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Influence of climatic, site and stand characteristics on some structural parameters of scots pine (*Pinus sylvestris*) forests situated on degraded lands from east Romania

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Abstract
The ecological restoration of degraded lands has significance in countries where their deterioration process covers large periods of time. The present paper starts by establishing three types of classes. As such, age, phytoclimatic area and degradation level significantly influence the resulting characteristics expressed by the average diameter (average height) in scots pine (*Pinus sylvestris*) stands from degraded lands (R^2_a = 0.784; R^2_a = 0.639). Evaluating some climatic, site and stand characteristics over the dynamic of certain structural parameters in stands situated on degraded lands is a basic action where the current objectives are dedicated to the ecological restoration of forests from certain lands.

Keywords: Degraded lands, Mixed linear models, Scots pine

Introduction

Besides their role in protecting areas that have a role in conserving biodiversity, newly created forests are not sufficient for a long-term conservation of the environment. Therefore, the ecological restoration of areas more or less modified by the action of various disruptive factors is also necessary (Hobbs and Norton, 1996; Young, 2000; Honnay *et al*., 2002). Ecological restoration represents the rehabilitation of a degraded land and its transformation into a system that becomes protective, productive, aesthetic, pleasant or valuable on a long-term (Hobbs and Norton, 1996). The silvicultural operations made for the recovery of ecosystems increases biodiversity as well as ecosystem services at a landscape scale (Aronson *et al*., 2006).

The ecological restoration of degraded ecosystems has a peculiar importance in countries where their deterioration process occurred over a long period of time (Perez-Trejo, 1994). Recent investigations emphasize the importance of reforestation processes on degraded lands in order to accelerate natural succession and also to highlight pioneers followed by successive vegetation (Chand *et al*., 2017; Kumar *et al*., 2017). The ecological restoration of degraded lands by reintroducing wood species has gained importance worldwide (Carnevale and Montagnini, 2002; Maestre and Cortina, 2004; Dincã *et al*., 2012; Bernard *et al*., 2014; Pilon *et al*., 2018). The benefits of reforestation include biodiversity improvement, ecosystem stability, protection against soil erosion and the increase of carbon accumulation (Semwal *et al*., 2013; Dincã *et al*., 2015; Moscatelli *et al*., 2017). Furthermore, other aspects are also noted, such as the amelioration of unfavorable microclimate or soil conditions as well as ensuring a habitat for the dispersion of wild flora seeds which highly accelerate the natural regeneration of forests and fosters the reinstallation of fauna (Tucker, 2000; Sanchez-De Leon *et al*., 2003; Carnus *et al*., 2006; Shono *et al*., 2006; Tang and Li, 2014; Singh *et al*., 2015).

Approximately 300,000 hectares of degraded lands were afforested in Romania until 2008, most of them with black pine, scots pine and locust (Untaru *et al*., 2012). Technical solutions were adopted based on the obtained results in the long-term experimental amelioration parameters (Constandache *et al*., 2010, 2016). As a result, the forest crop planting scheme was established by the land's productive potential, as well as by the nature and intensity of the degradation processes (Constandache *et al.,* 2015). As such, between 4000 and 10000 seedlings per hectare were used for the afforestation of degraded lands with Mediterranean pine, based on the erosion degree and with considerably higher densities than the ones used in other geographical areas (Ganatsas *et al*., 2011).

The action of harmful abiotic factors (wind, snow, drought etc.) significantly influences the behavior of pine stands installed on degraded lands (Martín-Benito *et al*., 2013; Mérian and Lebourgeois, 2011; Zang *et al*., 2012), espec-

-ially when they have a low consistency which affects their stability (Vlad and Constandache, 2014). During the last period of time, a health decline of pine cultures, as well as the decrease of annual growth, is the consequences of damages caused by drought, snow-breaks and wind-breaks (Dinulicã *et al.*, 2015; Merlin *et al.,* 2015; Silvestru-Grigore *et al.*, 2018).

The analysis of stands at different ages has emphasized a different behavior regarding the phytoclimatic area, site conditions, harmful factors and the forestry operations. These analyses have asserted aspects with a negative effect on the development of stands, especially for those with pine (reducing consistency and structure disturbances, the regeneration of some species with low ecological value, altering the health state based on their aging) (Vlad and Constandache, 2014; Jagodziñski *et al.,* 2018). This aspect leads to diminishing the ecosystem's stability and has negative ecological and economic consequences (Constandache *et al.,* 2015).

The present paper intends to establish the influence of some climatic, site and stand factors over the dynamic of certain structural parameters (average diameter, average height) in pine stands installed on degraded lands.

Materials and Methods

Study site: The study was carried out in nine experimental areas (sixty permanent research plots) located in different scots pine stands from lands with different degradation processes, different site conditions and from different phytoclimatic levels from Romania (Fig 1).

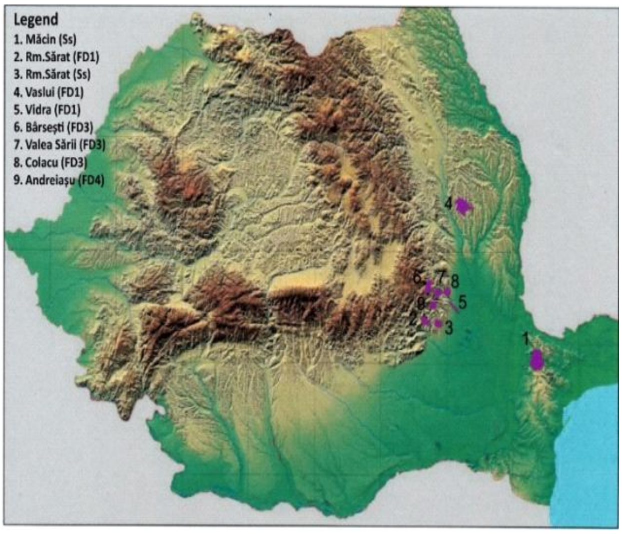

Fig 1. The study site

Experimental plots characteristics: The nine experimental areas were installed between 1949-1977. Their area ranges from 5.0 ha to 94.6 ha. The researched stands were installed in four phytoclimatic areas, with different pine species, pure or mixed with hardwood species, situated on different eroded lands, on different soil substrates and using different tree planting techniques.

Scots pine stands have ages between 35 and 65 years old, so that they are capable of offering valuable scientific information concerning the type of cultures and silvicultural operations necessary for an efficient management of stands from degraded lands, particularly where the action of ecological stand restoration presents an improper state and are affected by harmful agents. The stand's health and the collection of land data were permanently monitored through periodic measurements (at five years) concerning the main biometric (diameters, heights etc.) and quality (breaks, drying) parameters in 60 long-term research areas.

Design of modelling process: The statistical data has focused on quantifying the influence of some climatic characteristics of scots pine stands installed on degraded lands, expressed by the phytoclimatic area (silvosteppe– Ss; hill oak stand area– FD1; hill oak, common beech and oak-common beech area – FD3; mountainous, pre-mountainous beech area - FD4, based on the Romanian site typology), the degradation form (E1–4 = surface erosion: moderate– E1; strong– E2; very strong– E3; very strong erosion associated with other degradation forms– E4; landslides– A1; depth erosion– R; rock-land– S) and some qualitative elements (stand age), over some structural parameters (average diameter and height at the current stand age).

Generalized mixed linear models were used in order to compare the performance of the used variables as predictors and in order to identify the independent variables that have mostly influenced a series of structural characteristics of stands installed on degraded lands. The tested variables were both continuous (stand age) as well as factorial (type of phytoclimatic area, form of degradation). Three model classes were first of all established and differentiated based on the number of predictable factors. The first class of models has three different variables (stand age, type of phytoclimatic area and degradation form). The second class was composed of combinations between the three variables, while the third class contained all the variables consider as predictors. The selection of the optimal model was realized by using the Akaike (AIC) information criteria (Burnham and Anderson, 2004). Furthermore, the multiple determination coefficient was also calculated (R^2_a) (Quinn and Keough, 2002). Simulations were realized with the help of Statistica 12 software and with IBM SPSS 20.

Results and Discussion

Generalities: Recent investigations identified five main reasons for the ecological restoration of degraded ecosystems (lands): idealist, technocratic, heuristic, biotic and pragmatic. The ecological restoration pragmatic model was described as being composed of two components - restoration of natural capital (forest) and climate improvement (Clewell and Aronson, 2006).

Statistical parameters of the diameter in scots pine stands: Regarding the phytoclimatic area, the highest value of the average diameters encountered in the FD4 category (28.1±1.5 cm), while the lowest one in the FD1 and Ss categories (21.1±1.5 cm), with a variation of 46% in the specified extremes. An increase of the average diameter could be observed from the forest steppe phytoclimatic area to the common phytoclimatic area corresponding to the common beech mountain pre-mountain area (FD4). Considering the degradation form, the largest average diameter was encountered in the E1 category (26.2±2.6 cm), while the lowest one was in the S category (13.7±4.9 cm), with significant variations between the specified extremes (between 12% and 39%). From the point of view of phytoclimatic area – degradation form combinations, the largest average diameter was the FD4-E3 category (28.3±1.6 cm), while the lowest one belonged to the Ss-S category (13.8±4.9 cm). The standard deviation registered the highest values in the FD3-R category (18.8±8.3 cm), while the lowest ones were recorded in the FD1-Al category (21.1±1.5 cm).

A positive and linear correlation for Ss-E1, Ss-E2, Ss-S, FD3-E1, FD3-E3 and a negative and linear correlation for Ss-E3, FD1-Al, FD3-Al were identified in the relationship between the stand's independent age and the stand's average diameter, by taking into consideration the phytoclimatic areas and degradation forms. The considered hypothesis regarding the influence of the analyzed factorial characteristics was satisfied in all cases presented (data not shown).

Influence of some climatic and site characteristics on the dynamic of average diameter in scots pine stands: Treated alone, the factorial characteristics (age, erosion type and phytoclimatic area) explained between 14% and 44% of the average diameter's variation in stands from degraded lands (Table 1, models 4, 6 and 7), while the combination of two predictive elements explained between 17% and 72% of the average diameter's variation (Table 1, models 2, 3 and 5). Together, these three factorial characteristics explained approximately 80% of the analyzed resulted characteristics (Table 1, model 1).

A significant influence over the resulted characteristics expressed by the average diameter in pine stands installed on degraded lands (R^2_a = 0.784) was confirmed when age was used as covariate, phytoclimatic area and degradation form as factorial characteristics (Table 2). In this case also, the model based on the three predictors proved to comply with a specific statistical-mathematical modelling law (*Bias* = 0.009), having also a reduced value of the square root average error (*RMSD* = 2.04 cm) (Fig 2).

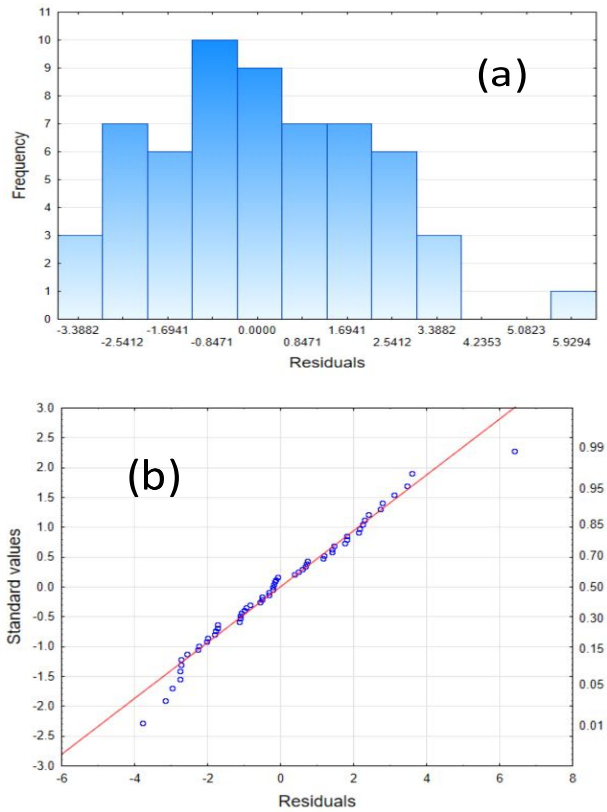

Fig 2. Quantifying frequency (a) and standard values (b) for residues in the case of the optimal model with average diameter

Table 1. The performance of models used for estimating the average diameter

Code No.	Model class	Predictors	Freedom degrees	*AIC*	R^2_a
1	3	Age, phytoclimatic area, degradation form	56	273.7*	0.784
2	2	Age, phytoclimatic area	57	282.3	0.718
3	2	Age, degradation form	57	327.0	0.522
4	1	Age	58	340.9	0.445
5	2	Phytoclimatic area, degradation form	57	356.6	0.167
6	1	Degradation form	58	372.2	0.167
7	1	Phytoclimatic area	58	372.9	0.141

*R^2_a - adjusted multiple determination coefficient; * - the best model*

Table 2. Estimating model 1 parameters using the normal distribution as calculation elements and the logarithmic equation as binding function

Predictors	Predictors level	Value	Standard deviation	*t*	*p*
Free term		1.4840	0.1200	-2.187	0.0000
Age		0.0317	0.0023	9.596	0.0000
Phytoclimatic area	Ss	-0.2234	0.0309	-5.958	0.0000
Phytoclimatic area	FD3	0.1099	0.0527	3.072	0.0372
Phytoclimatic area	FD4	-0.0777	0.0253	-4.581	0.0021
Degradation form	E1	0.0862	0.0317	3.221	0.0065
Degradation form	S	-0.3142	0.0898	-3.114	0.0004
Degradation form	E3	0.0801	0.0304	2.352	0.0085
Degradation form	Al	0.1082	0.0528	-1.357	0.0407

Statistical parameters of the height in scots pine stands: Regarding the phytoclimatic area, the highest value of the average height was encountered in the FD4 category (19.0±0.8 m), while the lowest one was in the Ss category (14.2±5.2 m), with a variation of 34% in the specified extremes. A specific dynamic of the average height was thus ascertained. This increase from the forest steppe area to the FD1 phytoclimatic area, decreased for the FD3 area, followed by an increase in the common beech mountain-pre-mountain area (FD4).

In regard with the degradation form, the highest average height was found in the E1 category (18.9±1.9 m), while the smallest one was in the S category (6.8±3.2 m), with significant variations between the specified extremes (between 15% and 29%). From the point of view of phytoclimatic area – degradation form combinations, the largest average height was found in the FD4-E2 (E3) category (18.9±1.5 m), while the smallest one was in the Ss-S category (6.8±3.2 m). Standard deviation recorded the highest values in the FD1-Al category, while the smallest ones were in the FD4-E3 category.

A positive and linear correlation for Ss-S, Ss-E1, Ss-E2, FD3-E1, FD3-E3, FD3-R and a negative and linear correlation for Ss-E3, FD1-Al, FD3-Al were determined in the relationship between the independent stand age variable and the stand's average height, by taking into consideration phytoclimatic areas and degradations forms. The hypothesis considered for the influence of the analyzed factorial characteristics was satisfied in all the presented cases (data not shown).

Influence of some climatic and site characteristics to the average height dynamic in Scots pine stands: Considered on their own, factorial characteristics (age, degradation form and phytoclimatic area) explain between 10% and 29% of the average height variation in stands from degraded lands (Table 3, models 5-7), while the combination between each two predictive elements explained between 39% and 49% of this variation (Table 3, models 2-4).

All three factorial characteristics explained together approximately 64% of the analyzed resulted characteristic (Table 3, model 1). The relation between age and average height for stands installed on degraded lands was significantly influenced by the phytoclimatic area where they vegetated and by the degradation form of the soils on which they were installed.

When age was used as covariant, while the phytoclimatic area and degradation form as factorial characteristics, a significant influence was observed over the resulting characteristic expressed by the average height in forest scots pine cultures installed on degraded lands (R^2_a =

Table 3. The performance of models used for estimating the average height

Code No.	Model class	Predictors	Freedom degrees	*AIC*	R^2_a
1	3	Age, phytoclimatic area, degradation form	56	272.7*	0.639
2	2	Age, phytoclimatic area	57	289.7	0.464
3	2	Age, degradation form	57	298.9	0.392
4	2	Phytoclimatic area, degradation form	57	299.3	0.494
5	1	Degradation form	58	313.8	0.294
6	1	Age	58	320.3	0.155
7	1	Phytoclimatic area	58	328.0	0.100

*R^2_a - adjusted multiple determination coefficient; * - the best model*

Table 4. Estimating model 1 parameters using the normal distribution as calculation elements and the logarithmic equation as binding function

Predictors	Predictors level	Value	Standard deviation	*t*	*p*
Free term		1.8863	0.168	1.376	0.0000
Age		0.0167	0.003	4.628	0.0000
Phytoclimatic area	Ss	-0.2512	0.046	-5.243	0.0000
Phytoclimatic area	FD1	0.2072	0.077	2.333	0.0076
Phytoclimatic area	FD3	-0.1003	0.035	-2.196	0.0047
Degradation form	E1	0.2579	0.054	4.614	0.0000
Degradation form	S	-0.6012	0.193	-3.864	0.0018

0.639) (Table 4). In this case also, the model based on the three predictors proved to obey a specific statistical-mathematical law (*Bias* = 0.0057), having also a reduced value of the square root average error (*RMSD* = 2.19 m) (Fig 3).

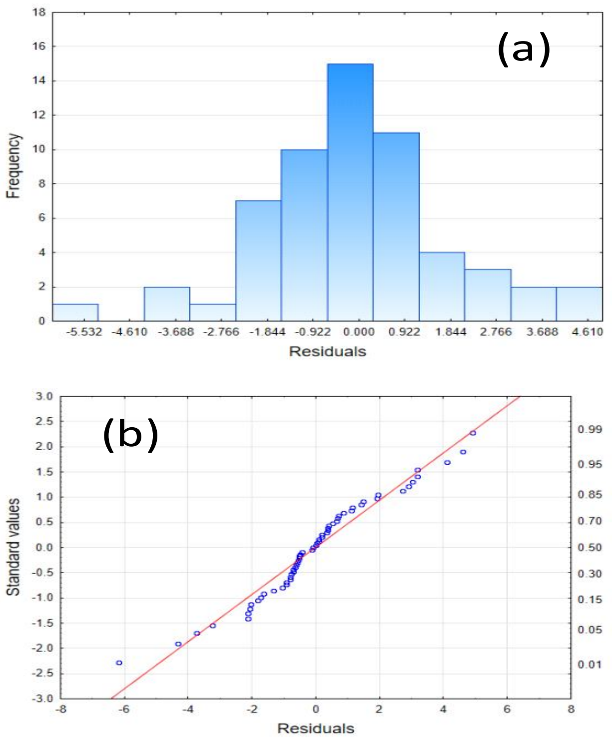

Fig 3. Quantifying frequency (a) and standard values (b) for residues in the case of the optimal model with average height

As a consequence, commonly statistical-mathematical methods used for analyzing the influence of some climatic, site and stand characteristic over the dynamic of certain structural parameters from scots pine stands installed on degraded lands were applied in the present study. These coordinates were fitting in the previously described concept regarding the ecological restoration of degraded lands and the factors influence analyze in this process.

Biometric parameters dynamic: From the performed analyses, the most active scots pine diameter growths were realized on lands affected by a complex degradation (very strong erosion associated with gullying) from the FD3 oak-common beech area. In this area, even though the erosion was accentuated, stands were realized through special preparation/ consolidation land works. In association with white sea buckthorn, these lands were less affected by harmful abiotic factors. More active growths were correlated with the weak depletion of trees, emphasizing the adaptability of these types of cultures to site conditions. In comparison with the broad-leaved species present in experimental blocks, Scots pine species registered higher growths.

The abroad specialty literature mentions that the scots pine forests had shown significant differences in regard with the biometric parameters, in comparison with broad-leaved species. Even though the number of trees was 5.4 times lower, this species reached a base surface larger than 189.6%, a higher volume with 30.8% and a growth of 30.9% of the current volume in comparison with broad-leaved species (black locust). Furthermore, the dimensions of average trees were also larger in scots pine stands, with an average diameter larger with 128.2% and an average height higher with 40.7% than the locust stands (Lukić *et al*., 2015). In addition, comparing the biological characteristics of species, this fact could be caused by the present high density used in plantation (over 5000 trees per hectare), with a very slow differentiation in diameter. Reducing the number of trees could encourage the extension of crowns and roots, having a positive impact in stabilizing degraded soils (Lukić *et al*., 2015). The analyzed biometric parameters from the scots pine stands were significantly influenced by the age of stands, phytoclimatic area and degradation form. In other words, the limitative factors for stands installed on degraded lands, beside age, refer to climate and site conditions.

Factors influencing the stand's development on degraded lands: The development of stands installed on degraded lands was influenced by the phytoclimatic area where they were installed. As such, the survival rate of installed trees proved to be higher in sub-humid, dry conditions (Vilagrosa *et al*., 2003), unlike the results obtained for other wood species from semiarid areas (Cortina *et al*., 2004). Data concerning the growth and development of experimental plantations proved the results variability, depending on the type of soil, land preparation and climatic conditions (Baró *et al*., 2014). Similar results concerning the low productivity of experimental stands were obtained in the Alicante province (Maestre and Cortina, 2004).

The influence of climate and site conditions manifested through the mortality of scots pine. This was linked with the increase of aridity in some southern populations (Navarro-Cerrillo *et al*., 2007). In comparison, the black pine was not so much affected by these changes (Barbéro *et al*., 1998; Martinez-Vilalta and Pinõl, 2002). This could be explained by the fact that black pine is a Pan-Mediterranean species with a large distribution areal (Barbéro *et al*., 1998), while Scots pine is a boreal pine considered the most widespread conifer that spreads from the Iberic Peninsula up to Siberia (Nikolov and Helmisaari, 1992).

With regard to the climate, the effects of temperatures over the annual radial growths were reversely proportional with the effect given by the precipitations. This interaction between temperature and precipitations had specific influences over tree growths (Vaganov *et al*., 2006, Hoch *et al*., 2003). The increased winter temperatures also increased the growth, reflecting the limitation of photosynthesis during the cold season and the importance of stocking carbon before the vegetation season (Hoch *et al*., 2003). The availability of water during summer allowed forests to extend their late wood productions rather than producing early wood in high percentages (Wimmer and Grabner, 2000). Drought periods of high temperatures had a multiple effect on the tree's physiology and growth. In drought conditions, the cambium's activity ceases earlier (Pichler and Oberhuber, 2007), causing shorter periods for wood formation (Gruber *et al*., 2010). Higher evapotranspiration or lower water availability determines the stomata to reduce plant exchanges and carbon absorption (Jones and Thompson, 1998). In addition, trees could allocate more carbon to their reserves during drought conditions (Wiley and Helliker, 2012), favoring root development and presenting a general inferior activity for reducing cambium and thickening cells (Cinnirella *et al*., 2002).

Recent investigations showed a significant positive relationship between the basis diameter and diameter growth for all analyzed species both in 2002 (humid year), as well as in 2003 (dry year), but with asymmetric competitions given by humidity. In drying conditions, the competition between trees proved to be more symmetric. The trees with higher diameters reacted differently, in comparison with the trees that presented lower dimensions. The pines from both diameter groups recorded a significant growth decrease associated with drought year, while the larger trees recorded a significant growth decline during these events, reducing their growth up to 50% of the average growth (Zang *et al*., 2012).

The obtained results emphasized the fact that scots pine is a species that can adapt to extreme site conditions and can be successfully used in afforestation projects for degraded lands. Nevertheless, managing stands towards a future stable desired ecosystem should be validated by long-term studies that should examine the ecosystem's changes through more successive stages (Ganatsas *et al*., 2011).

Conclusion

The evolution of the scots pine stand's biometric parameters demonstrated that the largest diameter growth was registered in the FD3-E3 category (17.5±0.7 cm), while the lowest in the Ss-S category (7.8±5.3 cm).

In regard with height growths, the highest was found in the FD3-E3 category (12.5±0.7 m), while the lowest was in the Ss-S category (3.0±2.1 m).

Quantifying the influence of some climatic characteristics expressed by the phytoclimatic area (Ss, FD1,FD3 and FD4), of some site elements expressed by the degradation form (E1, E2, E3, E4, Al, R, S) and of some qualitative elements of stands installed on degraded lands (stand age), in a multiple stages regression, denoted the significant influence of predictive characteristics considered over the resulted characteristics expressed by some structural parameters (average diameter, average height). As such, the average diameter and the average height for the scots pine species were significantly influenced by the stand age, the phytoclimatic area and the degradation form (R^2_a = 0.784; R^2_a = 0.639).

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