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THE *POST-HOC* POWER ANALYSIS OF FOREST PRODUCTIVITY ATTRIBUTES IN EXPERIMENTAL STUDY IN CENTRAL BOSNIA

SUMMARY

Forest productive attributes changes over time in native forests has been recognized as crucial challenge for management of uneven aged mixed forests in Bosnia and Herzegovina since middle of the last century. Experimental study has been carried out on set of experimental plots established in mixed stands on mountain Igman in central Bosnia. The most important forest productivity attributes changes based on repeated measures have been monitored over time. The aim of this research was to conduct the *post-hoc* power analysis for monitored forest attributes: basal area per ha (BA), growing stock per ha (GS) and current annual increment per ha (CAI_v). Here are used repeated measures conduced on the 10 experimental plots in two types of mixed stands: fir-spruce and fir-spruce-beech plots (five plots per each type) measured in five (BA and GS) and four (CAI_v) occasions in periods between 10–20 years. Analyses of variance (ANOVA) within and within-between repeated measures were applied and power analysis was performed. ANOVA within forest type over time showed highly significant differences for all attributes ($\alpha = 0.05$, $p < 0.001$). Here, power analysis for comparison of stand attributes resulted in observed high power values ranged from 82% to 99% (very low risk of Type II errors). Then, ANOVA between two forest types over time showed different significances for forest attributes ($\alpha = 0.05$, $p_{BA} = 0.25$, $p_{GS} = 0.23$ and $p_{CAIv} = 0.02$). The risks of Type II errors were high for BA and GS (from 66% to 72%) while conclusions for CAI_v could be accepted with very low risk (4%). So, the *post-hoc* power analysis of comparisons of stand attributes between forests types found low power for BA (28%) and GS (34%) and high power for CAI_v (96%). These findings confirm importance of proper forest species composition planning in mixed stands related to highest wood productivity and other forest characteristics as biodiversity.

Keywords: forest productivity, uneven aged mixed forest stands, experimental study, repeated measures, power analysis

INTRODUCTION

The native uneven aged mixed forests are the most productive and the most important forests in Bosnia and Herzegovina covering about 30% of

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forested area. The dominant native mixed beech (*Fagus sylvatica* L.), fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) H. Karst.) forests in different tree species mixtures have both ecological and productivity importance (Matić 1959, Kotar 2005). Their complex structural and productivity characteristics and dynamic changes have been analyzed in many researches (Bozalo 1980, Bončina 1994, Bončina and Devjak 2002, Bončina 2011, Kotar 2002, 2003, Dukić and Maunaga 2008, Diaci *et al.* 2008, Lojo 2013, Ibrahimspahić 2013, Motta *et al.* 2014).

The experimental research related to proper silvicultural treatments in those forests in Bosnia and Herzegovina (BiH) started at the middle of last century when series of permanent experimental plots were established in central Bosnia (Matić 1959). The strategic goal was to develop and maintain uneven aged mixed multilayer forests using selection cutting based on the positive selection principle aiming to create optimal stand structures that would support high wood production permanently.

Experimental plots were distributed randomly in two forest types: mixed fir and spruce forest (FS) and beech, fir with spruce forest (BFS). Measurements of forest attributes were conducted in several occasions with time span of 10 to 20 years reporting the most important forest productivity attributes: number trees per ha (N), number of ingrowths' trees per ha ($N_{ingrowth}$), number cut trees per ha (N_{cut}), basal area per ha (BA), growing stock per ha (GS) and current annual increment per ha (CAI_v). The main research questions were related to influences of stand structural changes affected by selection cutting in interaction with time on the most important forest productivity attribute (CAI_v). Experimental results related to stated research questions for successive occasions were reported (Drinić 1974, 1976, Pavlič 1987). The last occasion refers to measurements conducted in period 2006–2008. Then all long-term experiment data are summarized, analyzed and reported (Ibrahimspahić 2013).

Ibrahimspahić (2013) analyzed forest attributes mean differences applying univariate analysis of variance (ANOVA) as between forest types so between occasions. Conclusion related to stated null hypotheses that effect size (ES) is zero, was based on statistical significance of obtained *p*-value (the probability of Type I error). In the case of ANOVA, ES is the difference between means related to forest type and the means within occasions. Usually the ES is low in most monitoring studies so likelihood that a statistical test will detect a significant ES, if it exists, remains low.

Power is the probability of getting a statistically significant difference when a real treatment difference exists (Nemec 1991). Power analysis enables to calculate power in relation with experimental design, sample size, ES, significance level α and the variability of data (Foster 2001, Di Stefano, 2001). South and VanderSchaaf (2006) proposed a "*hybrid*" power analysis that could be useful to discuss reason for non-significant result: no effect or not enough replication to produce a small enough error term. Foster (2001) demonstrated application of power analysis related to forest monitoring program.

The objective of this research was to evaluate dynamic changes of forest productivity attributes between two forest types in interaction with successive occasions in long-term experimental research established in native uneven aged mixed multilayer forest and to perform power analysis. Following research aims were stated:

- to compare and evaluate dynamic changes of forest productivity attributes over the different occasions (main effect for occasions), between two forest types in terms of their influences on forest productivity attributes (main effect for factor) and over occasions for two forest types (interaction effect);
- to compare and evaluate magnitude of effect sizes on forest productivity attributes influenced by two different forest types;
- to identify minimal detectable effect (MDE) to obtain statistically significant result between forest types assuming power of 0.8 with this experimental design;
- to perform power analysis of forest productivity attribute mean differences between two forest types assuming datasets from whole time span as independent (without effects of occasions and interactions);
- to perform power analysis of forest productivity attribute mean differences between last measurement and target quantities for each forest type.

MATERIAL AND METHOD

Study area

The research has been conducted on data collected on ten experimental plots in beech-fir (with spruce) forests in the MU "Igman" over 50 years. MU "Igman" (area size 8.219,3 ha) encompasses the territory of mountain Igman near Sarajevo in central Bosnia and Herzegovina (Figure 1).

Mountain Igman (with Bjelašnica) make a geomorphologic complex unit of high Dinaric mountain with characteristic landscape related to frequent climate conditions (especially temperature) inversions. It is mostly a limestone mountain, with the main soil types alternating on a small area.

The permanent experimental plots were set up in forests which are related to species type and productivity the most dominant and significant in MU "Igman". Five locations were chosen on different altitude, different terrain expositions and inclinations in beech, fir and spruce forests and five in fir and spruce forests (without beech). The experimental plots size varied, ranging from 1.0 to 3.14 ha.

Owing to plant community nomenclature, plots are included in *Abieti Fagetum illyricum* Treg. (four plots), *Fagetum subalpinum* Horv. (one plot), *Abieti Piceetum Illyricum* Stef. (three plots), *Piceo Pinetum Illyricum* Stef. (one plot) and *Pyrolo-Piceetum* Fuk. community (one plot).

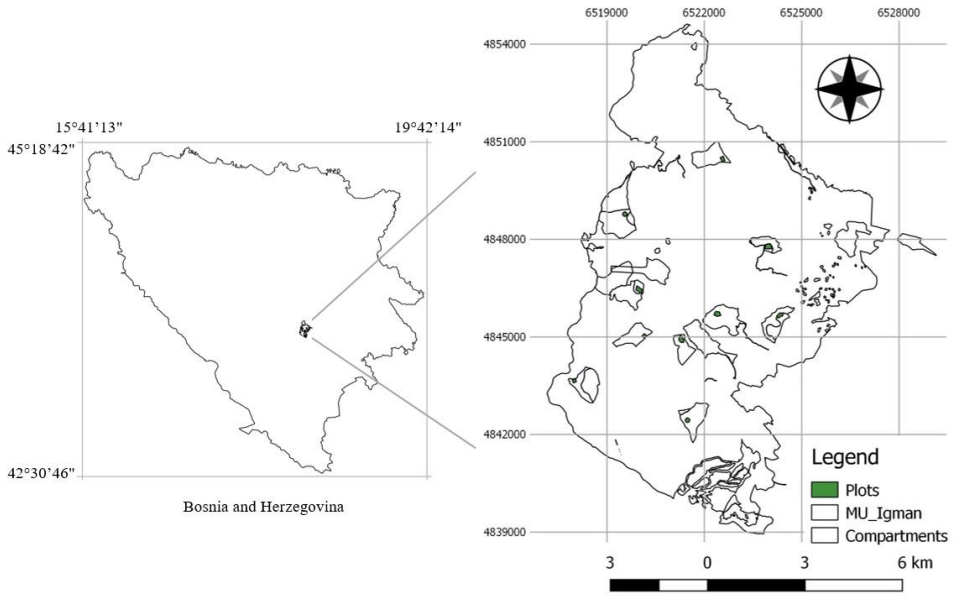

Figure 1. Study area

Experimental design

The long-term experiment with permanent plots was established in native uneven aged mixed multilayer forests in the middle of last century (between 1954 and 1958).

The experimental plots were distributed randomly in two types of forest tree species mixture: the fir-spruce mixture (FS) and the beech-fir-spruce mixture (BFS). First measurement (occasion) was conducted when plots were established, then in three occasions periodically in ten years periods. The last (fifth) measurement was conducted after twenty years period due to the war. The fifth measurement was not conducted on two experimental plots because they were in mined area so additional plots in assessable neighborhood were established and measured.

All measurements have been conducted using the unified methodology enabling connectivity of collected data and information. Detailed description about data collection and calculations of forest productivity attributes per experimental plot is given in Ibrahimspahić (2013).

Considering two different forest types ("between" effect) and successive measurements in five (four) repetitions (occasions) ("within" effect), experiment could be examined using linear mixed model (Čabaravdić and Ibrahimspahić 2017).

Statistical analysis

In this research, collected data are analyzed using descriptive statistics, analysis of variance (ANOVA) and power analysis. The basic statistics for data collected during whole period of experiment are determined: mean, standard deviations and 95% confidence interval for the most important forest productive

attributes: N (trees/ha), $N_{ingrowth}$ (trees/ha), N_{cut} (trees/ha), BA (m^2/ha), GS (m^3/ha) and CAI_v (m^3/ha/year), for two forest types.

We used a linear mixed model to assess the impact of two forest types (FS and BFS) on the forest productivity attributes across five (four) occasions (Occ.). The two forest types are assigned as the main factor (between-subject) and occasions (within-subject) as the factor where within variability is of interest. Here is combined multivariate and univariate approach related to ANOVA of within-between repeated measures (occasions). Differences within occasions and interaction between forest type and occasions were evaluated using multivariate tests of within–subjects effects. Here is evaluated Wilks lambda, F value, associated probability value, partial eta squared and estimated (observed) power. Difference between forest types was obtained using test of between–subjects effects. Here, F value, associated probability value, partial eta squared, Cohen's effect size and observed power were evaluated. The associated probability value in ANOVA points out if relationship exists, but cannot measure effect size. Here is used partial eta squared (η^2) as a measure of the degree of association between an effect (e.g., main effects, an interaction) and the value of the forest productivity attribute. A partial eta squared can be interpreted as the proportion (or percentage) of variance that is attributable to each effect. Then, partial eta-squared is used to calculate Cohen's metric f(U) to measure effect size for F-ratio in ANOVA. Then, the probability to detect the difference if difference exists was estimated and reported as power. Low power means low chance of finding significance if it exists (Faul *et al*. 2009).

In addition, the minimum detectable effects (MDE) as the minimum difference between main factor levels that yields a statistically significant result, for given sample size, power and type I error level were identified and presented on power curve. In our case, power analysis was used to determine effect size of forest attributes difference in two forest types and to identify magnitude of achieved power compared with 80% power level.

Then, using power analysis we examined what sample size is required to detect a same effect size with power of 0.80. An approach referred to look at each pairwise comparison by doing power analysis for a set of unpaired *t*-tests (Foster *et al.* 2001). Further, we compared GS and BA means and evaluated differences from last measurement with targeted values prescribed with management plans for each forest type. Finally, one-sided *t*-test was applied to identify significance between here obtained mean values and those reported in similar researches.

Here are used PASW Statistics 18 and G*Power 3.1.

RESULTS AND DISCUSSION

Descriptive statistics of forest structural and productivity attributes for two forest types over experimental period are presented in Table 1. All values are in average higher in fir-spruce forest considering whole period of measurement. The GS ranged from 198.4 m^3/ha to 612.3 m^3/ha with average of 407.1 m^3/ha in

FS forest type while range was narrower in BFS forest (from 159.2 m^3/ha to 454.9 m^3/ha) with average of 330.0 m^3/ha. In FS forest CAI_v mean of 9.51 m^3/ha/year was obtained with range between 5.74 m^3/ha/year and 12.80 m^3/ha/year. In BFS forest mean CAI_v was 6.85 m^3/ha/year varying between 3.12 m^3/ha/year and 10.71 m^3/ha/year.

Table 1. Descriptive statistics of forest structural and productivity attributes for two forest types over experimental period

Attribute	Forest type	N	Mean	Stnd. Dev.	Min	Max
N (trees/ha)	FS	5	458	140	277	819
	BFS	5	433	206	230	869
$N_{ingrowth}$ (trees/ha)	FS	4	92	89	23	343
	BFS	4	49	29	16	119
N_{cut} (trees/ha)	FS	4	68	48	6	182
	BFS	4	50	53	7	198
BA (m^2/ha)	FS	5	35.1	8.0	20.8	50.6
	BFS	5	30.3	6.0	17.5	40.5
GS (m^3/ha)	FS	5	407.1	116.9	198.4	612.3
	BFS	5	330.0	77.8	159.2	454.9
CAI_v (m^3/ha/year)	FS	4	9.51	2.09	5.74	12.80
	BFS	4	6.85	1.89	3.12	10.71

Analysis of the dynamic changes (variability within occasions)

Changes of forest productivity attributes during successive occasions (measurements) in for two different forest types are illustrated in Figure 2. Results of ANOVA with within-subjects factor (repeated occasions and interaction forest type × occasion) and between-subject factor of forest type (FT_1 and FT_2) are presented in Table 2 and Table 3. Results of multivariate test related to within-subject difference are given in Table 2. Mauchly test indicated that the assumption of sphericity had been violated (χ^2 (2) = 16.8, $p < .001$), therefore degrees of freedom were corrected using Greenhouse–Geisser estimates of sphericity ($\varepsilon = 0.98$).

Multivariate tests (within subjects) indicated:

There were significant mean differences in N, GS and CAI_v related to consecutive occasions (dynamic changes within occasions) regardless forest type:
N (Wilks Lambda = 13, F (4, 5) = 8.4, p = 0.02, partial eta squared = .975);
GS (Wilks Lambda =0.03, F (4, 5) = 48.7, $p < 0.001$, partial eta squared = .975);
CAI_v (Wilks Lambda =0.11, F (3, 6) = 15.9, $p < 0.001$, partial eta squared =0.888).

There were not significant mean differences in $N_{ingrowth}$ related to occasions (dynamic changes within occasions) nor interaction occasion × forest type ($p > 0.05$), but with low power.

There were significant mean differences in N_{cut} and BA between forest types within occasions (interaction occasions × forest type):

N_{cut} (Wilks Lambda =0.26, F (3, 6) = 5.76, p = 0.03, partial eta squared =0.742);

In this case 74.2% of variance of N_{cut} was explained by interaction between forest type and occasion;

BA (Wilks Lambda =0.18, F (4, 5) = 5.81, p = 0.04, partial eta squared =0.823);

In this case 82.3% of variance of BA was explained by interaction between forest type and occasion.

Table 2. Results of multivariate test (ANOVA within occasions and interaction occasions × forest type)

Attribute	Source	Wilks λ	F	df_1	df_2	Sig.	Part. ε^2	Est. Power
N (trees/ha)	Occ.	0.13	8.38	4	5	0.02	0.870	0.84
	Occ×FT	0.51	1.21	4	5	0.41	0.492	0.19
$N_{ingrowth}$ (trees/ha)	Occ.	0.49	2.06	3	6	0.21	0.507	0.30
	Occ×FT	0.75	0.66	3	6	0.61	0.248	0.12
N_{cut} (trees/ha)	Occ.	0.04	45.13	3	6	0.00	0.958	1.00
	Occ×FT	0.26	5.76	3	6	0.03	0.742	0.71
BA (m^2/ha)	Occ.	0.02	58.96	4	5	0.00	0.979	1.00
	Occ×FT	0.18	5.81	4	5	0.04	0.823	0.69
GS (m^3/ha)	Occ.	0.03	48.69	4	5	0.00	0.975	1.00
	Occ×FT	0.23	4.21	4	5	0.07	0.771	0.54
CAI_v (m^3/ha/year)	Occ.	0.11	15.86	3	6	0.00	0.888	0.99
	Occ×FT	0.72	0.77	3	6	0.55	0.278	0.14

Obtained statistical findings supported description of dynamic changes visible on graphical presentations (Figure 2). Analyzing dynamic changes through whole time span we noticed:

There were no significant differences of measured forest attributes (N, BA, GS) between two forest types in the first occasion. The same tendency remained in the second occasion as for the same attributes so for firstly measured attributes: $N_{inrowth}$ and CAI_v. Here appeared the significant difference of number N_{cut} in interaction occasion × forest type. It was the highest difference of cut intensity in the whole time span.

In the next (the third) occasion differences between means of all forest productivity attributes remained non-significant. In the fourth occasion the significant difference of BA was obtained for interaction occasion × forest type. Also, the significant difference of CAI_v was determined that remained in the next (the fifth) occasion too.

It seems that the higher cut intensity in the second occasion in FS forest type supported tendency of BA and CAI_v increase resulting in significant differences of CAI_v in the fourth occasion that remained next 20 years. Progressive tendency of CAI_v changes in FS forest type was consistent during the

whole time span while the tendency of CAI_v changes in BFS forest type was almost invariable with slight decrease. Bončina *et al* (2013) reported that changes were divergent in study areas in Dinaric uneven-aged forests of the NW Balkan too although stable structure over several decades were expected.

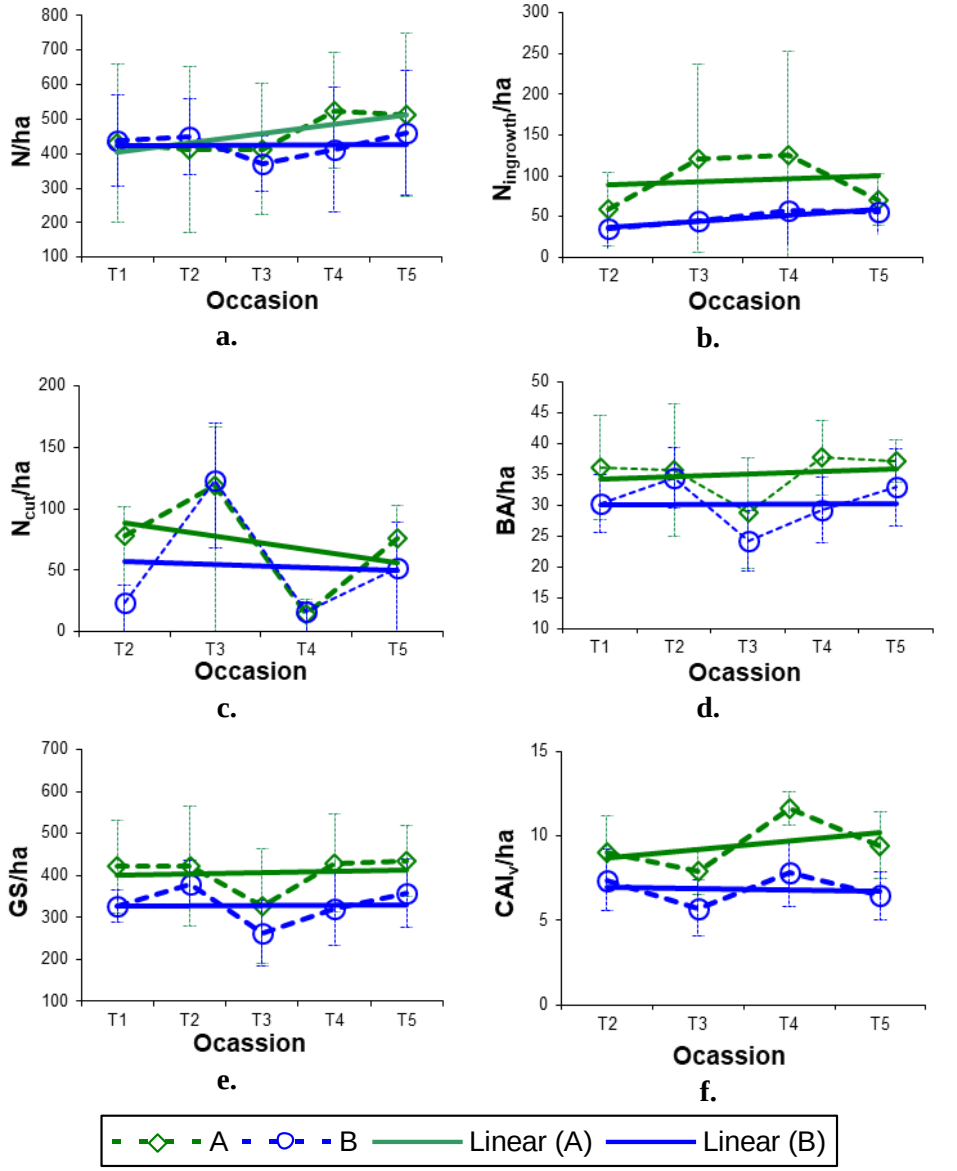

Figure 2. Changes of the observed averaged forest attributes (dotted lines) and trends (solid lines), for the number stem per ha (a), ingrowth number of trees per ha (b), number of cut trees per ha (c), basal area per ha (d), growing stock per ha (e) and current annual increment per ha (f). Error bars are standard deviations of the observed attributes.

Analyses of forest productivity attribute differences (variability between forest types)

Table 3 summarizes results of univariate tests. The main effects comparing the two forest types were not significant for all attributes ($p > 0.05$) except CAI_v ($F(1,8) = 9.32$, $p = 0.02$, partial eta squared = 0.538).

Table 3. The main factor means significances (ANOVA between forest types) and power *post-hoc* analysis of forest productivity attributes ($\alpha = 0.05$, $n_{groups} = 2$)

Attribute	N_{occ}	F	Sig.	Partial Eta Squared	Cohens f(U)	Est. Power
N (trees/ha)	5	0.11	0.75	0.013	0.12	0.06
$N_{ingrowth}$ (trees/ha)	4	1.79	0.22	0.183	0.47	0.22
N_{cut} (trees/ha)	4	4.83	0.06	0.377	0.78	0.49
BA (m^2/ha)	5	1.57	0.25	0.164	0.44	0.20
GS (m^3/ha)	5	1.70	0.23	0.175	0.46	0.21
CAI_v (m^3/ha/year)	4	9.32	0.02	0.538	1.08	0.76

The partial eta squared ranged from 0.013 (N) to 0.538 (CAI_v). Lower percentages of variance determined by forest type were obtained for BA and GS and $N_{ingrowth}$ (< 20%). The higher percentages of variance explained by forest type were found for N_{cut} (38%) and CAI_v (54%). Cohen's metric $f(U)$ of effect size points out the largest effect for CAI_v (1.08) reaching statistical significance and approaching to reliable power of 0.8 approximately. Compared to this value, effects for BA, GS, $N_{ingrowth}$ and N_{cut} could be assigned as medium (between 0.44 and 0.78) and effects for N as small (< 0.20). Then the highest association between forest types and N_{cut} (0.78), almost significant difference ($p = 0.06$) and observed power of 0.5 approximately points out probability of 50% to find out significant difference if is there. Finally, it is visible that probability to find out significant difference for other attributes, if they exist, is very low (< 25%).

Power analysis - minimal detectable effects (MDE)

Using sensitivity approach, minimal detectable effect (required effect size to reach power of 0.8) of attributes for forest type of 1.13 was determined assuming chosen experimental design.

The Figure 3 shows relationship between effect size and power for ANOVA, repeated measures, between factors (number of groups = 2, number of measurement, err prob = 0.05, total sample size = 10) produced using G*Power 3.1. It shows that power increases with larger effect size. It is visible that CAI_v approached to required effect size only. So evidence about significant mean difference between CAI_vs in two forest type reached high power was obtained and this significance could be accepted for generalization.

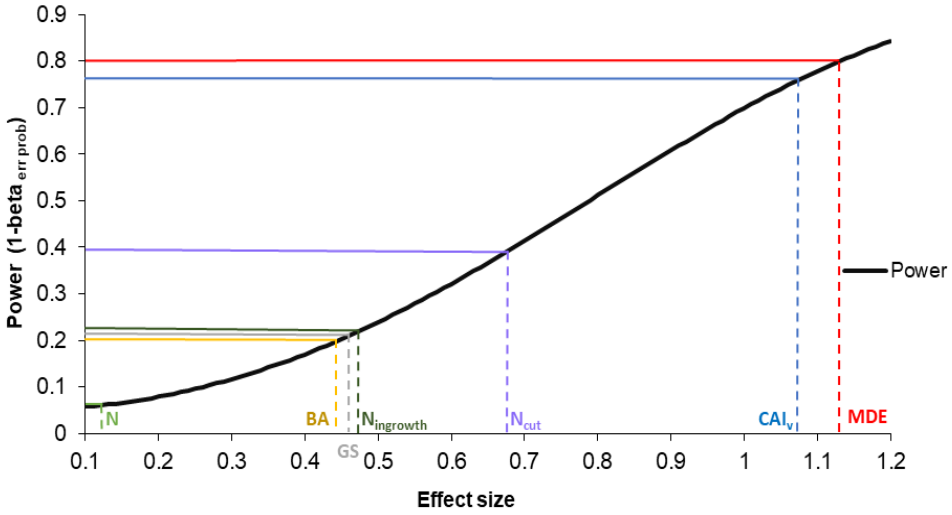

Figure 3. Power by effect size for forest productivity attributes (ANOVA repeated measures, between factors, Q*Power 3.1)

Hybrid power analysis – Sample size estimation

Many researchers emphasize that power analysis contributes the most in the planning research phase when desired effect size, significance level, test power and sample size should be chosen or estimated (Foster 2001, Di Stefano 2001). Foster (2001) demonstrated capacities of *a priori* power analysis discussion forest monitoring program in native uneven aged multispecies forests in the United States. He stated the relative mean difference of forest productivity attribute (expressed in percentage) as desired effect size and calculated required sample size and estimated power (based on data collected in the first monitoring phase). For example, desirable change over time to detect was the decrease of 20% for the canopy cover and three density, BA to remains the same and to detect the GS increase of 20%.

In this research, power analysis was performed for sample size estimation, based on data from last occasion, with an idea to compare difference between means of BA, GS and CAI_v in new simple comparative experiment using minimal sample size to reach power of 80%.

The minimum sample size CAI_v to detect this effect with exact power of 80% in new experiment is similar (n = 7 plots per forest type) (Figure 4) (G*Power 3.1 or other software).

The effect size for BA of 0.44, could be qualified as medium. With an alpha =0.05 and power = 0.80, the projected sample size needed with this effect size is approximately N =38 (19 plots per each forest type) for the pairwise comparison. The effect size for GS of 0.46, could be qualified as medium too. With an alpha = .05 and power = 0.80, the projected sample size needed with this effect size is approximately N = 48 (24 plots per each forest type).

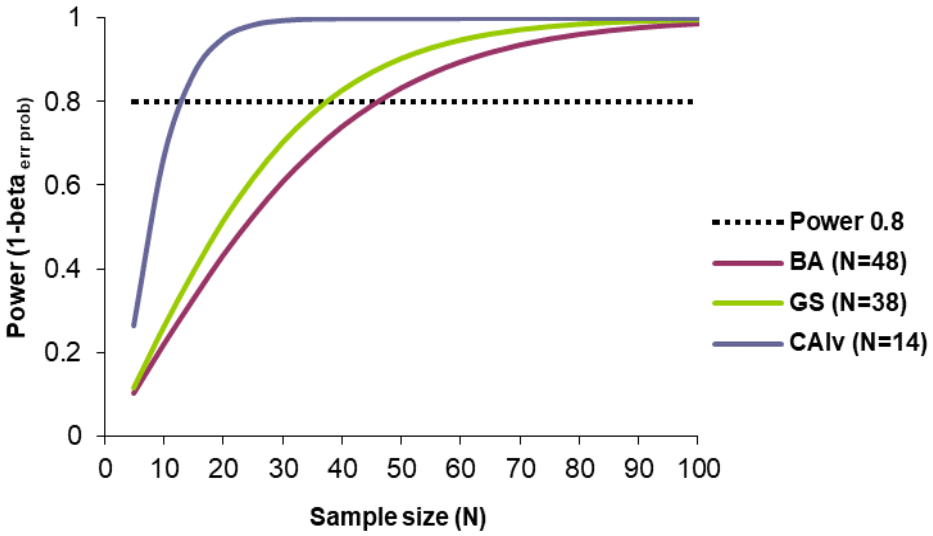

Figure 4. Power by sample size for forest attributes (*t*-test two independent groups, Q*Power 3.1)

Choosing larger sample size (24 plots per each forest type), uncertainty related to BA and GS could be clarified in the frame of common research planned as simple comparative experiment (two independent samples) (Figure 4).

If it acceptable for researchers to neglect impacts of occasions (from the practical reasons although their significances were confirmed earlier) and experimental data accept as independent observations in two forest types, then two data sets related to forest types could be used to clarify relations between effect size, sample size and power additionally. In this case we assume the independency of observation within forest type. Results of pairwise comparisons of forest productivity attributes mean differences between two forest types are given in Table 4.

This approach results in conclusions that the larges effect sizes related to CAI_v, GS, BA and $N_{ingrowth}$ (Cohens d > 0.60) become statistically significant with larger sample sizes ($n_{II\text{-}V}$ = 40 and $n_{I\text{-}V}$ = 50). Difference related to (N) remains non-significant with low power.

Significant difference between mean growing stocks in two forest types on experimental sample plots is expected and consistent with recent findings (Matić 1959, 1963, 1971, 1980; Kotar 2005). Higher conifers participations with narrow crowns and emphasized adaptation on limited light contribute to higher density enabling higher growing stock consequently (Ibrahimspahić, 2013).

The power *post-hoc* analysis

In the first phase of the experiment, plots structural and productivity characteristics were determined and then stand productivity normal quantities

proposed for each plot within forest type (Drinić 1974, Pavlič 1987). Last measurement was used in order to compare differences between observed and stated GS and CAI_v quantities within each forest type. Results are presented in Table 5.

Table 4. The main factor (forest type) means significances (unpaired *t*-test) and power analysis of forest productivity attributes ($\alpha = 0.05$, $n_{groups} = 2$) (completely randomized design)

Attribute	N	t	*p* value	Effect size	Est. Power	α level (power 0.8)	Sample Size (Power 0.8)
N (trees/ha)	50	0.66	0.512	0.18	0.099	0.753	910
$N_{ingrowth}$ (trees/ha)	40	2.22	0.033	0.70	0.584	0.174	66
N_{cut} (trees/ha)	40	1.16	0.254	0.36	0.201	0.632	240
BA (m^2/ha)	50	2.42	0.019	0.61	0.658	0.122	70
GS (m^3/ha)	50	2.77	0.008	0.79	0.779	0.059	54
CAI_v (m^3/ha/year)	40	4.29	<0.01	1.36	0.987	0.002	20

Table 5. The *post hoc* power - observed *vs.* targeted (normal) values in two forest types (n=5)

Type	Attribute	Obs.	Normal	p - value	Effect Size	ES conv.	Est. Power
FS	GS (m^3/ha)	434.6	344.8	0.06	2.63	very large	0.95
	CAI_v (m^3/ha/year)	9.44	7.21	0.07	2.47	very large	0.93
BFS	GS (m^3/ha)	357.9	357.7	1.00	0.01	small	0.05
	CAI_v (m^3/ha/year)	6.48	7.23	0.38	0.98	large	0.28

There are no statistically significant differences between GS and CAI_v means in both forest types (α=0.05, p>0.05). The *p* values in FS forest type are almost critical pointing out high risks of errors type II what is confirmed with very high estimated power (0.95 and 0.93 respectively). It means there are 95% and 93% chances of significant differences but we did not find them (probably sample size is critical). On other size, in the BFS forest types GS effect size is very small, difference is not significant and a chance of being significant is very low (5%). Also, CAI_v difference is not significant (p=0.38) although effect size is large. Obtained results support conclusions that nonsignificant differences between observed and proposed values hold very high risk in FS forest type while the same statement could be accepted for BFS forest type with very low risk.

Recently, mixed uneven aged beech, fir and spruce forests particularly have been recognized as the most challenging forest type considering competitive abilities of broadleaves and conifers exposed to dynamic environmental, economic and social conditions and changes. Their particular importance related to productivity, biodiversity and other forest functions have been identified very early. Many papers reported that old-growth BFS forests on Balkan peninsula achieve very high wood production (Keren *et al.* 2014, Motta *et al.* 2014, Chivulescu *et al.* 2016) and preserve very high biodiversity (Gazdić *et al.* 2016). Then, forest management planning strives to adapt proper silvicultural treatments in order to achieve high wood production and maintain sustainable principles. Bončina et al. (2014) reported about structural characteristics as in managed mixed forests so in old-growth virgin across region: Slovenia (SI), Croatia (CRO), Serbia (SRB), Bosna and Herzegovina (BIH) (Foča-Toholji), and Montenegro (MNE). We compared means of BA and GS obtained for experimental plots in BFS on Igman and correspondent values reported for managed stands in study areas across region (chosen as representative of selection forest management in the country) (Bončina *et al.* 2014) (Table 6). Also, we found as comparable result from similar experimental research completed in Biogradska Gora (Čurović *et al.* 2013) and reported about difference between GS mean from Igman and proposed normal value of 389 m^3/ha in this study area (Table 6). It was noticeable that reported values were higher than Igman's means mainly (GS of 330.0 m^3/ha and BA of 30.3 m^2/ha) so we examined if they were significantly higher. Comparison was based on the one-sample *t*-test (one-sided) where reported values were used for statistical research hypothesis.

Table 6. The *post hoc* power – GS and BA comparison with other study areas (managed mixed uneven aged beech and fir with spruce forest stand) in region

	Stand volume (m^3/ha)				Stand basal area (m^2/ha)			
Country	Mean	*p* value	Effect Size	Est. Pow	Mean	*p* value	Effect Size	Est. Pow
SI	428	0.06	1.96	0.97	36	0.17	1.08	0.63
CRO	436	0.05	2.18	0.99	35	0.25	0.72	0.38
SRB	493	0.01	3.78	1.00	35.6	0.20	0.93	0.35
BIH	447	0.03	2.49	0.99	41	0.02	2.87	1.00
MNE	361	0.47	0.09	0.06				
MNE[a]	389	0.22	0.87	0.49				

Note: The data in columns two and six are from "A comparative analysis of recent changes in Dinaric uneven-aged forests of the NW Balkans" (Bončina *et al.* 2014, p. 75); [a] Value from "The ratio between the real and theoretically normal number of trees in mixed fir, beech and spruce forests in the national park "Biogradska gora" (Čurović *et al.* 2013, p. 14)

Almost significant difference is obtained for GS from Slovenia (p=0.06) with high probability that actual difference exists but was not found (97%). Significant differences are found for Croatian, Serbian and BIH (Foča-Toholji) forest stands ($p \leq .05$). On other side, non-significant differences for GS related to Montenegrin forest stands confirm quantity similarities in Bosnian (Igman) and Montenegrin experimental trials. The BA differences are not significant in cases of Slovenian, Croatian and Serbian forest stands while BA obtained on Bosnian forest stand located in Foča-Toholji is significantly larger (p=0.02). Effect sizes for Slovenian and Serbian BA are very large (approx. 1) while for Croatian could be qualified as large (approx. 0.7).

The complexity of natural processes in native uneven aged mixed forests needs various analyses relevant as for ecological stability so for economic forest management on sustainability principles (Miletić 1950, Matić 1980). Power analysis applied in this research shows potentials to clarify forest productivity attribute differences between two forest types, effect sizes of their dynamic changes in time and results in similar research.

CONCLUSION

Here are demonstrated applications of linear mixed analysis of variance related to the analysis of dynamic changes and power analysis of forest productivity data collected in long-term experimental research conducted as repeated measurements (occasions) in native uneven aged multilayer forests.

Behind evaluation of their statistical significance here are identified and interpreted effect sizes of forest productivity attributes related to difference caused by forest type, occasion and their interactions. Power curves for main effect (forest type) related to effect sizes and sample sizes are determined. The minimal detectable effect size is calculated for presented experimental design pointing out that only estimated significant difference of current annual increment (m^3/ha/year) between two forest type could be generalized with adequate power (near 80%). Then, obtained data of basal area (m^2/ha) and growing stock (m^3/ha) in last occasions could be used as preliminary data to plan sample size for new experiment in order to achieve test power of 80%. Also, we performed power analysis of forest productivity attributes pairwise comparison assuming all measurements as timely independent and confirmed very high significance for current annual increment per ha. In this approach significant mean differences were obtained for growing stock (m^3/ha), basal area (m^2/ha) and ingrown trees per ha demonstrating capacities of sample sizes. Accepting this approach obtained results support expected significant differences between forest attributes in fir-spruce and beech, fir with spruce forests.

Then, obtained growing stock (m^3/ha) and basal area (m^2/ha) means are compared with targeted values from management plans for two forest types finding out no significant differences. The very large effects sizes were found in fir-spruce forest pointing out large differences between obtained and targeted values.

Finally, forest attributes comparisons with similar managed uneven mixed beech, fir with spruce stands in region were performed. The non-significant differences of growing stock (m^3/ha) were obtained between Bosnian forest stands on Igman and Montenegrin forest stands Ljubišna and Biogradska Gora only. Effect size for the first difference was small (0.06) while the second effect size was large (0.87). Effect sizes for basal area (m^2/ha) ranged from large (Croatia, Serbia) to very large (Slovenia).

In conclusion, presented research integrates possibilities to analyze long-term experimental forest structural and productivity data focusing on dynamic changes analysis and power analysis as rarely used statistical method. Here was emphasized importance of effect size and power in non-significant differences between forest attributes as within stands so between forest types on different scales.

Further research could include other forest attributes and additional available environmental data as covariates and explore their participation in effects (climate, soil, terrain and others) locally and globally.

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