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INDICATORS OF THE STRUCTURAL AND COMPOSITIONAL DIVERSITY OF STANDS ON DEGRADED LANDS IN THE VRANCEA AREA

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Abstract

The ecological reconstruction of degraded lands was based on the predominant use of pine species (Pinus nigra and Pinus sylvestris), resulting in pure stands or sometimes mixed with deciduous trees, with a fragile structure, prone to damage. The research was carried out during 2023-2024, in 18 research areas located on degraded lands in the Vrancea area, in stands of different ages with the aim of the knowledge of compositional and structural indicators that reflect the intensity of competitive processes. The results indicate a pronounced predisposition to disturbances in pure young stands, with a high level of compositional homogeneity and relative abundances of Scots pine. The relationship between the structural diversity index (Gini) and the coefficient of variation allowed the determination of the structure type of the stand, the correlation coefficient being significant (r=0.9923). Research has shown that mixed stands are more structurally stable than pure stands, promoting mixed species being essential in increasing the resistance of stands. The results are useful for decision-makers, the goal being to create stands with structures resistant to the action of damaging factors.

***Key words**: structural and compositional diversity, pine species, degraded lands.*

INTRODUCTION

Forest biodiversity is closely correlated with the diversified horizontal and vertical structures of the component stands, and the so-called silviculture (silvotechnics) close to nature is largely based on observations and measurements carried out either in strict research plots located in the improvement perimeters, in the case of degraded stands or in forests affected by disasters (natural disasters due to climatic factors, anthropogenic degradation, etc.) (Seidl, 2017).
Global-scale studies highlight a consistent positive relationship between tree species diversity and productivity, using tree species richness as a proxy for biodiversity, as taxonomic diversity is considered to incorporate other traits, such as those of a functional, phylogenetic, or genomic nature (Liang et al., 2016). Studies from North America and Europe also indicate a positive relationship between species richness and tree productivity, while addressing the influence on the environment and climate (Ruiz-Benito et al., 2017). Other studies highlight that the role of biodiversity tends to be stronger in harsher climates (arid or boreal lands) (Ratcliffe et al., 2017).
Because both productivity and biodiversity depend on a wide range of factors, controlled or not by forest management, the scientific hypotheses of various researchers have mostly supported the role of forests in capturing and storing carbon but also as shelters for the protection of biodiversity (Bodin & Wiman, 2007). An important challenge for forest management and conservation is to achieve an appropriate balance between biodiversity and aboveground biomass in order to support forest managers and decision-makers in developing sustainable management plans in relation to the intended purpose (e.g. conservation, increasing forest resilience, and so on) (Silva et al., 2017).
Within stands on degraded lands, their evolution over time is influenced by harmful abiotic and biotic factors, which destabilize the structure of

the stands and endanger the dynamic balance (Giurgiu, 2004). The ecological reconstruction of degraded lands was achieved through repeated afforestation interventions and the predominant use of pine species (*Pinus nigra* and *Pinus sylvestris*), resulting in stands with a fragile structure, prone to damage, in which there is a risk of diminishing eco-protective functions. (Constandache et al., 2015). The installation of protective forestry crops is made difficult in most situations due to difficult environmental conditions, consisting of lands affected by complex degradation processes, which requires the use of special techniques for arranging/consolidating the respective lands. (Constandache & Nistor, 2008).

The role of forestry crops established through ecological reconstruction consists of limiting surface erosion, increasing infiltration, and improving internal drainage (Sandu et al., 2015), soil improvement and so on. Protective forest crops installed on degraded lands, consisting of pine species, associated with various deciduous species (sycamore, ash, cherry, alder, oak, sea buckthorn, and so on) have demonstrated their hydrological and anti-erosional efficiency, but also their increased resistance to the action of disturbing factors. Many stands are affected by drying, breakage, and so on, due to climate change on the one hand (Vlad et al., 2019), or improper application of silvicultural operations on the other hand (Nistor & Constandache, 2013).

The specific conditions in which each stand develops show that it is necessary to abandon the application of rigid, template measures at stand level. To this end, it is necessary to know the inter- and intraspecific relationships that are established between trees, more precisely, specific indicators, estimators and descriptors of the structure of stands (Ciubotaru & Păun, 2014). These parameters can constitute the basic elements for creating models of stands structures appropriate to environmental conditions, stable and resistant to the action of harmful factors, which can properly fulfill their protective functions (Cristinel et al., 2024).

The research conducted aimed to determine indicators of compositional and structural diversity of stands on degraded lands. These indicators, expressed in measurable/evaluable and comparable units, are necessary to ensure sustainable management of forestry ecosystems installed on degraded lands. The results were obtained based on research on monitoring stands on degraded lands carried out in the period 2023-2024.

MATERIALS AND METHODS

The research was carried out in permanent research plots (SEP), located in representative situations of stands on degraded lands in three experimental perimeters in the Vrancea area (Figure 1):

Caciu-Bârsești (CB), Pârâul Sărat-Valea Sării (PS) and Roșoiu-Andreiașu (RA), located from a phytoclimatic point of view in the hilly storey of sessile oak, beech and sessile oak-beech codified as FD_3.

Figure 1. Location of the study (marked on the map with red dots). Source: www.wikipedia.org

The research consisted in observations, measurements, field data collection, processing and interpretation. The working methodology consisted of applying empirical equations to determine compositional and structural diversity indices at the stand level (Giurgiu & Drăghiciu, 2004; Ciubotaru & Păun, 2014).

In the first stage, to determine the indexes, it was necessary to collect raw field data that include the dimensional characteristics of the trees, which enter into the empirical equations, namely: compositional diversity indices: Shannon index (H), compositional diversity index (A), equity index (Pielou) (E), Simpson index (D); structural diversity indices: Camino index (C), Gini index (G), density index (Id), density index (IG).

The Shannon diversity index (H) measures the diversity of species within a stand.
The compositional diversity index (A) is an indicator of biodiversity, based on the relative abundance of species in a stand (Jaehne & Dohrenbusch, 1997).
The Pielou-Equity index (E). Evenness (E) shows the relationships between the abundances of species or categories of species. In the case of similar relative abundances, the equity will have a unitary value, and if most observations belong to a single category, it tends to value zero. Equity represents a form of standardization of the Shannon index, as the ratio between observed diversity and maximum diversity (Pielou, 1969; Lexerod & Eid, 2006).
The Simpson index (D) expresses the probability that two observations drawn at random from the analyzed perimeter belong to the same category. It is strongly influenced by the abundance of categories and little sensitive to the number of categories (Simpson, 1949).
The analysis of the type of structure and homogeneity of pine stands on degraded lands was carried out using the Camino and Gini indices, which have as their scientific basis the variability of experimental values on Lorenz curves. The indices were calculated using the Gini-Lorenz statistical application (Popa, 1999), implemented through Microsoft Excel. The Camino index shows the trend of structural diversification over time, even for even-aged stands. Research has shown that homogeneity provides information on the type and intensity of interventions in stands: if extractions are performed in the upper storey, homogeneity is reduced, while interventions in the middle and lower storey increase homogeneity (Cenuşă et al., 2002).
The Gini index (G) determined according to the basal area is calculated as the ratio between the area determined by the Lorenz curve and the reference line on the one hand and the area of the triangle formed by the reference line with the abscissa and the parallel to the ordinate through the intersection point between the Lorenz curve and the reference line, on the other hand (Katholnig, 2012; Duduman, 2011). Gini coefficient values range between 0 and 1, with a value of 1 indicating maximum biodiversity or maximum heterogeneity (Roibu, 2010).
The density index (Id) expresses the ratio between the actual number of trees per unit area and the optimal number of trees according to the production tables (Giurgiu & Drăghiciu, 2004) in relation to the species and production class.
The density index (GI), also called the basal area index or area index (Rădulescu, 1956)*,* is calculated as the ratio between the actual basal area per hectare and that in the production tables, considered normal for a stand in conditions similar to the one analyzed. The analysis of the relationships between the dimensional variables was carried out based on modelling the linear regression equations of the form $y = a \cdot x + b$, where y is the analyzed parameter, x-the considered independent variable; a, b- the coefficients of the regression equation. The significance testing of the Pearson r-correlation coefficient was performed at a coverage probability of 95% (α=5%).

RESULTS AND DISCUSSIONS

The trees on the degraded lands (strongly to very strongly eroded and ravined in the analyzed perimeters, are mostly made up of a mixture of Scots pine and black pine (Figure 2), sometimes mixed with deciduous species, with an age between 42 and 69 years (Table 1).

Figure 2. Scots pine grove mixed with black pine, on very heavily eroded land (SEP 11, Caciu-Bârsești perimeter)

Analysis of compositional diversity indices

Information on the characteristics of the current structure of stands is provided by the *Shannon index (H).*

The H-index is an index of diversity and takes into account species richness and evenness of species distribution (E) (Shannon, 1948), so its value increases with the number of species. At the experimental plot level, calculated in relation to the frequencies of individuals and species (for the tree layer) it is between 0.32 (PS 9) and 1.03 (PS 1). These values, compared to the maximum value that can be reached in each sample area (ln(k) - where k is the abundance of species), signal a high level of compositional homogeneity, the ratio being between 29.13 and 93.75%, this aspect indicating that the differences between the relative frequencies of species in the composition of each stand are relatively small. The most diverse structures are found in mixtures of pine with deciduous trees where this index shows higher values (Table 1). *The compositional diversity (A)* at the experimental surface level is between 1.25 (PS 9) and 2.30 (CB 11). The values within this range are mainly determined by the maximum relative abundance of the main species in the stand composition.

Table 1. Indicators of structural and compositional diversity

PA	SEP	Composition after N / Composition after G	Age (years)	$N \cdot ha^{-1}$ / $G \cdot ha^{-1}$	I_d / I_G	H	A	E	D
Caciu-Bârsești (CB)	3	52Pi 38Pi.n 10Dt	49	1577	1.17	0.48	1.98	0.34	0.42
		59Pi 33 Pi.n 8Dt		42.03	1.29				
	4	42Pi 57Pi.n 1Mj	49	1753	1.31	0.68	1.90	0.49	0.50
		40Pi 60Pi.n		37.27	1.19				
	5	42Pi 55Pi.n 3 An.a	49	3127	2.22	0.80	2.09	0.58	0.48
		44Pi 53Pi.n 3An.a		60.37	1.90				
	6	29Pi 69Pi.n 2Dt	49	1933	1.37	0.70	1.71	0.50	0.56
		44Pi 55Pi.n 1Dt		33.66	1.11				
	7	84Pi 14 Pi.n 2Mj	49	1423	1.09	0.51	1.74	0.37	0.73
		90 Pi 8Pi.n 2Mj		24.42	0.71				
	9	26Pi 73Pi.n 1Sc	50	1860	1.34	0.63	1.69	0.45	0.60
		31Pi 69Pi.n		24.71	0.91				
	8	89Pi 11Pi.n	49	1854	1.37	0.35	1.54	0.25	0.80
		93Pi 7Pi.n		24.49	0.72				
	10	37Pi 53Pi.n 10Mj	50	1232	0.87	0.93	2.05	0.85	0.43
		45Pi 52Pi.n 3Mj		23.30	0.78				
	11	28Pi 72Pi.n	50	2030	1.54	0.57	2.30	0.41	0.62
		33Pi 67Pi.n		41.16	1.27				
	12	75Pi 25Pi.n	42	1682	1.27	0.56	2.27	0.41	0.63
		84Pi 16Pi.n		44.08	1.20				
	13	64Pi 28Pi.n 8An.a	42	800	0.71	0.86	1.76	0.62	0.51
		76Pi 12Pi.n 12An.a		27.69	0.76				
Pr. Sărat-Vl. Sării (PS)	1	39Pi 44Pi.n 17 Dt	67	925	0.95	1.03	2.22	0.74	0.37
		44Pi 48Pi.n 8 Dt		39.06	1.10				
	9	6Pi 92Pi.n 2Vi.t	69	1515	1.66	0.32	1.25	0.23	0.85
		8Pi 92 Pi.n		81.40	2.29				
Roșoiu-Andreiașu (RA)	4	66Pi 32Pi.n 2 Ci	63	630	0.62	0.72	1.39	0.52	0.54
		79Pi 20Pi.n 1 Ci		25.23	0.70				
	7	20 Pi 80 Pa	63	783	0.94	0.50	1.57	0.36	0.68
		34 Pi 66 Pa		33.89	1.02				
	9	8Pi 74 Pi.n 18Dt	63	678	0.68	0.74	1.51	0.53	0.58
		9Pi 85 Pi.n 6Dt		29.26	0.76				
	10	83 Pi 17 Dt	62	470	0.51	0.46	1.36	0.33	0.71
		93 Pi 7 Dt		26.78	0.66				

Symbols: PA - improvement perimeter; SEP - permanent experimental plot;.N - number of trees; G - basal area; Id - density index according to number of trees; IG - density index according to basal area; H - Shannon index; A - compositional diversity index; E - equity index (Pielou); D - Simpson index; Composition (forest species) Pi - Scots pine; Pi.n - black pine; Dt - various hardwoods; Pa - sycamore; Ci - cherry; Vi.t - Turkish sour cherry; An.a - white alder; Mj - manna ash; Sc - locust.

The relative abundance of a species represents the proportion between the number and/or biomass of individuals (specimens) of a species in relation to the other species, at a given time. Abundance can be expressed both by the number of individuals and by their biomass, in order to obtain undistorted information regarding the structure of the biocenosis (Sava, 2012).
Evenness (E) ranges between 0.23 (CB 9) and 0.85 (CB 10), indicating that most stands exhibit maximum relative abundances belonging to a single category. For example, in the case of the stand in the Caciu-Bârsești perimeter, SEP 8 (CB 8), Scots pine has maximum relative abundance, the value being close to 0 (zero). The values tend towards the unitary value when there is similarity between the relative abundances. In the case of the stand in CB 10, the similarity is reflected by the close relative abundances of the two pine species (Scots pine and black pine) in the composition.
The Simpson index (D) expresses the probability that two observations randomly drawn from the analyzed surfaces belong to the same category. It ranges between 0.37 (PS 1) and 0.85 (PS 9). Given that the stands are predominantly made up of main species (Scots pine and black pine), there is a high probability that two extracted observations belong to these species, being correlated with their abundance.

Analysis of structural diversity indices
In the case of younger stands less than 50 years old (Caciu-Bîrsești perimeter), *the Camino index (C)* has values ranging from 2.90 (CB 6) to 6.47 (CB 11), which indicates that most of the analyzed stands have an even-aged structure (Figure 4). The exception is the stand in CB 10, where the structure is relatively even aged, and the stands in CB 6 and CB 13, where the structure is relatively plurien.
The types of structure reflected by *the Gini index (G)* are similar. This indicator ranges between 0.25 (CB 5) and 0.46 (CB 6) and additionally indicates the homogeneity of the structures based on the distributions of *the Lorenz curves* (Figure 3 a, b). *The Gini index* was determined separately for each species (Table 2). This results in bimodal structures, with *the Gini index* ranging from 0.17 (CB 9) to 0.36 (CB 12) for Scots pine, and from 0.22 (CB 8) to 0.48 (CB 12) for Scots pine. The closer the *Gini index* values are to the straight line, the more homogeneous the structures are (*Gini* tends to take the value 0 in this case).

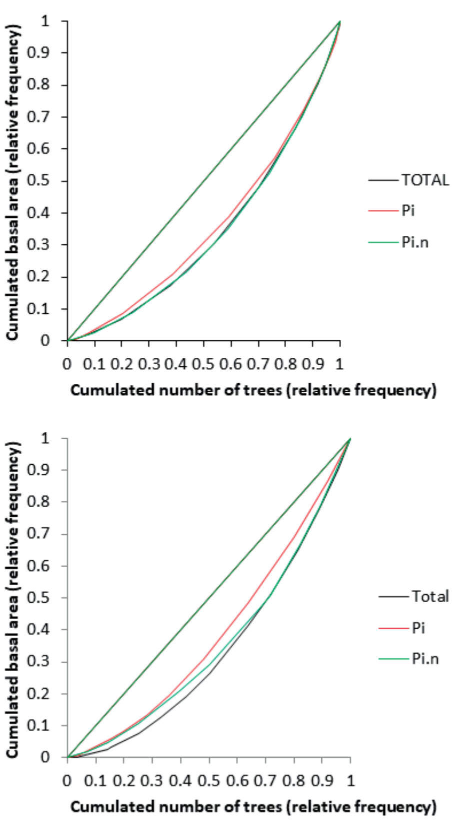

Figure 3. Lorenz curves generated by the Gini index and structural homogeneity analysis after Camino (a - CB11; b - PS1)

The density indexes (ID and IG) (Table 1) reflect the horizontal structure of the stands.
The density index according to the number of trees (Id) is between 0.71 (CB 13) and 2.22 (CB 5), being determined by the actual number of trees per hectare, as well as by the proportion of species in the composition of the stand and the production class. Values lower than 1 indicate a lower number of trees than normal. These indices correspond to a minimum real number of 800 trees per hectare (Id = 0.71), respectively a maximum real number of 3127 trees per hectare (Id = 2.22 which represents a real number of trees, 2.22 times higher than the normal number), the explanation being the dense

planting scheme but also the failure to carry out silvitechnical works.

The density index according to basal area (IG) is between 0.71 (CB 7) and 1.90 (CB 5) and expresses the quality of the stands in relation to the development of their horizontal structure. The basal area expressed per hectare is between 23.30 and 60.37 m^2 (Table 1) indicating a very high variability, especially within stands with a relatively multi-year structure, where the coefficients of variation for the diameter characteristic show high values (CV > 30%) (Figure 4).

Table 2. Structure types according to Camino and Gini indices for young stands predominantly composed of main pine species in the Caciu-Bârsești PA (CB)

SEP	3	4	5	6	7	8	9	10	11	12	13
DEG	R	R	E_3	E_3	E_3	E_3	E_3	E_3	E_3	E_3	E_3
(C)-total	4.485	4.259	6.445	2.900	4.992	5.554	4.488	4.070	6.465	4.810	3.420
(C)-Pi	4.075	4.336	6.893	2.770	5.389	5.372	7.809	3.895	6.300	6.358	4.120
(C)- Pi.n	12.260	4.259	6.422	3.343	3.209	17.823	4.102	3.131	6.919	2.440	2.460
(G)-total	0.277	0.298	0.252	0.455	0.319	0.333	0.280	0.340	0.318	0.335	0.410
(G)-Pi	0.267	0.305	0.225	0.357	0.295	0.334	0.172	0.304	0.285	0.268	0.330
(G)-Pi.n	0.261	0.288	0.267	0.430	0.369	0.223	0.307	0.362	0.322	0.484	0.450
Structure type after C	E	E	E	RP	E	E	E	RE	E	E	RP
Structure type after G	E	E	E	RP	E	E	E	RE	E	E	RP

Symbols: PA - improvement perimeter; SEP - permanent experimental area; DEG - form and intensity of degradation; R - ravine; E3 - very strong erosion; (C) - Camino index; (G) - Gini index; Pi - Scots pine; Pi.n - black pine; Structure type: E = even aged trees; RP = relatively pluriennial; RE = relatively even

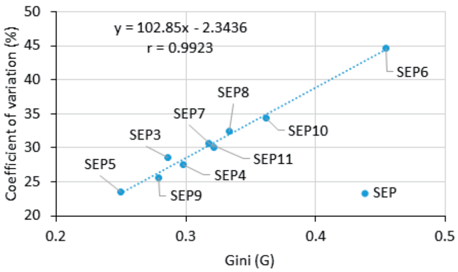

Figure 4. Pearson's r-correlation between the Gini homogeneity index and the coefficients of variation (%)

In the case of older stands (62-69 years old), the Camino index (C) per total stand has values between 2.72 (RA 4) and 4.75 (PS 9), which indicates that most of the analyzed stands present different structures (from even-aged to relatively multi-aged) determined both by the growth conditions and by the action of damaging factors (Figure 5).

The types of structure reflected by the Gini index (G) are similar. This indicator ranges between 0.23 (RA 10) and 0.37 (RA 4). The Gini index determined separately by species indicates bimodal structures, with values ranging between 0.08 (PS 9) and 0.31 (RA 9) for Scots pine, respectively between 0.27 (PS 9) and 0.44 (RA 4) for Scots pine.

The closer the Gini index values are to the straight line, the more homogeneous the structures are (the Gini index tends to take the value 0. In this case, populations formed mainly by Scots pine are more homogeneous than those made up of its competitor, the black pine (Figure 3 a, b).

The density index according to the number of trees (Id) and the density index according to the basal area (IG) reflect the horizontal structure of the stands. *The density index (Id) has ranges between 0.51 (RA 10) and 1.66 (PS 9).* In general, the density of older stands is lower, compared to young ones, the thinning being caused, in most cases, by damage caused by wind and snow at the age of 30-40 years, sometimes by drying but also by natural elimination, etc. These indices correspond to a minimum real number of 470 trees per hectare, respectively a maximum real number of 1515 trees per hectare. The higher values of *the density index* (over-unit) in older stands are the result of the use of small planting schemes (1.0-

1.5 x 1.0 m), the high participation proportion of pine trees (over 90%) but also the failure to carry out silvitechnical works.

The density index (IG) is between 0.66 (RA 10) and 2.29 (PS 9), corresponding to the basal area per hectare, between 26.78 and 81.40 m^2.

These values indicate a reduced variability of stands with even and relatively even structure, where the coefficients of variation for the diameter characteristic show values below 30% (Figure 5).

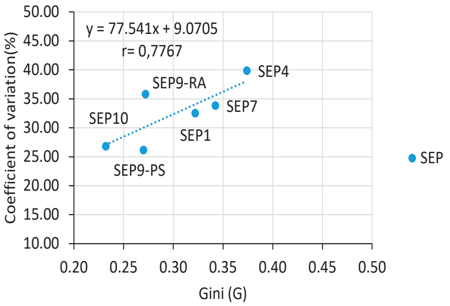

Figure 5. Pearson's r-correlation between the Gini homogeneity index and the coefficients of variation (%)

CONCLUSIONS

The structural and qualitative assessment of stands on degraded lands in the context of climate scenarios provides useful scientific information for the monitoring and sustainable management of forestry ecosystems on degraded lands.

By applying specific data processing methods, indices/parameters regarding the state and structure of stands were obtained. These parameters reflect the intensity of physiological and competitive processes at the tree and stand level (growth, natural pruning, natural elimination, regeneration and so on), having different variability in relation to the composition (component species) and age of the stands, the environmental conditions (form and intensity of degradation) but also to the damage caused by harmful abiotic factors. By the exercise of a optimal functional efficiency throughout their entire evolution period, stands installed on degraded lands require careful supervision and intervention with specific silvotechnical works in relation to their condition, stage of evolution, component species and environmental conditions in which they evolve.

From the point of view of the Shannon compositional diversity index, the analyzed stands present a high level of compositional homogeneity. This aspect derives from the relatively small differences between the relative frequencies of species in the compositions of each stand.

From the point of view of the Gini structural index (G), most of the stands, especially the youngest ones, present an even structure in terms of the distribution of the number of trees and the basal area by diameter classes. The homogeneity of stands is more pronounced especially in stands where the relative abundance of a species (especially Scots pine) is maximum. The exception is made by the older stands with a higher proportion of mixed species (deciduous), where the variability of diameters is high, even if the specimens correspond to the same age class, being determined by competitive and natural elimination processes.

The structure of stands can be easily identified if the coefficients of variation of the actual basal diameters of trees in a population and the Gini index of the respective population are known. From the Gini-coefficient of variation relationship, the correlation coefficients r was obtained, which indicate a high level of significance at a 95% coverage probability, the correlative links being direct and positive for the analyzed cases.

The density indices (Id and IG), determined by the actual number of trees and the basal area per hectare, capture the horizontal structure of the studied stands. In **younger stands**, due to the relatively high number of real trees per hectare and the active development of growth in the basal diameter of the trees, the two indicators present values above unity. In **older stands**, thinned as a result of damage caused by wind and/or snow, the same indicators present values below unity.

Considering the aforementioned conclusions, the following recommendations can be drawn:

1) *Sustainable management of forest ecosystems on degraded lands is ensured by knowing the variability of structural and compositional diversity indices of stands.*

2) *Planning silvicultural works, based on these indicators, establishes urgent measures to*

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regulate the homogeneity of stands in order to create optimal and stable structures necessary to ensure resistance to the action of damaging factors.

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