikon Coolpix 995-4523409 FC-E8-NA) and north finder. The photographs were taken 1.3 metres above the ground in clear daylight, but before the sun was in the field of vision, and at a time when the sky was evenly covered with clouds (Diaci, Thorman, 2002). The WINScanopy program (WINScanopy, 2003) was used to analyze the photographs.

Stand structure analysis

Within each SUBPLOT 1, we determined the species and measured the following parameters: number of trees, height and diameter of each tree, growing stock and basal area. All trees larger than 5 cm in diameter at breast height were included. The growing stock was calculated from the measured diameters and tree heights. We estimated the volume using the equations from Kotar (2003).

Cover index (CI) gives vegetation cover values within each vertical stratum of the stand. The methodology used to determine the CI follows Ferris et al. (2000). Within each SUBPLOT 1 (12.5x2.5 m), four vegetation strata were defined: (S_1) field 0.1–0.5 m; (S_2) shrub 0.5–4 m; (S_3) lower tree layer 4–20 m; and (S_4) upper tree layer 20–30 m. The percentage cover of vegetation within each vertical stratum was described to the nearest 5%. CI was calculated using the formula:

$CI = 0.4\ S_1 + 3.5\ S_2 + 16\ S_3 + 10\ S_4$,

where S_1–S_4 correspond to field, shrub, lower and upper tree layers, and numbers refer to the depth of each stratum in metres. The CI therefore ranges in possible values from 0 to 1990 (assuming a maximum cover value of 100% in each layer).

Statistical analyses

Statistical analyses were conducted at two levels. We used SigmaStat 3.1 (SigmaStat, 2004) for the bulk of the statistical analysis of ecological, stand, and individual tree characteristics. Because we had a range of sample intensities down to the soil sample at one per plot, we evaluated differences using the Mann-Whitney Rank Sum test, with a 95% confidence interval. Finally, we used the CANOCO program (ter Braak, Šmilauer, 1998) to conduct a redundancy analysis (RDA) of phytosociological relevés and solar radiation.

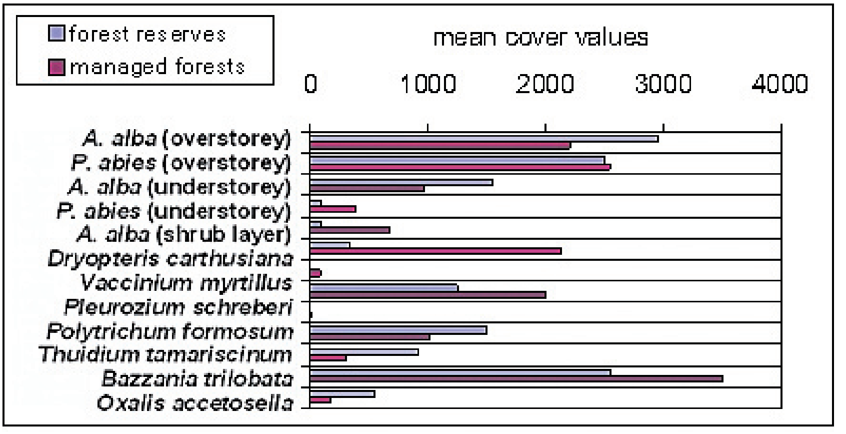

Fig. 2. Mean cover values for a constant combination of species of the association *Bazzanio trilobatae-Abietetum albae* in the investigated forest stands.

Results

Vascular plants and ecological factors

Mean cover values analysis for species from the constant combination (Fig. 2) indicated that the presence and coverage of silver fir in both the upper and the lower tree layer was higher in forest reserves than in managed forests. The values were similar only for Norway spruce in the upper tree layer. In the shrub layer and understorey, on the other hand, Norway spruce had a considerably stronger presence and coverage in the managed forests. There were a total of 57 different vascular plant and moss species in forest reserves and 61 different species in managed forests.

We found almost no difference between the soils of the two treatments (managed and forest reserves) (Table 4). Both were very acidic, as reflected in the low pH, low amount of base cations (less than 30% of all exchangeable cations) and the high H+ values. The soils were lacking in phosphorus, but rich in organic matter and nitrogen.

Values of precise ecological measurements of the parameters from forest reserves and managed forests produced statistically significant differences among all three kinds of solar radiation (direct [DSF], diffuse [ISF], and total [TSF]). We found that forest reserves had significantly lower levels than managed forests (Table 4).

Comparison of some dendrometric parameters also revealed statistically significant differences among CI indexes. We determined by this means statistically significant different vegetation coverage in the vertical section of the stands, which was higher in forest reserves.

Tree species composition and stand structure

The research confirmed our presumption that forest reserves have on average a larger number of trees than managed forests (Table 3). Since the average tree diameter is not the most suitable criterion when determining differences in the stand structure of multi-storeyed stands, we compared only the average diameters of trees considered to be dominant[1]. Our research showed that not only was the number of trees in forest reserves higher, their average diameter was also higher than in managed stands. As presented in Table 3, the difference between mean diameters was 2.2 cm. No statistically significant differences were discovered between diameters or between heights, but they were determined in basal areas (Table 4). Higher values were obtained in forest reserves (Table 1).

T a b l e 1. General data for the trees sampled in the study (FR – forest reserve, MF – managed forest).

	Trees (N/ha)	dbh of stand carriers (cm)	Height of stand carriers (m)	Growing stock (m^3/ha)	Basal area (m^2/ha)	CI
FR average	768	39.6	31.6	808.7	52.3	1049.9
MF average	589	37.4	31.8	584.6	37.6	804.9

Although the average growing stock was not statistically significantly different from the growing stock in managed forests (Table 4), the arrangement of the growing stock according to extended diameter classes is interesting (Table 2). Up to 19 cm in diameter, the proportions of growing stock in forest reserves and managed forests were similar. In the next 30 cm, the proportion of growing stock in managed forests was 16.1% higher than in forest reserves. In the final, 50+ cm class, the situation was reversed: 42.3% of the forest reserve growing stock was in this diameter class, while less than 16.6% of the managed forest growing stock was in the same class. The higher proportion of this largest diameter class in forest reserves is understandable, since there has been no tree felling in these stands and the growing stock has been accumulating.

T a b l e 2. Proportion of growing stock/ha according to extended diameter classes.

Diameter classes (cm)	5–19	20–49	50–	Σ
		Forest reserve		
Growing stock (m^3/ha)	22.7	443.8	342.1	808.6
%	2.8	54.9	42.3	100
		Managed forest		
Growing stock (m^3/ha)	19.3	415.3	150,0	584.6
%	3.3	71.0	25.7	100

[1] Trees that have won the "dominant" position in the overstorey. Their ascent in the community has concluded.

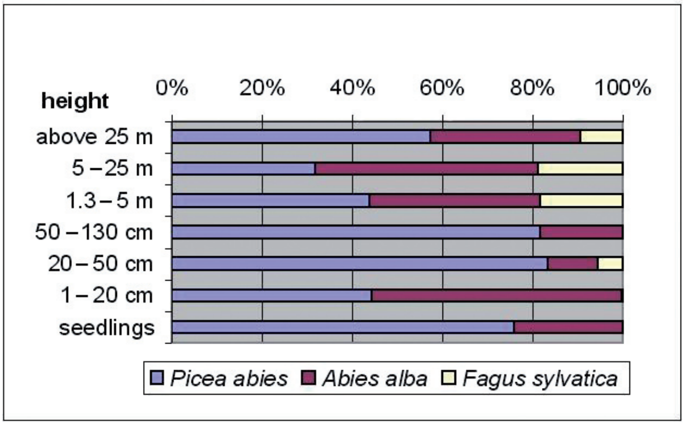

Fig. 3. Numerical proportion of the main tree species according to height classes in managed forests.

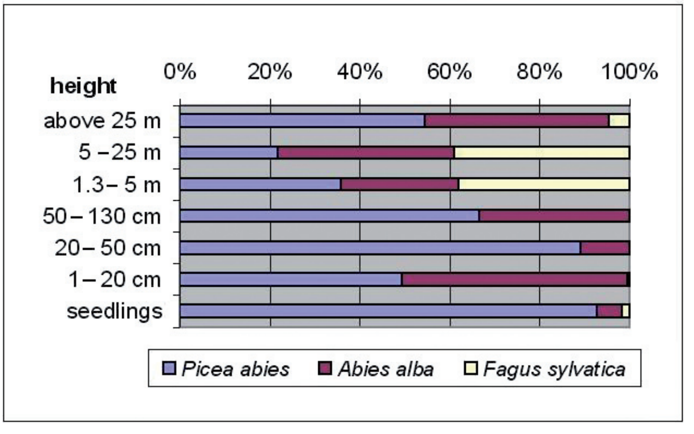

Fig. 4. Numerical proportion of the main tree species according to height classes in forest reserves.

The average ratio of the proportion of the main tree species in single layers in forest reserves and managed forests was relatively similar (Figs 3, 4). The most prominent difference was in the proportion of beech in the two layers between 1.3 and 25 m. In forest reserves, these layers comprised more beech and a smaller proportion of spruce than in managed forests. The proportion of spruce was higher in all of the layers in managed forests, except in seedlings and saplings less than 50 cm in height, in which the proportions were similar. The only difference was that there was no beech regeneration in this segment of the forest reserves. The top tree layer was dominated by spruce, which reached a proportion (according to the number of trees above 25 m) of over 50% in both cases (reserves – 54.3%, managed forests – 57.4%). The proportion of silver fir in this layer was fairly big in the reserves and amounted to 41.1%, but silver fir occupied only a third (33.2%) in the same layer in managed forests. There was, however, almost 5% less beech in forest reserves (reserves – 4.5%, managed forests – 9.3%).

Tree regeneration and light climate

By counting individual seedlings, we determined that there was twice as much regeneration in managed forests than in forest reserves in the class 1–20 cm (Table 3). Silver fir and spruce seedlings predominated, but there were also seedlings of other tree species (*Castanea sativa*, *Quercus petraea*, *Acer pseudoplatanus*, *Sorbus aucuparia*), which, however, gradually disappeared with the height of the tree layer. Their percentage was very small and we therefore focused only on major tree species.

The proportion of individual saplings of major tree species taller than 1.3 m that were less than 5 cm in diameter at breast height was smaller in forest reserves. The proportion of beech in this height class in forests reserves on the other hand was almost twice as high as in managed forests.

While the number of spruce (32,000/ha) and beech one-year-old seedlings (556/ha) was higher in reserves, the number of silver fir one-year-old seedlings was almost four times higher in managed forests (7,780/ha). Not even one sample of beech one-year-old seedlings was found on any of the MICROPLOTS in the managed forests.

T a b l e 3. The number of individual trees, by major tree species and height class.

	Forest reserve (N/ha)			Managed forest (N/ha)		
height	*P. abies*	*A. alba*	*F. sylvatica*	*P. abies*	*A. alba*	*F. sylvatica*
> 25 m	131	99	11	147	85	24
5–25 m	99	176	176	72	112	43
1.3–5 m	194	141	205	272	233	114
50–130 cm	278	139	-	2.500	556	-
20–50 cm	3.473	417	-	10.555	1.389	695
1–20 cm	21.389	21.806	139	40.972	51.111	278
Seedlings (1 year)	32.500	1.944	556	24.444	7.778	-

Analysis of our measurements of solar radiation found that all three types of solar radiation (DSF, ISF, TSF) from forest reserves were statistically significantly different from those in managed forests (Table 4). All three types were significantly lower in forest reserves. Fig. 5 shows the dispersion of individual microplots by radiation type. Eigenvalues of the first and the second axis were 0.062 and 0.030, respectively. Statisti-

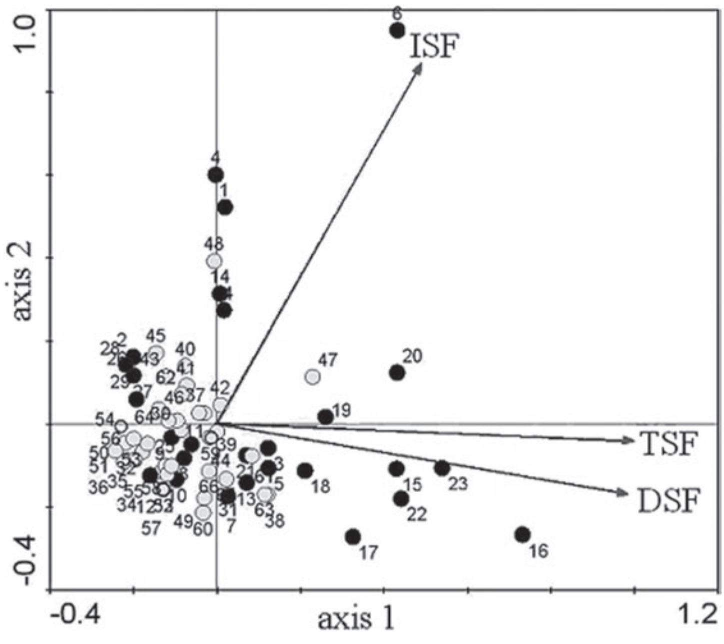

Fig. 5. RDA analysis of 66 relevés compared with solar radiation values (ISF – indirect site factor, DSF – direct site factor, TSF – total site factor; ○ – forest reserve, ● – managed forest).

cal analysis indicated that the total (TSF) and direct (DSF) solar radiation statistically significantly ($p < 0.05$) affected data dispersion (TSF: p-value = 0.002, DSF: p-value = 0.042). Total explained variance was 9.3%, of which TSF explained 60% and DSF 30% of the variance.

Direct solar radiation (DSF) had no statistically significant influence on regeneration and the quantity of young growth, nor on the number of silver fir, spruce and beech seedlings from both classes – < 20 cm class and 20 to 130 cm class (Table 5). There was, however, a negative influence of DSF, and a positive influence of ISF and TSF, on the seedlings of all three tree species. We found significant positive relationships between ISF and TSF values and the number of silver fir and Norway spruce seedlings under 20 cm in height. Of all three tree species in the class above 20 cm, only spruce seedlings demonstrated a statistically significant positive connection with diffuse solar radiation, which shows a higher requirement for light at this stage as compared to silver fir. None of the solar radiation variables demonstrated a statistically significant influence on beech regeneration. However, there was a negative correlation between DSF and ISF and beech seedlings up to 20 cm tall, and a positive correlation between TSF and this young growth.

T a b l e 4. Results of ecological measurements on researched plots and some dendrometric parameters with statistical differences between forest reserves and managed forests.

Plots		Forest reserve						Managed forest						N	p-value
		1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**N**	**p-value**
DSF (average)		2.157	1.430	1.073	1.710	2.647	2.427	5.470	0.985	3.290	5.260	1.985	2.750	66	**0.035***
ISF(average)		6.058	3.553	3.633	3.753	4.527	5.200	5.633	4.847	4.860	6.482	3.948	8.235	66	**0.001***
TSF(average)		2.665	1.708	1.408	1.975	2.893	2.788	5.492	1.488	3.620	5.428	2.242	4.465	66	**0.011***
pH		2.9	3.3	3.5	3.4	3.4	3.2	2.8	3.2	3.1	3.0	3.5	3.0	12	0.240
P_2O_5 mg/100 g		6.70	3.1	4.1	3.6	3.1	4.7	6.4	1.8	4.2	4.7	3.5	3.2	12	0.937
K_2O		16.6	17.3	18.4	15.8	14.0	17.6	19.4	12.9	13.2	12.9	19.5	11.6	12	0.394
org. matter (%)		29.6	22.2	21.5	19.4	13.3	36.0	31.4	12.8	32.4	26.1	23.9	19.7	12	0.818
C (%)		17.1	12.9	12.4	11.2	7.7	20.8	18.2	7.4	18.8	15.1	13.8	11.4	12	0.818
C/N		20.4	20.2	20.3	14.7	18.8	23.1	27.2	20.0	27.6	23.2	21.6	19.3	12	0.180
N total (%)		0.84	0.64	0.61	0.76	0.41	0.90	0.67	0.37	0.68	0.65	0.64	0.59	12	1.000
Ca	$mmol_{C+}$/100 g	1.26	1.00	0.96	1.42	1.24	0.78	1.22	0.52	0.66	0.78	1.23	0.96	12	0.132
Mg		0.71	0.63	0.56	0.59	0.47	0.55	0.61	0.28	0.58	0.43	0.75	0.39	12	0.485
K		0.42	0.45	0.45	0.39	0.32	0.45	0.46	0.30	0.34	0.33	0.49	0.25	12	0.589
Na		0.15	0.10	0.12	0.12	0.08	0.18	0.15	0.09	0.13	0.13	0.13	0.11	12	0.818
H		35.50	35.20	35.15	35.4	33.8	35.65	35.55	32.10	35.55	35.50	35.55	35.30	12	0.485
S		2.5	2.2	2.1	2.5	2.1	2.0	2.4	1.2	1.7	1.7	2.6	1.7	12	0.240
T (S + H)		38.0	37.4	37.3	37.9	35.9	37.7	37.9	33.3	37.3	37.2	38.2	37.0	12	0.589
V (S/T)		6.6	5.9	5.6	6.6	5.8	5.3	6.3	3.6	4.6	4.6	6.8	4.6	12	0.240
Ca (%)		3.3	2.7	2.6	3.7	3,5	2.1	3.2	1.6	1.8	2.1	3.2	2.6	12	0.132
Mg (%)		1.9	1.7	1.5	1.6	1.3	1.5	1.6	0.8	1.6	1.2	2.0	1.1	12	0.485
K (%)		1.1	1.2	1.2	1.0	0.9	1.2	1.2	0.9	0.9	0.9	1.3	0.7	12	0.394
Na (%)		0.4	0.3	0.3	0.3	0.2	0.5	0.4	0.3	0.3	0.3	0.3	0.3	12	0.937
H (%)		93.4	94.1	94.2	93.4	94.2	94.6	93.8	96.4	95.3	95.4	93.10	95.40	12	0.240
CI		1028	1158	1043	1178	931.3	961.8	879.3	810.4	908	788.5	836.3	606.1	12	**0.002***
gr. stock (m^3/ha)		1165	711.1	675.3	1029	401.1	870.7	541.2	502.1	574.8	566.7	668.8	654	519	0.163
dbh – all (cm)		29.38	23.23	24.03	22.65	23.75	25.58	24.73	22.09	23.85	24.95	24.15	30.93	519	0.621
dbh – domin. (cm)		39.1	44.3	41.9	36.8	43.4	32.3	50.7	34.2	34	39.6	34.8	31.1	236	0.394
height – all (m)		28.3	19.7	21.1	19.85	14.56	20.78	22.6	20.25	20.75	23.35	21.58	24.03	519	0.145
height – domin. (m)		28.7	33.5	37.9	29.2	34.8	25.6	38.3	28.9	29.4	34.9	31.6	27.5	236	0.304
basal area (m^2/ha)		50.8	54.4	56.9	44.3	61.3	46.1	36.3	45.9	39.6	30.6	35.5	36.0	12	**0.004***

Notes: DSF – direct site factor, ISF – indirect site factor, TSF – total site factor, H – hydrogen, S – sum of basic cations (Ca^+, Mg^+, K^+, Na^+), T – sum of all exchangeable cations, V – base saturation, Ca to H – results of ammonium-acetate extraction), * statistically significant difference ($p < 0.05$).

T a b l e 5. Dependence between regeneration of different tree species and solar radiations.

	N	r_s, p	DSF	ISF	TSF
A. alba (< 20 cm)	66	r_s	0.193	0.415	0.244
		p	0.120	**0.000***	**0.048***
A. alba (20–130 cm)	66	r_s	0.225	0.131	0.222
		p	0.069	0.293	0.074
P. abies (< 20 cm)	66	r_s	0.222	0.601	0.289
		p	0.074	**0.000***	**0.019***
P. abies (20–130 cm)	66	r_s	0.173	0.394	0.230
		p	0.165	**0.001***	0.063
F. sylvatica (< 20 cm)	66	r_s	-0.072	-0.157	0.230
		p	0.566	0.207	0.063
F. sylvatica (20–130 cm)	66	r_s	0.090	0.122	0.108
		p	0.474	0.327	0.387
A. alba seedlings (1 year old)	66	r_s	-0.036	0.229	0.000
		p	0.776	0.064	0.999
P. abies seedlings (1 year old)	66	r_s	-0.008	0.146	0.019
		p	0.947	0.240	0.879
F. sylvatica seedlings (1 year)	66	r_s	-0.051	-0.121	-0.070
		p	0.683	0.334	0.578

Notes: r_s = Spearman's rank correlation coefficient, * statistically significant influence ($p < 0.05$).

Discussion

Our expectation when we started this research was that we would find substantial differences in terms of ecological and stand factors between managed forests and forest reserves. The only variables that were significantly different were the solar radiation variables, CI indexes and stand basal area. These variables are inter-related. Stancioiu, O´Hara (2006) found that light penetrating through the crowns to the ground was usually the most important growth hindering factor in their study plots. Light is definitely a very important ecological factor, but the quantity that reaches the ground depends on the structure of the stands. The stand structure is regulated by intra- and interspecific relationships between tree species, and in managed forests also by human action through tree felling.

Considering that the stands studied belong to the same forest association, and that forest reserves were excluded from management more than 28 years ago, we did not expect considerable differences in biochemical soil properties. Biomass accretion due to litterfall and fine root turnover would not have had time substantially to alter the soil biochemistry. This is an ecological complex that is subject to direct or indirect human influence and therefore less prone to change than aboveground stand structure, which humans can alter almost immediately. Moreover, climatic changes after tree felling in continuous-cover forestry, where trees are eliminated individually or in small groups, are very gradual. Even within a clear-cut management system, the impact of tree felling on the soil is not always obvious. Bergstedt, Milberg (2001), who investigated the influence of felling intensity on the herbaceous layer in Swedish boreal forests, allowed the possibility that only light increases linearly with felling, while other parameters increase exponentially (changes in soil moisture, mineralization, nitrogen emissions, different pH values etc.). Gilliam's research (2002) indicated that, although the most extreme felling technique – clear-cutting – did not significantly change the herbaceous layer, it did affect the connection between biotic and abiotic factors, such as tree density and soil nutrients. In comparison with a mature stand, no statistically significant differences in organic matter, cation exchange capacity and nutrients were detected on an even-aged stand that was clear-cut twenty years ago. The fact that there were no statistically significant differences between a clearing and a mature stand with regard to soil factors suggests that timber harvesting does not affect the soil or that its impact is so insignificant that it enables the restoration of organic matter, pH values, nutrients and cation exchange capacity in twenty years. A lot, of course, depends on the type of the forest and felling technique.

The data from our study allowed us to compare the light, soil reaction and nitrogen in the soil. Using the results of light measurements in the field, we concluded that there were lower light levels in the forest reserves. Even pH values obtained with pedological analyses showed very similar values and conditions in the stands studied. In both cases, the values of soil reaction in reserves are higher than in managed forests, but not statistically significant.

The proportion of silver fir in reserves and managed stands, in terms of the number of trees, was very similar – 36 and 37%. The proportion of Norway spruce varied more widely: 40% in managed stands and 30% in reserves. More considerable differences occurred in the proportion of beech: as much as 25% in forest reserves but only 12% in managed forests. Together with the fact that the proportion of beech in reserves was higher in the seedling layer and in tree layers of 1.3 to 25 m, this could be the answer to the hypothesis that discontinuation of management leads into an increased proportion of hardwoods. For a comparable site in the Repiško forest reserve, where management has been discontinued for over 25 years, Bončina et al. (2002) reported that the proportion of beech had already increased in the smallest diameter classes. Dubravac et al. (2005) reported a similar situation in beech-silver fir forests in Croatia, where they detected a complete absence of fir of the smallest diameter, and an absence of medium diameter trees in both non-managed and managed forests. However, it seems that the high game densities there influence the lack of silver fir recruitment, as has already been shown for the neighbouring part of the Dinaric Mountains in Slovenia (Roženbergar et al., 2007). We expect that there will be a high proportion of beech in the top tree layer in the next generation of managed forests, too, partly because of the silver fir decline, which had a fatal impact on fir and fir-beech forests in the 1960s, 1970s and 1980s and caused a fast decrease in their stability – in its broadest sense. However, since the early 1990s, silver fir vitality has improved (Prelc et al., 1993). This was very likely due to improved air quality. The causes of the changes in tree composition are probably a decline in the presence and vigour of silver fir and discontinuation of forest management. We therefore expect stands with less than 20% of silver fir on silver fir-beech classified forest communities (*Omphalodo-Fagetum*), while on silver fir – Norway spruce classified forest communities (e.g. *Bazzanio-Abietetum*) stands will have more than 20% of beech in the future. In our research, examining various tree species in height layers suggested a trend towards a higher proportion of hardwoods after an extended period of non-management. This, in turn, reflects the partly anthropogenic character of the forest association.

We found no major differences in species composition in the regeneration in forest reserves or in managed forests. Young silver fir and Norway spruce were present in almost equal proportions, up to 130 cm in height. The small proportion of beech is not surprising, since beech regenerates under a dense beech midlevel canopy only with great difficulty, and there was a considerable proportion of beech in our stands at that canopy level. Bončina (1994) found that in Dinaric silver fir-beech forests, regeneration and, later, the structure of young growth (especially beech) are affected by the seed years.

We found that silver fir one-year-old seedlings grow in smaller numbers in forest reserves than in managed forests. The main reasons for the lower silver fir regeneration, according to Dobrowolska (1998), are low participation of fir in the stands, competition of different seedlings and saplings for light, water and nutrients, and poor light conditions in the stand, particularly where there was oak, poplar, lime or spruce. Other authors explain the unsuccessful emergence of fir seedlings by reasons such as sparse cone production due to crown damage (Filipiak, 2002), excessive volume of wood accumulated in old over-mature fir trees and soil cover by tree-crowns (Dubravac et al., 2007). Paluch (2005) presumed that the survival rate of fir regeneration up to the sapling phase was higher in spots with a relatively higher local basal area. In contrast, our findings show that the number of silver fir seedlings in class 1 – 20 cm is almost four times lower in forest reserves, where the local basal area is significantly higher. A lower density of silver fir regeneration in virgin forest compared to managed forest was also reported by Bončina et al. (2002). Szymura (2007) presumed that silver fir seedlings occurred more often on broadleaved litter, in patches of seedlings of other species and patches of mosses, *Oxalis acetosella* and *Vaccinium myrtillus*. In his study in forest reserves he also mentioned the small share of fir seedlings, especially one year old.

We found a statistically significant positive correlation between ISF and TSF and the amount of silver fir and Norway spruce regeneration. Stancioiu, O´Hara (2006) found that, while on microsites with low light intensity beech and silver fir clearly surpassed spruce, all three species demonstrated a similar growth percentage on open areas. Paluch (2006) put forward a very interesting hypothesis that the spatial pattern of regeneration of fir in Carpathian beech forest is controlled by edaphic factors – in particular, the humus form – and that light conditions play only a secondary role.

Considering the poor light conditions, large basal area and growing stock, the proportion of spruce in the young growth is surprisingly high – especially in reserves. Everything points to the conclusion that spruce is very shade tolerant in the study area. This result is probably due to favourable soil conditions.

Conclusion

For various reasons, many silver fir-dominated forests in Slovenia have been gradually converted from a single tree selection system to an irregular shelterwood system (Diaci, Roženbergar, 2002). This has resulted in simpler and more uniform forest structures. In our view, several simultaneous processes can be found in the studied stands, mutually influencing one another. First, these forests have been subjected to a reduced intensity of management and excessive deer browsing. The latter is one of the complex interactions affecting regeneration and the subsequent growth and survival of this (and other) tree species (Senn, Suter, 2003). In any case, this research has shown that management in these forests has had no negative impact on the structure of stands, including the biodiversity of vascular plants, soil composition and fertility of the site. Finally, we found that the management of light is a significant factor in the management of regeneration.

Further investigations into forest management of silver fir-Norway spruce forests should examine: (1) the adequacy of various sustainable silvicultural systems (single tree selection versus irregular shelterwood) and (2) the role of hardwoods in managed forests.

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