

INTERDISCIPLINARY DOCTORAL SCHOOL

Faculty of Silviculture and Forest Engineering

Ciprian TUDOR

**Structural and auxological characteristics of
pine stands established on degraded lands in the
Curvature Subcarpathians and the evaluation of
certain physical-mechanical indicators of the
wood**

SUMMARY

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LIST OF ABBREVIATIONS

FD ₃	Phytoclimatic zone of beech and sessile oak forests in the hilly region
S _s	Internal forest-steppe zone
FD ₁	Phytoclimatic zone of oak forests and mixed oak species stands in the low hills and submontane plains region
PA	Improvement perimeter
CA	Acronym for the Caciū-Bârseşti improvement perimeter
PS	Acronym for Pârâul Sărat-Valea Sării improvement perimeter
RO	Acronym for Roşoiu-Andreiaşu improvement perimeter
LI	Acronym for Livada-Râmnicu Sărat improvement perimeter
MU	Acronym for Murgeşti improvement perimeter
SEP	Permanent Experimental Plot
ICAS	Forest Research and Management Institute
O.S	Forestry District
U.P	Production Unit
u.a	Management Unit
B.E	Experimental Base
Pi, Pi.n, Pa, Fr, Mj, Sc, Ul, Ci, Vi.t, An.a, Dt, Ds	Pi- Scots pine; Pi.n- Black pine; Pa- sycamore; Fr- common ash; Mj- manna ash; Sc- black locust; Ul-field elm; Ci-bird cherry; Vi.t- Mahaleb cherry; An.a- white alder; Dt-Variou hardwoods; Ds-Variou conifers
CA3, CA4, CA5, CA6, CA7, CA8, CA9, CA10, CA11, CA12, CA13	Permanent Experimental Plots within the Caciū-Bârseşti Improvement Perimeter
PS1, PS2, PS3, PS4, PS6, PS7, PS8, PS9, PS10, PS11	Permanent Experimental Plots within the Pârâul Sărat-Valea Sării Improvement Perimeter
RO4, RO7, RO9, RO10	Permanent Experimental Plots within the Roşoiu-Andreiaşu Improvement Perimeter
LI6, LI9, LI10, LI12	Permanent Experimental Plots within the Livada-Râmnicu Sărat Improvement Perimeter
MU12, MU17, MU18	Permanent Experimental Plots within the Murgeşti Improvement Perimeter
TSD	Site Types Characteristic of Degraded Lands
I.C.1.a	Eroded soils in the lowland and silvosteppe regions characterized by moderate to severe

	erosion, occurring on soils with light to medium texture
I.D.1.a	Eroded lands in the hilly region exhibiting moderate to severe erosion, on eroded soils with light to medium texture.
I.D.1.b	Eroded lands in the hilly region exhibiting moderate to severe erosion, on eroded soils with heavy texture.
III.D.1.b	Gullies and slopes in the hilly region with molassic substrate composed of unconsolidated or poorly consolidated sedimentary rocks, on regosol or erodisol soils with heavy texture.
I.D.2.a	Eroded lands in the hilly region with very severe erosion, on erodisol soils with light to medium texture.
I.D.2.b	Eroded lands in the hilly region with very severe erosion, on erodisol soils with heavy texture.
V.D.1.b	Unstable lands in the hilly region with disturbed, heavily fragmented, and crusted soils.
E ₁	Moderate erosion
E ₂	Severe erosion
E ₃	Very severe erosion
R	Gully erosion
Al	Landslide
d _{1,30m}	Diameter at breast height (DBH)
h	Total height
H	Camino Index
G	Gini Index
DEF%	Average defoliation percentage
IPCC	Intergovernmental Panel on Climate Change
MMAP	Ministry of Environment, Waters and Forests
G _u	Average moisture content
G _v	Degree of damage
R _i	Drying class
N _s	Number of healthy trees
N _{sb}	Number of slightly defoliated trees
N _m	Number of moderately defoliated trees
N _p	Number of heavily defoliated trees
N _u	Number of dead trees
N _t	Total number of trees sampled from the first three Kraft positional classes
V1, V2, V3, V4	Wind damages
Z1, Z2, Z3, Z4	Snow damages

dg	Quadratic mean diameter
hg	Height corresponding to the quadratic mean diameter
N	Number of trees
G	Basal area
V	Unit volume
I_N	Density index
I_G	Stocking index
Cl.P	Production class
Cl.V	Age class
Beta	Theoretical Beta function
Gamma	Theoretical Gamma function
χ^2	Chi-square goodness-of-fit test
K-S	Kolmogorov–Smirnov statistical test
Anova	Analysis of Variance
Wilcoxon	Rank analysis
r	Correlation coefficient
R^2	Coefficient of determination
sd	Standard deviation
df	Degrees of freedom
t	Student's t-test
F	Fisher test (Analysis of Variance)
ir	Radial growth
iv	Annual volume growth for the diameter class considered
i_{r10}	Radial growth over the last 10 years
i_{d10}	Growth in diameter over the last 10 years
i_{g10}	Growth in basal area over the last 10 years
i_{v10}	Volume growth over the last 10 years
piv	Percentage of current growth in volume
pig	Percentage of growth in basal area
pihf	Percentage of reduced average height growth
λ	Annual percentage of reduced height growth obtained from production tables, depending on the current age of the stands, production class and species considered
CWB	The climatic Water Balance
PET	Potential evapotranspiration
SPEI	Standardized Precipitation-Evapotranspiration Index
BAI	Basal area increment
TRW	Tree-Ring Width
Rt	Resistance

Rc	Recovery
Rs	Resilience
RWI	Ring Width Index
WD	Wood density
$\overline{WD}$	Average wood density
AGB	Aboveground biomass
$\overline{AGB}$	Average aboveground biomass
C	Carbon stock
$\bar{C}$	Average carbon stock
IML	Instrumenta Mechanik Labor
R	Micro-drilling resistance
$\bar{R}$	Average Micro-drilling resistance
v	Sound velocity
$\bar{v}$	Average sound velocity

FORWARD

In the context of intensifying land degradation processes, caused by both natural and anthropogenic factors, the need for effective ecological restoration interventions is becoming increasingly urgent. In Romania, as in many other regions of the world, historical deforestation, overgrazing, and improper land use have led to the emergence of extensive areas of unstable land, prone to erosion, landslides, and other forms of degradation. These processes affect not only the productive capacity of the land but also the ecological balance of the entire region. Afforestation of degraded lands has emerged, over the past century, as one of the most effective methods to combat these phenomena. In particular, the use of pine species has provided viable solutions for the stabilization and improvement of affected lands. The success of these actions has been demonstrated through extensive experience accumulated in Romania, especially in the post-war period, within large-scale reforestation and ecological reconstruction projects. The doctoral thesis, "Structural and auxological characteristics of pine stands established on degraded lands in the Curvature Subcarpathians and the evaluation of certain physical-mechanical indicators of the wood," aims to investigate, through a rigorous scientific approach, the efficiency of pine species in the process of restoring forest vegetation on degraded lands. The study focuses on analyzing the structure and auxology (growth dynamics) of pine trees and stands, their climatic resilience under stress conditions, and the creation of research premises based on the evaluation of qualitative physical-mechanical indicators. The thesis also aims to contribute to improving current forest management models in vulnerable areas, offering practical insights for environmental policies and for the promotion and development of sustainable forestry. The accomplishment of these objectives would not have been possible without the unconditional support and competent guidance of my scientific advisor, Senior Researcher I Dr. Eng. Nicolae Ovidiu Badea, corresponding member of the Romanian Academy. I hereby express my deepest gratitude for his continuous support, generosity, patience, and professionalism demonstrated throughout the entire period of elaborating this doctoral thesis, as well as for his fundamental contribution to my professional development in the field of forest amelioration science. I would also like to express my special thanks to Professor Dr. Eng. Lucian Curtu, Dean of the Faculty of Silviculture and Forest Engineering in Braşov, for the rigor and excellence with which the doctoral programme has been coordinated within the faculty, and for his acceptance to serve as Chair of the Public Defense Committee for this thesis. My sincere thanks also go to Senior Researcher I Dr. Ionel Popa, Professor Dr. Cătălin Roibu, and Professor Dr. Florin Hălălişan for accepting the invitation to serve as members of the Committee for the analysis and public defense of this doctoral thesis. I extend my heartfelt appreciation to Professor Dr. Gheorghe Marian Tudoran, Professor Dr. Florin Dinulică, and Senior Researcher I Dr. Şerban Octavian Davidescu for their unwavering support during the doctoral training, for their guidance in preparing research reports, and for their valuable insights offered during the preliminary and final pre-defense sessions of the thesis. I also express my sincere gratitude to my colleagues from the "Marin Drăcea" National Institute for Research and Development in Forestry (INCDS), especially to Senior Researcher II Dr. Eng. Cristinel Constandache, Senior Researcher I Dr. Eng. Radu Vlad, Researcher III Eng. Laurenţiu Popovici, Researcher III Dr. Eng. Andrei Popa, and Researcher III Eng. Gheorghe Ştefan, for their support throughout various stages of the research process.

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1. INTRODUCTION

The prevention and mitigation of land degradation represent major concerns at both European and global levels. In Romania, at the end of the 19th century and the beginning of the 20th century, deforestation and excessive grazing led to the emergence of extensive areas of degraded land, affected by erosion and landslides, particularly in steep slope areas (Silvestru-Grigore et al., 2016). Due to their low ecological requirements regarding soil and climatic conditions, pine species have been successfully used for the afforestation of degraded lands, acting as pioneer species and contributing to slope stabilization (Șofletea & Curtu, 2007). Pine not only contributes to soil improvement but also enhances biodiversity by facilitating the establishment of other forest species (Constandache, 2019). In Romania, approximately 300,000 hectares of degraded land were afforested with Scots pine, black pine, and black locust by the year 2008, with the majority of these works carried out between 1948 and 1965, covering around 75,000 hectares (Traci & Costin, 1966). It has been observed that mixed stands of pine and broadleaf species are more effective than pure pine cultures, particularly in the internal forest-steppe zone (Constandache, 2003).

Since 1913, the Subcarpathian area of Vrancea has been affected by major land degradation phenomena caused by erosion, leading to changes in both the relief and microclimate (Constandache et al., 2010). The monitoring of degraded lands and afforestation efforts have played an important role in reintegrating these lands into the forest management system and in enhancing ecosystem services at the national level (Constandache et al., 2006). Pine forest plantations contribute to the protection of socio-cultural assets by mitigating the effects of torrential rainfall, preventing and controlling erosion, and positively influencing the local microclimate (Silvestru-Grigore et al., 2016).

The evaluation of stand structure requires the analysis of individual trees in terms of size, age, growth, and site conditions (Kaźmierczak & Zawieja, 2016). Current research utilizes mathematical models based on aerial imagery captured by drones to estimate biometric parameters (Tudoran et al., 2021). Due to the complexity of interactions among trees, structural dynamics are effectively modeled through competition and reciprocal influence relationships between neighboring trees (Muth & Bazzaz, 2003). In stands established on degraded lands, structural evolution is negatively affected by harmful abiotic factors, which promote the destabilization of the dynamic balance within forest ecosystems (Vlad & Constandache, 2014).

The health status of forest ecosystems is determined by the site's potential to support the ecological requirements of the established species (Giurgiu, 1979). The eco-protective functions of pine stands established on degraded lands depend on their structure and vitality (Vacek et al., 2023). In the current context, the intensification of natural disturbances generates structural imbalances, leading to significant losses at the stem and crown levels of the trees (Viljur et al., 2022).

The intensified climate warming in recent years has indirectly contributed to increased mortality in affected pine stands (Rebetez & Dobbertain, 2004). Severe abiotic factors—such as drought, wind, and snow—negatively impact pine plantations established outside their natural range, reducing growth capacity and necessitating ecological reconstruction measures (Constandache et al., 2017). Monitoring of radial growth reveals significant declines correlated with the severity of damage, highlighting the need for complex silvicultural interventions to maintain the stability and functionality of forest ecosystems (Badea & Tănase, 2004). Climate change, characterized by decreased precipitation and

increased frequency of droughts, adversely affects growth dynamics and stand stability (Carnicer et al., 2011), particularly in lowland and arid sites (Sumner et al., 2003). The influence of edaphic-climatic factors on annual ring width reflects year-to-year variations in growth and biomass accumulation. Dendroclimatic models predict significant productivity losses for spruce, while pine growth is less affected by stress factors such as precipitation and temperature (Vacek et al., 2021). Pine species show variable responses to climate change, particularly in arid regions, where prolonged droughts reduce growth rates and productivity, with emerging trends of altitudinal and latitudinal migration (Martín-Benito et al., 2010). In the forest-steppe zone of Eastern Europe, pine plantations provide a relevant framework for investigating radial growth in relation to climate variability, anthropogenic impact, and the ecological and phytocoenotic conditions of the stands (Matveev, 2003).

Increased climate variability and the growing frequency of extreme events inducing drought are affecting the resilience of forest ecosystems (IPCC, 2007), leading to reduced growth and potential structural changes (Folke et al., 2004). Dendrochronological analyses provide a valuable tool for assessing tree resilience by interpreting annual rings as responses to climatic stress (Lloret et al., 2011). The response of black pine to climate change has shown its growth sensitivity to extreme climatic events (Loustau et al., 2005), particularly to reduced water availability during the growing season, with productivity being limited under such conditions (Móricz et al., 2018).

Understanding wood quality is important from several essential perspectives—scientific, economic, and ecological (Beldeanu, 2008). Wood density has played a fundamental role in the development of biomass and carbon estimation equations (Wiemann & Williamson, 2013), in functional ecology studies, as well as in the genetic selection of forest reproductive material (Sprague et al., 1983). Modern technologies applied to wood quality control have enabled the early detection of internal defects and the estimation of intrinsic properties (such as stiffness and strength) of standing trees (Bucur, 2023). The evolution of these technologies over time has contributed to a better understanding of wood quality at its internal structural level, offering new research opportunities for the sustainable management of forest ecosystems with a focus on wood quality (Wang et al., 2007).

2. AIMS AND OBJECTIVES OF THE RESEARCH

2.1. Aims of the research

The purpose of the research carried out during the elaboration of the doctoral thesis entitled “Structural and Auxological Characteristics of Pine Stands Established on Degraded Lands in the Curvature Subcarpathians and Evaluation of Certain Physical-Mechanical Indicators of the Wood,” is ***to ensure sustainable management of pine stands located on degraded lands in the Curvature Subcarpathians, based on the analysis of the radial growth potential, the evaluation of the health status of the stands as well as some qualitative physical-mechanical indicators of wood.***

2.2. Objectives of the research

To achieve the purpose of the research conducted, the following general scientific objectives were established:

OG1. Analysis of the structure of the pine stands;

OG2. Diagnosing the health status of pine stands;

OG3. Dynamics of growth processes in pine stands on degraded lands;

OG4. Resilience of pine stands at climate change;

OG5. Quantification of indicators of a physical-mechanical nature of pine wood.

3. METHODOLOGY AND RESEARCH MATERIAL

3.1 Research Location

The research was conducted in pine forests established on degraded lands located in the central-eastern area of the Curvature Subcarpathians, encompassing the Subcarpathians of Vrancea and Buzău (Figure 3.1), regions widely affected by land degradation processes.

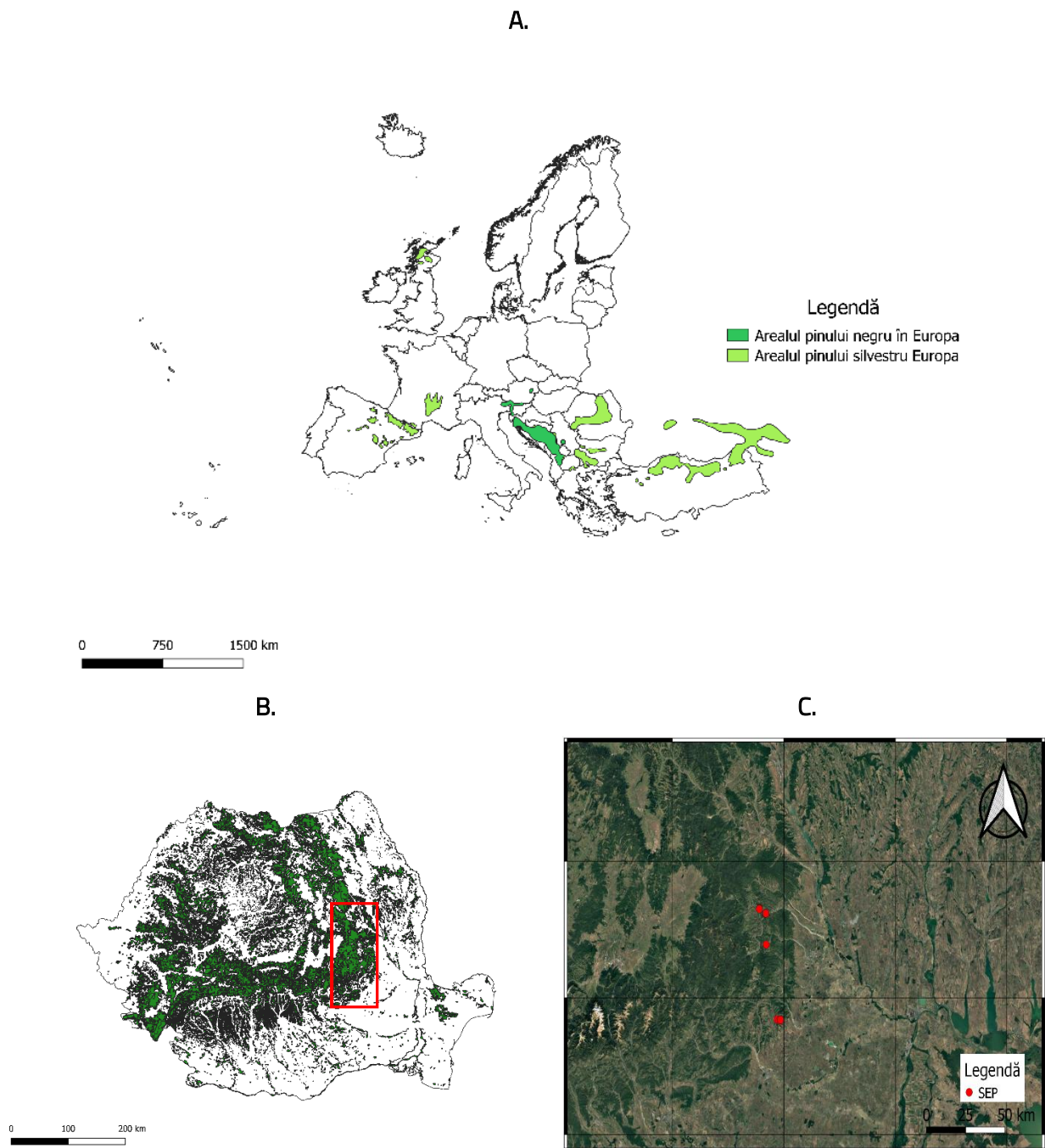


Figure 3.1 Research location: A. Natural distribution range of Scots pine and black pine species in Europe (Euforgen, 2008); B. Forest cover in Romania (the study area highlighted in red); C. Permanent experimental plots where the research was conducted.

In the Subcarpathians of Vrancea, within the phytoclimatic zone of beech and sessile oak forests in the hilly region (FD₃), the research was carried out in three improvement perimeters (PA): Caci-Bârsești (CA) (45°55'19.69"N, 26°44'44.74"E), Pârâul Sărat-Valea Sării (PS) (45°52'35.57"N, 26°47'51.97"E) and Roșoiu-Andreiașu (RO) (45°44'56.24"N, 26°49'55.96"E).

In the Subcarpathians of Buzău, within the internal forest steppe zone (S₅) and in the phytoclimatic zone of hill oak forests (FD₁), the research was carried out in two improvement perimeters (PA): Livada-Râmnicu Sărat (LI) (45°23'55.78"N, 26°55'29.49"E) and Murgești (MU) (45°23'39.43"N, 26°53'30.86"E).

The Caci – Bârsești (CA) Improvement Perimeter includes severely to excessively eroded lands, developed on complex substrates of marl and sandstone, where past experiments involved pine plantations in mixture with shrub species, aimed at stabilizing degraded terrains. (Figure 3.2).

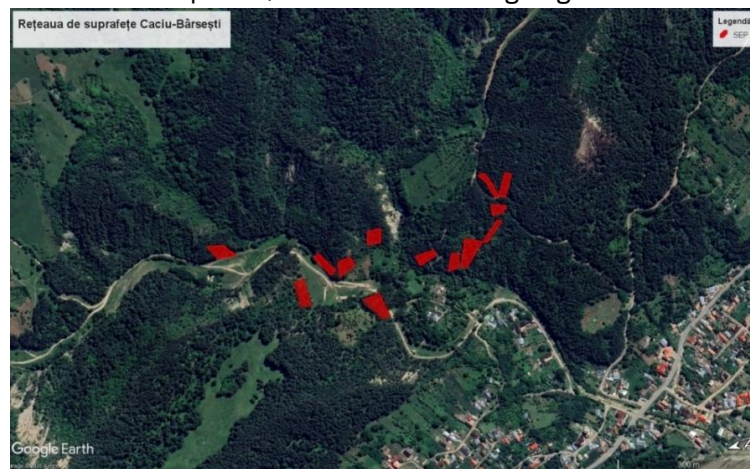


Figure 3.2 Network of Permanent Experimental Plots from PA Caci-Bârsești

The Pârâul Sărat-Valea Sării (PS) Improvement Perimeter includes very severely eroded lands, developed on complex substrates of clayey marl with cross-bedded sandstone, marly schist and clay shales, where past experiments involved pure pine plantations or mixtures with broadleaved species (Figure 3.3).

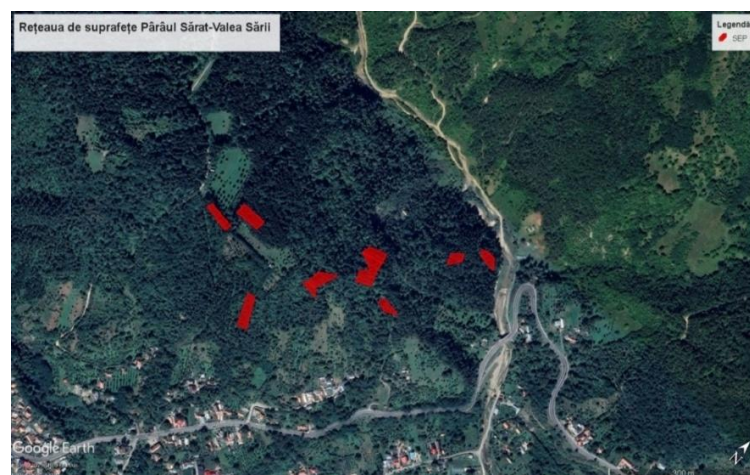


Figure 3.3 Network of Permanent Experimental Plots from PA Pârâul-Sărat-Valea Sării.

The Roșoiu-Andreiașu (RO) Improvement Perimeter includes severely to excessively eroded lands, developed on substrates consisting of marl, sandstone, and gypsum complexes, where past experiments involved ombrophilous species (silver fir, beech). (Figure 3.4).



Figure 3.4 Network of Permanent Experimental Plots from PA Roșoiu-Andreiașu.

The Livada-Râmnicu Sărat (LI) Improvement Perimeter (the internal forest steppe zone -S_s) includes moderately eroded, gullied, and landslide-prone terrains developed on substrates of loess and sands alternating with clay layers, where pure pine plantations or mixtures with broadleaved species were previously tested. (Figure 3.5).



Figure 3.5 Network of Permanent Experimental Plots from PA Livada-Râmnicu Sărat.

The Murgești (MU) Improvement Perimeter (the phytoclimatic zone of hill oak forests FD₁) includes landslide-prone terrains, developed on substrates of sands, gravels, marl, and levantine-aged clays. In the past, pure pine plantations or mixtures with broadleaved species were tested on these sites (Figure 3.6).



Figure 3.6 Network of Permanent Experimental Plots from PA Murgești.

Climatic data

The climatic database, consisting of monthly time series of temperature (mean, minimum, and maximum) and precipitation, was downloaded from the Climate Explorer online platform for the period 1901–2020, at a geospatial resolution of 5×5 km (<https://climexp.knmi.nl/>).

Subsequently, the climatic dataset was processed into Walter and Lieth-type climatograms (Figures 3.7 and 3.8). Monthly climatic series were analyzed for the period 1960–2020.

Through interpolation, the climatic series from the internal forest-steppe zone (S_s) and from the FD_1 phytoclimatic zone were found to be similar and were therefore combined into a single climatogram (Figure 3.8).

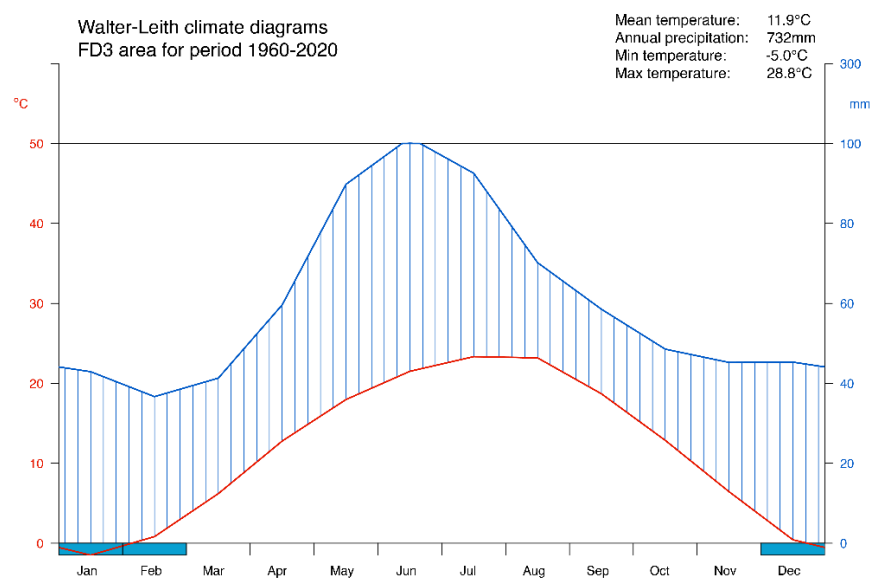


Figure 3.7 Climatogram corresponding to the FD_3 phytoclimatic zone (after Walter & Lieth, 1967).

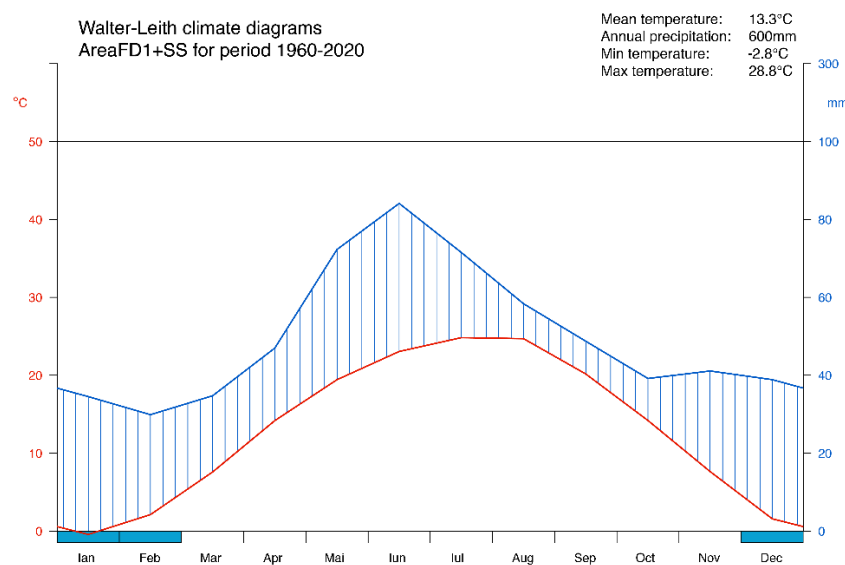


Figure 3.8 Climatogram corresponding to the forest steppe zone and FD_1 phytoclimatic zone (after Walter & Lieth, 1967).

3.2 Research Material

Network of Experimental Plots

The research was carried out within a network of permanent experimental plots (SEP), continuously monitored since 1950, comprising representative stands of Scots pine (*Pinus sylvestris* L.) and black pine (*Pinus nigra* Arn. ssp. *nigra*). During the research, a complete re-inventory was conducted for 32 permanent experimental plots (SEP), which varied in shape and size (Table 3.1), with a total inventoried area of 3.00 hectares.

Table 3.1 Network of permanent experimental plots

Improvement perimeter	Research plot code Surface area (m ²)	Forest allocation criteria O.S/B.E, U.P, u.a	** Current stand composition (by N)	Stand age (in the year 2025)	GPS Coordinates (WGS84)		
					Latitude	Longitude	Altitude
Caciu-Bârsești	<u>CA3</u> 415,00	Vidra, III Valea Sării, 151B	52Pi38Pi.n10Dt	51	45°54'26.76"N	26°45'21.57"E	470
Caciu-Bârsești	<u>CA4</u> 577,00	Vidra, III Valea Sării, 151B	42Pi57Pi.n1Mj	51	45°54'25.52"N	26°45'23.93"E	470
Caciu-Bârsești	<u>CA5</u> 422,00	Vidra, III Valea Sării, 151B	42Pi55Pi.n3An.a	51	45°54'26.43"N	26°45'22.08"E	470
Caciu-Bârsești	<u>CA6</u> 578,00	Vidra, III Valea Sării, 151B	29Pi69Pi.n2Dt	51	45°54'29.83"N	26°45'18.27"E	427
Caciu-Bârsești	<u>CA7</u> 2517,00	Vidra, III Valea Sării, 151B	84Pi14Pi.n2Mj	51	45°54'30.91"N	26°45'19.00"E	406
Caciu-Bârsești	<u>CA8</u> 712,00	Vidra, III Valea Sării, 153	89Pi11Pi.n	51	45°54'34.75"N	26°45'22.35"E	424
Caciu-Bârsești	<u>CA9</u> 757,00	Vidra, III Valea Sării, 153	26Pi73Pi.n1Sc	50	45°54'37.14"N	26°45'20.39"E	411
Caciu-Bârsești	<u>CA10</u> 650,00	Vidra, III Valea Sării, 153	37Pi53Pi.n10Mj	50	45°54'38.28"N	26°45'21.72"E	412
Caciu-Bârsești	<u>CA11</u> 846,00	Vidra, III Valea Sării, 153	28Pi72Pi.n	50	45°54'44.03"N	26°45'24.77"E	426
Caciu-Bârsești	<u>CA12 *</u> 1387,00	Vidra, III Valea	75Pi25Pi.n	50	45°54'34.82"N	26°45'14.26"E	428

Improvement perimeter	Research plot code Surface area (m ²)	Forest allocation criteria O.S/B.E, U.P, u.a	** Current stand composition (by N)	Stand age (in the year 2025)	GPS Coordinates (WGS84)		
					Latitude	Longitude	Altitude
		Sării, 135D					
Caciu-Bârsești	CA13 * 1139,00	Vidra, III Valea Sării, 134B	64Pi28Pi.n7An.a 1Dt	50	45°54'39.55"N	26°45'17.19"E	458
Pârâul Sărat-VI.Sării	PS1 693,00	Vidra, III Valea Sării, 102A	39Pi44Pi.n17Dt	68	45°53'22.82"N	26°48'36.89"E	306
Pârâul Sărat-VI.Sării	PS2 584,00	Vidra, III Valea Sării, 102A	88Pi12Dt	66	45°53'21.02"N	26°48'34.65"E	311
Pârâul Sărat-VI.Sării	PS3 523,00	Vidra, III Valea Sării, 102A	86Pi14Dt	64	45°53'15.48"N	26°48'33.50"E	367
Pârâul Sărat-VI.Sării	PS4 719,00	Vidra, III Valea Sării, 101A	24Pi58Ci18Dt	64	45°53'17.21"N	26°48'29.02"E	384
Pârâul Sărat-VI.Sării	PS6 943,00	Vidra, III Valea Sării, 102A	53Ci27Pi4Pi.n16Dt	65	45°53'15.63"N	26°48'29.70"E	384
Pârâul Sărat-VI.Sării	PS7 870,00	Vidra, III Valea Sării, 102A	53Pi31Ci14Pi.n2Dt	64	45°53'13.09"N	26°48'26.04"E	429
Pârâul Sărat-VI.Sării	PS8 307,00	Vidra, III Valea Sării, 102A	89Pi7Pi.n4Ci	64	45°53'12.63"N	26°48'26.69"E	429
Pârâul Sărat-VI.Sării	PS9 1116,00	Vidra, III Valea Sării, 101A	6Pi92Pi.n2Vi.t	70	45°53'13.15"N	26°48'18.49"E	431
Pârâul Sărat-VI.Sării	PS10 749,00	Vidra, III Valea Sării, 102B	100Pi.n	70	45°53'12.09"N	26°48'16.49"E	414
Pârâul Sărat-VI.Sării	PS11 1220,00	Vidra, III Valea Sării, 102B	77Pi13Mj9Pi.n	55	45°53'7.90"N	26°48'23.90"E	414

Improvement perimeter	Research plot code Surface area (m ²)	Forest allocation criteria O.S/B.E, U.P, u.a	** Current stand composition (by N)	Stand age (in the year 2025)	GPS Coordinates (WGS84)		
					Latitude	Longitude	Altitude
Roșoiu-Andreiașu	<u>R04</u> 719,00	Focșani, IV Stoichița, 87A	66Pi32Pi.n 2Ci	64	45°44'46.14"N	26°48'49.32"E	445
Roșoiu-Andreiașu	<u>R07</u> 716,00	Focșani, IV Stoichița, 87A	20Pi80Pa	64	45°44'50.19"N	26°48'40.53"E	464
Roșoiu-Andreiașu	<u>R09</u> 1116,00	Focșani, IV Stoichița, 86A	8Pi74Pi.n18Dt	64	45°44'39.89"N	26°48'38.86"E	499
Roșoiu-Andreiașu	<u>R010</u> 749,00	Focșani, IV Stoichița, 86A	83Pi17Dt	63	45°44'39.84"N	26°48'38.49"E	499
Livada-Rm.Sărat	<u>LI6</u> 1530,00	Râmnicu-Sărat, II Dedulești, 20	60Pi20UI10Dt10Dr	77	45°23'52.35"N	26°55'29.87"E	514
Livada-Rm.Sărat	<u>LI9</u> 740,00	Râmnicu-Sărat, II Dedulești, 20	80Pi.n10Mj10Dt	74	45°23'48.11"N	26°55'30.64"E	516
Livada-Rm.Sărat	<u>LI10</u> 2270,00	Râmnicu-Sărat, II Dedulești, 20	52Pi48Dt	69	45°23'48.96"N	26°55'29.42"E	527
Livada-Rm.Sărat	<u>LI12</u> 2460,00	Râmnicu-Sărat, II Dedulești, 20	95Pi.n5Dt	75	45°23'54.52"N	26°55'36.43"E	478
Murgești	<u>MU12</u> 1000,00	Râmnicu-Sărat, I Câlnău, 79A	48Pi39Mj12Fr	56	45°24'0.42"N	26°53'59.51"E	366
Murgești	<u>MU17</u> 550,00	Râmnicu-Sărat, I Câlnău, 81H	100Pi.n	56	45°23'45.72"N	26°54'56.98"E	484
Murgești	<u>MU18</u> 560,00	Râmnicu-Sărat, I Câlnău, 81G	100Pi	58	45°23'43.54"N	26°54'49.34"E	465

Improvement perimeter	Research plot code	Forest allocation criteria	** Current stand composition (by N)	Stand age (in the year 2025)	GPS Coordinates (WGS84)		
	Surface area (m ²)	O.S/B.E, U.P, u.a			Latitude	Longitude	Altitude

Note: *) new experimental plots, installed in year 2019; O.S- Forestry district; B.E- Experimental Base; U.P- production unit; u.a- management unit; N- number of trees;

****) Forestry species symbols:** Pa- sycamore; Fr- common ash; Mj- manna ash; Sc- black locust; Ul- field elm; Ci- bird cherry; Vi.t- Mahaleb cherry; An.a- white alder; Pi- Scots pine; Pi.n-Black pine; Dt-various hardwoods; Dr-various conifers.

Meaning of symbols:

- CA3, CA4, CA5, CA6, CA7, CA8, CA9, CA10, CA11, CA12, CA13- permanent experimental plots, where "CA"-acronym for Caci-Bârsești Improvement Perimeter, and 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13- represents the identification number of the permanent experimental plot;
- PS1, PS2, PS3, PS4, PS6, PS7, PS8, PS9, PS10, PS11- permanent experimental plots, where "PS"- acronym for Pârâul Sărat-Valea Sării Improvement Perimeter, and 1, 2, 3, 4, 6, 7, 8, 9, 10, 11- represents the identification number of the permanent experimental plot;
- RO4, RO7, RO9, RO10- permanent experimental plots, where "RO"- acronym for Roșoiu-Andreiașu Improvement Perimeter, and 4, 7, 9, 10- represents the identification number of the permanent experimental plot;
- LI6, LI9, LI10, LI12- permanent experimental plots, where "LI"- acronym for Livada-Râmnicu Sărat Improvement Perimeter, and 6, 9, 10, 12- represents the identification number of the permanent experimental plot;
- MU12, MU17, MU18- permanent experimental plots, where "MU"- acronym for Murgești Improvement Perimeter, and 12, 17, 18- represents the identification number of the permanent experimental plot.

The selection of irregular shapes and variable sizes for the experimental plots was based on the specific characteristics of the degraded lands. The boundary of each plot precisely delineates the type and intensity of degradation, while the site mapping, defined by unique stationary units in time and space, accurately reflects the *in situ* site conditions.

The historical database regarding the establishment of the permanent experimental plot network was obtained from the archive of the Forest Research and Management Institute (ICAS), covering the period 1985–2020 (Table 3.2).

Table 3.2 Site mapping of the studied experimental plots

Improve-ment perimeter	Exp. plot	Altitude (m)	Slope (°)	Slope exposure	Degradation nature	Degradation intensity	Degraded land category	Phyto-climatic zone.	TSD	Installation year
Caci-Bârsești	CA3	470	35	NV	Pluvial erosion in depth	R	Gullies and slopes	FD ₃	III.D.1.b	1977
Caci-Bârsești	CA4	470	35	NV	Pluvial erosion in depth	R	Gullies and slopes	FD ₃	III.D.1.b	1977
Caci-Bârsești	CA5	470	25	NV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1977
Caci-Bârsești	CA6	427	35	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1977
Caci-Bârsești	CA7	406	40	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1977
Caci-Bârsești	CA8	424	40	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1977
Caci-Bârsești	CA9	411	40	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.a	1978

Improve- ment perimeter	Exp. plot	Alti- tude. (m)	Slope (°)	Slope expo- sure	Degradation nature	Degra- dation inten- sity	Degraded land category	Phyto- climatic zone.	TSD	Installa- tion year
Caciu- Bârsești	CA10	412	35	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1978
Caciu- Bârsești	CA11	426	25	SV	Pluvial erosion in surface	E ₃	Teren erodat	FD ₃	I.D.2.a	1978
Caciu- Bârsești	CA12*	428	15	SE	Pluvial erosion in surface	E ₁	Eroded land	FD ₃	I.D.2.a	1978
Caciu- Bârsești	CA13*	458	25	SE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.a	1978
Pârâul Sărat- VI.Sării	PS1	306	30	NE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1960
Pârâul Sărat- VI.Sării	PS2	311	25	NE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1962
Pârâul Sărat- VI.Sării	PS3	367	20	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.a	1964
Pârâul Sărat- VI.Sării	PS4	384	25	NE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.a	1964
Pârâul Sărat- VI.Sării	PS5	384	30	NE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.a	1964
Pârâul Sărat- VI.Sării	PS7	429	25	NE	Pluvial erosion in surface	E ₁	Eroded land	FD ₃	I.D.2.b	1964
Pârâul Sărat- VI.Sării	PS8	431	30	S	Pluvial erosion in surface	E ₁	Eroded land	FD ₃	I.D.1.a	1964
Pârâul Sărat- VI.Sării	PS9	414	15	NE	Pluvial erosion in surface	E ₁	Eroded land	FD ₃	I.D.1.b	1958
Pârâul Sărat- VI.Sării	PS10	414	5	NV	Pluvial erosion in surface	E ₁	Eroded land	FD ₃	I.D.1.b	1958
Pârâul Sărat- VI.Sării	PS11	412	35	SV	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.a	1973
Roșoiu- Andreiașu	RO4	464	25	SV	Pluvial erosion in surface	E ₂	Eroded land	FD ₃	I.D.1.a	1964
Roșoiu- Andreiașu	RO7	499	10	SV	Pluvial erosion in surface	E ₂	Eroded land	FD ₃	I.D.1.a	1964
Roșoiu- Andreiașu	RO9	499	25	SE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.D.2.b	1964
Roșoiu- Andreiașu	RO10	514	25	SE	Pluvial erosion in surface	E ₃	Eroded land	FD ₃	I.M1.2.b	1965

Improve- ment perimeter	Exp. plot	Alti- tude. (m)	Slope (°)	Slope expo- sure	Degradation nature	Degra- dation inten- sity	Degraded land category	Phyto- climatic zone.	TSD	Installa- tion year
Livada- Rm.Sărat	LI6	516	15	E-NE	Pluvial erosion in surface	E ₂	Eroded land	S _s	I.C.1.a	1951
Livada- Rm.Sărat	LI9	527	5	E-NE	Pluvial erosion in surface	E ₁	Eroded land	S _s	I.C.1.a	1954
Livada- Rm.Sărat	LI10	478	5	E-NE	Pluvial erosion in surface	E ₁	Eroded land	S _s	I.C.1.a	1959
Livada- Rm.Sărat	LI12	366	10	E-NE	Pluvial erosion in surface	E ₁	Eroded land	S _s	I.C.1.a	1953
Murgești	MU12	484	20	SE	Pluvial erosion in depth	AI	Unstable terrain	FD ₁	V.D.1.b	1972
Murgești	MU17	465	10	V	Pluvial erosion in depth	AI	Unstable terrain	FD ₁	V.D.1.b	1972
Murgești	MU18	470	15	NV	Pluvial erosion in depth	AI	Unstable terrain	FD ₁	V.D.1.b	1970

Note: *) new experimental plots, installed in year 2020.

Meaning of symbols: E₁- moderate erosion; E₂- severe erosion; E₃- very severe erosion; R- gully erosion; AI- highly fragmented landslide (after Ciortuz & Păcurar, 2004); TSD- Site Types Characteristic of Degraded Lands (classification after Ciortuz & Păcurar, 2004); I.C.1.a- eroded soils in the lowland and silvosteppe regions characterized by moderate to severe erosion, occurring on soils with light to medium texture; I.D.1.a- eroded lands in the hilly region exhibiting moderate to severe erosion, on eroded soils with light to medium texture; I.D.1.b- eroded lands in the hilly region exhibiting moderate to severe erosion, on eroded soils with heavy texture; III.D.1.b- gullies and slopes in the hilly region with molassic substrate composed of unconsolidated or poorly consolidated sedimentary rocks, on regosol or erodisol soils with heavy texture; I.D.2.a- eroded lands in the hilly region with very severe erosion, on erodisol soils with light to medium texture; I.D.2.b- eroded lands in the hilly region with very severe erosion, on erodisol soils with heavy texture; V.D.1.b- unstable lands in the hilly region with disturbed, heavily fragmented, and crusted soils.

During the re-inventory, standard procedures for marking the boundaries of the experimental plots and trees within them were observed and applied. Field data collection was carried out at the tree level, recording dendrometric and qualitative characteristics: species, tree number, diameter at breast height ($d_{1.30m}$ -DBH), height (h), KRAFT positional classes, defoliation (%), and types of damages encountered on the stem and crown. *At the office, the modelling* of the pine stands' structure was performed based on the field measurements. The main structural indicators reflecting the horizontal and vertical organisation and functioning of the stands were established during the research.

The health status of pine stands on degraded lands was assessed in relation to the degree of crown defoliation and damage caused by abiotic harmful factors (Table 3.3). Based on damage intensity, trees were evaluated using the classification scale developed through fundamental research in biometrics and forest monitoring (Badea, 2008).

Table 3.3 Tree damage intensity according to defoliation percentage

Defoliation class	Tree vigor
0	Healthy tree, with no defoliation or less than 10% foliage loss
1	Tree with slight defoliation, with foliage loss between 11–25%
2	Tree with moderate defoliation, with foliage loss between 26–60%
3	Tree with severe defoliation, with foliage loss over 61%
4	Dead tree

For determining radial growth at the tree level, growth cores were collected from Scots pine and black pine trees within each diameter class. A sufficient number of trees was selected according to their frequency within each class. Growth cores were extracted using a Pressler increment borer in the radial direction at breast height (1.30 m).

Dendroclimatic Approach

After applying standard sanding and scanning procedures to the growth cores (at a resolution of 1200 dpi), the technique of electronic measurement and reading of annual ring widths was employed using the software CooRecorder 9.0, generating .pos files. The .pos files, containing individual growth series, were imported into the software Cdendro 9.0 for initial standardization. This process and the derivation of growth index series required the use of the „*detrend()*” function from the „*dplR*” package (Bunn, 2008). The mean growth index chronology was obtained by calculating the biweighted mean using the „*chron()*” function.

Residual growth index series (RWI) were used *in dendroclimatic models*. Pearson correlation coefficients between growth index series and monthly climate variables were calculated using the „*ddc()*” function from the „*treeclim*” package (Zang & Biondi, 2015). The analyzed period ranged from June of the previous year to August of the current year.

Analysis and modelling of wood's physico-mechanical qualitative indicators (density, micro-drilling resistance, and sound velocity propagation) were performed considering species, degradation type, and phytoclimatic zone within the permanent experimental plots (SEP).

For *wood density (WD)* determination, radial samples were collected from Scots pine and black pine trees across each diameter class, with a sufficient number of trees selected according to their frequency within the class. Growth cores were extracted from healthy trees using a Pressler increment borer at breast height (1.30 m) (Chave, 2005). In the field, the total length and diameter at the middle of each sample (average of two readings) were measured using an electronic caliper. During length measurement, end compression of the wood samples was avoided as much as possible. At the laboratory, standard procedures were applied to determine the oven-dry mass of the samples (Popescu & Dinulică, 2020; Kollmann & Côté, 1968), repeated until a constant dry mass was obtained.

Micro-drilling resistance (R) and sound velocity through wood (v) were obtained using automated processing and recording techniques with modern equipment. Radial direction resistance and sound velocity samples were recorded from a sufficient number of Scots pine and black pine trees within each diameter class, based on their frequency distribution. The resistance data were electronically stored on the memory device of the modern IML Resistograph F300-S instrument (Ross, 2015).

The *sound velocity* data were electronically stored on the memory device of the modern IML MicroHammer instrument.

3.3 Statistical processing of data

Structural indicators of pine stands on degraded lands

The determination of these indicators required, in an initial phase, the processing of experimental data using software applications from the Microsoft Office suite (Microsoft Excel). *To characterize the structure of the pine stands*, the following structural indicators were calculated:

- stand composition;
- quadratic mean diameter (dg);
- height corresponding to the quadratic mean diameter (hg);
- number of trees per hectare ($N \cdot ha^{-1}$);
- basal area per hectare ($G \cdot ha^{-1}$);
- volume per hectare ($V \cdot ha^{-1}$);
- density index (I_N);
- stocking index (I_G);
- Camino (H) and Gini (G) indexes (De Camino, 1976, Popa, 1999).

Unit volumes (v) were calculated using a two-variable (double-entry) volume equation (Eq. 1) (Giurgiu et al., 2004):

$$\log v = a_0 + a_1 \cdot \log d + a_2 \cdot \log^2 d + a_3 \cdot \log h + a_4 \cdot \log^2 h \quad (\text{Eq.1})$$

The Camino (H) and Gini (G) structural diversity indexes express the trend toward structural diversification over time, depending on how closely the Lorenz curves approach the reference line. The values within the range of variation of these indices define the structural type of the stands, as well as their degree of homogeneity or heterogeneity (Roibu, 2010). The Camino index (H) was calculated using Equation 2:

$$H = \frac{\sum_{i=1}^{n-1} SN\%}{\sum_{i=1}^{n-1} SN\% - SG\%} \quad (\text{Eq.2})$$

The general formula for calculating the Gini index (G) is as follows (Eq. 3):

$$G = 1 - 2 \cdot \int_0^1 f(x) dx \quad (\text{Eq.3})$$

The analysis of stand structure in relation to diameter, height, and volume was performed using the SilvaStat statistical application (Popa, 1999), which integrates commonly used theoretical frequency functions in forestry (Giurgiu, 1979). The adjustment of the empirical distributions was carried out using Pearson theoretical frequency functions suitable for structural modelling of pine stands (specifically the *Beta* and *Gamma* theoretical functions). *The analysis of stands structure* was analyzed at the phytoclimatic zone level, by grouping the experimental plots based on three criteria: species, age, and type of land degradation.

Diameter–height relationship

The analysis of the diameter–height relationship described the distribution pattern of tree heights in relation to basal diameter for pine trees, with the connection between the two variables following well-known growth laws. The strength of this relationship was expressed using the coefficient of determination (R^2). *The adjustment of empirical distributions* was performed using logarithmic regression equations, which demonstrated a high degree of flexibility in this context.

The assessment of stand health was carried out in three stages (MMAF, 2022):

- a) Establishing the *intensity of tree and stand defoliation* by determining the *mean defoliation percentage (DEF%)*;

- b) *Determining the average drying degree of the stands (G_u)* (Table 3.4), using the following calculation formula (Eq. 4):

$$G_u = (R_0 \times N_s + R_1 \times N_{sb} + R_2 \times N_m + R_3 \times N_p + R_4 \times N_u) / N_t \quad (\text{Eq. 4})$$

Table 3.4 Drying degree by damage classes

Drying class rank R_i	Class interval	Stand drying degree
0	<0.1	No drying
1	0.1-1.4	Slightly affected (U_1)
2	1.5-2.4	Moderately affected (U_2)
3	2.5-3.4	Severely affected (U_3)
4	>3.5	Very severely affected (U_4)

- c) *Determining the degree of stand damage (G_v)* using the classification scale (Table 3.5):

Table 3.5 Establishing the degree of damage in pine stands

Stand damage degree	Frequency of fallen (uprooted)/broken trees (%)
Slight damage (V1/Z1)	isolated uprooting/breakage 1-10
Moderate damage (V2/Z2)	fairly frequent uprooting/breakage 11-25
Severe damage (V3/Z3)	frequent uprooting/breakage 26-50
Very severe damage (V4/Z4)	very frequent uprooting/breakage over 50

Meaning of symbols: V1, V2, V3, V4- damage caused by wind; Z1, Z2, Z3, Z4- damage caused by snow.

The analysis of auxological characteristics of stands is essential for understanding the structure of tree growth within them (Giurgiu, 1979). In this context, the research conducted in the doctoral thesis captured the physiological status of Scots pine and black pine species by analyzing radial growth in diameter, basal area, and volume over the last 10 years (2011–2020), using a method based on a single inventory combined with growth cores extracted from standing trees (Leahu, 1994).

From a dendroclimatic perspective, the standardization of individual growth series was performed using a theoretical *Spline* function with a 30-year length, resulting in residual growth indices (RWI). *Dendroclimatic models* were developed based on correlations between RWI indices and the main climatic stress factors. Correlation coefficients were modeled using the “*Treeclim*” package and the R programming language (Dendoncker et al., 2025).

The analysis of resilience components as a response of trees to extreme drought events required identifying the three driest years within the analyzed period (1960–2020), based on equations determining potential evapotranspiration (PET) and water availability (Climatic Water Balance – CWB). To quantify the influence of water availability (CWB) on the radial growth processes of Scots pine and black pine, the standardized precipitation evapotranspiration index (SPEI) was used. The SPEI data were accessed through the R Studio software, using the “*SPEI*” package (Beguería et al., 2017).

Subsequently, based on the trees’ response to the extreme climatic factor (drought), *resilience components* were evaluated: a) *resistance* (Eq. 5); b) *recovery and recovery period (years)* (Eq. 6); and c) *resilience* (Lloret et al., 2011), in those three identified drought years (2000, 2003, and 2007), being selected only those permanent experimental plots where drought effects were effectively observed (Eq. 7). *Resilience components* were determined based on the actual width of annual rings at the tree level, using the R package “*pointRes*” (van der Maaten-Theunissen et al., 2021).

$$Resistance (Rt) = \frac{Dr}{\frac{PreDr}{Post Dr}} \quad (Eq. 5)$$

$$Recovery (Rc) = \frac{Dr}{\frac{Post Dr}{Pre Dr}} \quad (Eq. 6)$$

$$Resilience (Rs) = \frac{Dr}{\frac{Post Dr}{Pre Dr}} \quad (Eq. 7)$$

A comparative analysis of means between groups formed by the two pine species (Scots pine and black pine) was performed using statistical tests: ANOVA (analysis of variance) and Wilcoxon rank-sum test, the significance testing being performed at confidence levels of 95% and 99%, respectively.

Wood density (WD), expressed in $[kg \cdot m^{-3}]$ or $[g \cdot cm^{-3}]$, is the most defining indicator of wood quality. It was determined as the ratio between the dry mass and the green volume of the sample (Chave et al., 2005). Using the values of wood density (WD) and unit volumes measured at the tree level, the **aboveground biomass (AGB) of the stem** and **the carbon stock (C)** were estimated as averages at the stand level (IPCC, 2003).

Modern technologies employing automated data processing and recording techniques have enabled the determination of **micro-drilling resistance (R)** and **sound velocity (v)** along the radial direction in standing trees, as important parameters for assessing the internal structural quality of the wood.

In the case of **micro-drilling resistance**, these techniques use mathematical algorithms that automatically divide the wood cross-section into concentric rings of $\frac{1}{2}$ mm width, the resistance being calculated as a weighted average considering the area delimited by each ring, the total cross-sectional area, and the total number of concentric rings. *At the office*, the resistance samples were modeled using the *F-tools Pro* software.

In the case of **velocity of sound propagation through wood**, the methods utilize acoustic waves as a means of automatic recording of the velocity along the radial direction. Subsequently, the data files were exported in .txt format for processing and interpretation using dedicated software applications (Microsoft Excel, Statistica 8.0).

4. RESULTS

4.1 Particularities of the structure of pine stands installed on degraded lands

Grouping method of the Experimental Plots

The experimental plots with homogeneous characteristics in terms of *species, age class, and type of land degradation* were grouped, providing a solid basis for relevant statistical comparisons (Table 4.1).

Table 4.1 Grouping of the experimental plots for the analysis of stand structure and tree health status

Phytoclimatic zone	Species	Grouped SEP	Age class	Degradation class	Degradation nature
FD ₃	Pi, Pi.n	CA5, CA6, CA7, CA8, CA9, CA10, CA11, CA12, CA13	III	E ₁ -E ₃	Pluvial erosion in surface
	Pi, Pi.n	CA3, CA4	III	R	Pluvial erosion in depth
	Pi, Pi.n	PS1, PS2, PS3, PS4, PS6, PS7, PS8, PS9, PS10, PS11, RO4, RO7, RO9, RO10	IV	E ₁ -E ₃	Pluvial erosion in surface

Phytoclimatic zone	Species	Grouped SEP	Age class	Degradation class	Degradation nature
FD ₁ +S _s	Pi, Pi.n	MU12, MU17, MU18	III	AI	Pluvial erosion in depth
	Pi, Pi.n	LI6, LI9, LI10, LI12	IV	E ₁ -E ₂	Pluvial erosion in surface

Determination of the main structural indicators

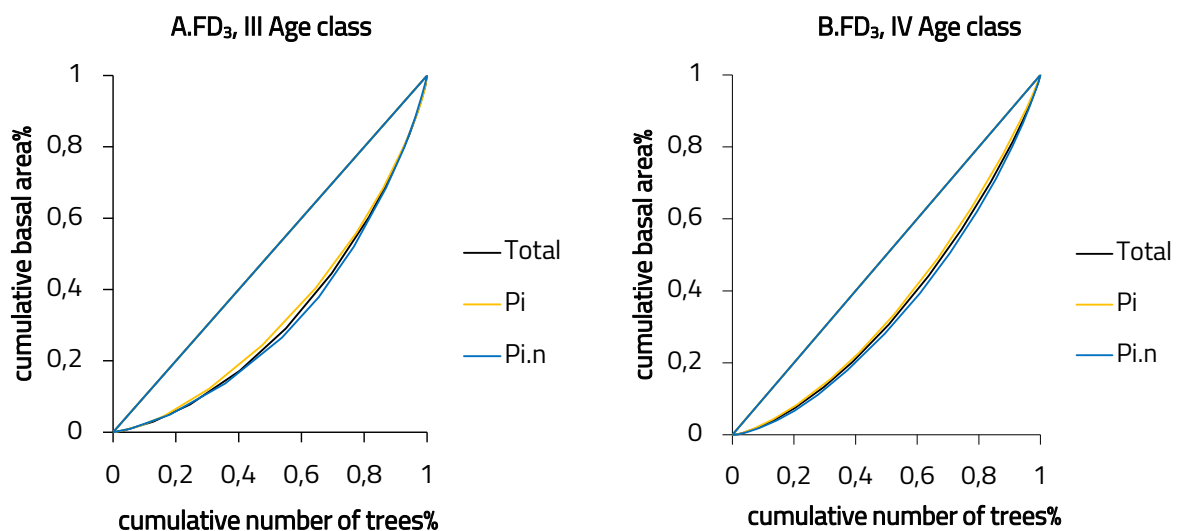
A significant reduction in the number of trees was observed in Scots pine stands classified in age class IV, which led, on the one hand, to a decrease in stand density below the 0.5 threshold, and on the other hand, to an increase in volume (Table 4.2).

Table 4.2 Main structural indicators of pine stands

Phytoclimatic zone	Cl.V	Species	Cl.P	dg (cm)	hg (m)	N·ha ⁻¹	G·ha ⁻¹ (m ² ·ha ⁻¹)	V·ha ⁻¹ (m ³ ·ha ⁻¹)	I _N	I _G	H	G
FD ₃	III	Pi	3	16,48	16,17	964	20,56	168,67	0,92	0,68	7,25	0,34
		Pi.n	3	14,22	13,49	699	11,10	80,12	0,71	0,62	8,10	0,37
	IV	Pi	3	24,86	18,38	325	15,74	129,97	0,48	0,41	8,01	0,26
		Pi.n	3	26,17	18,90	263	14,12	132,55	0,35	0,39	5,27	0,30
FD ₁ +S _s	III	Pi	3	23,75	21,21	590	26,13	211,57	0,95	1,40	5,36	0,18
		Pi.n	2	21,00	19,58	345	11,94	97,95	0,30	0,30	6,34	0,21
	IV	Pi	2	25,12	21,72	384	19,04	224,30	0,41	0,46	8,04	0,23
		Pi.n	2	27,28	21,12	379	22,11	249,94	0,42	0,54	6,77	0,22

Symbols Pi- Scots pine; Pi.n- black pine; dg- quadratic mean diameter; hg- height corresponding to the quadratic mean diameter; N·ha⁻¹- number of trees per hectare; G·ha⁻¹- basal area per hectare; Cl.P- production class; Cl.V- age class; V·ha⁻¹- volume per hectare; I_N- density index; I_G- stocking inde; H- Camino index; G- Gini index.

The structural diversity indices Camino (H) and Gini (G) confirmed the presence of even-aged and homogeneous stand structures, providing important premises for the future development of the structural dynamics of the pine stands (Fig. 4.1A, 4.1B, 4.1C, 4.1D).



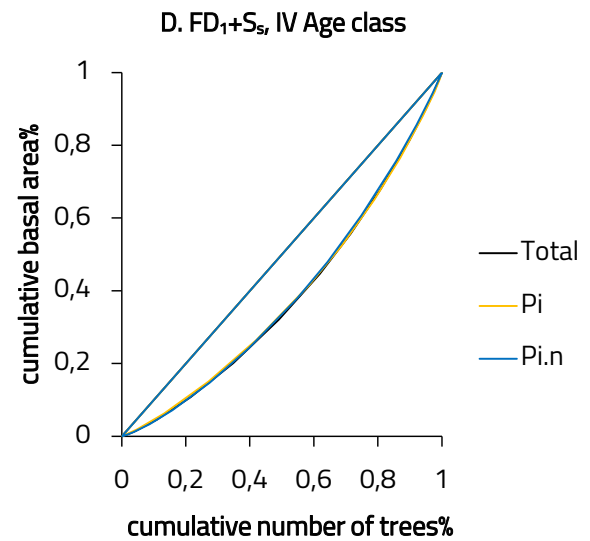
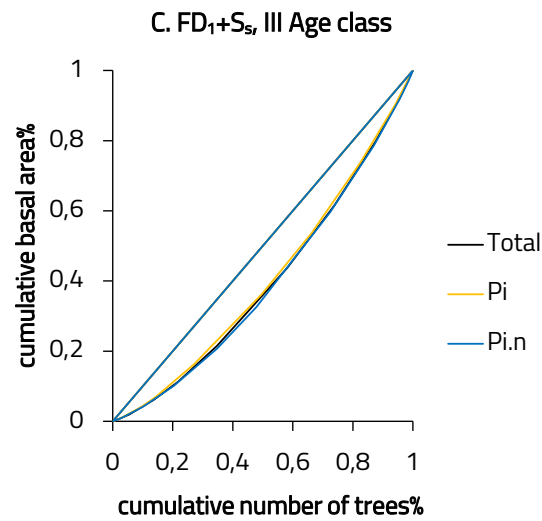


Figure 4.1 Analysis of stand structure homogeneity.

Stand structure in relation to tree diameter

The experimental distributions showed positive (left-skewed) asymmetry, due to a significant concentration of trees in the small and medium diameter classes.

The adjustment of the experimental distributions was performed using the theoretical *Beta* function (Fig. 4.2A, 4.2B, 4.2C, 4.2D).

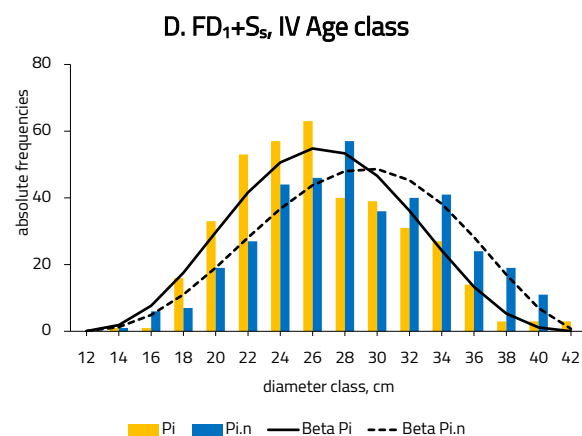
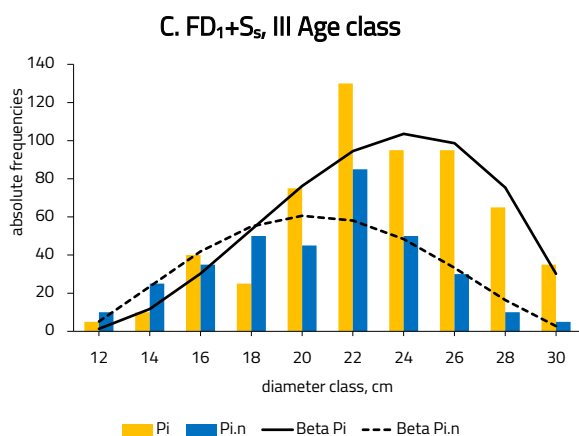
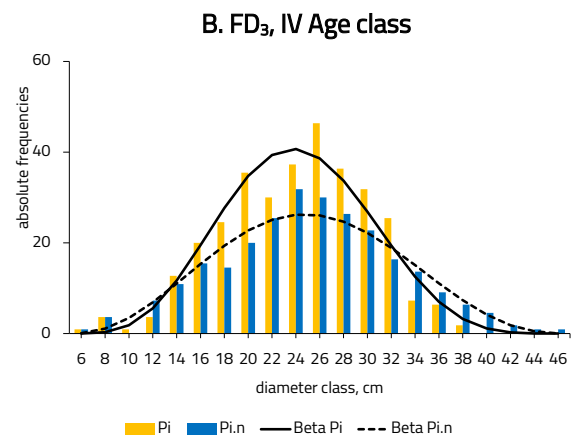
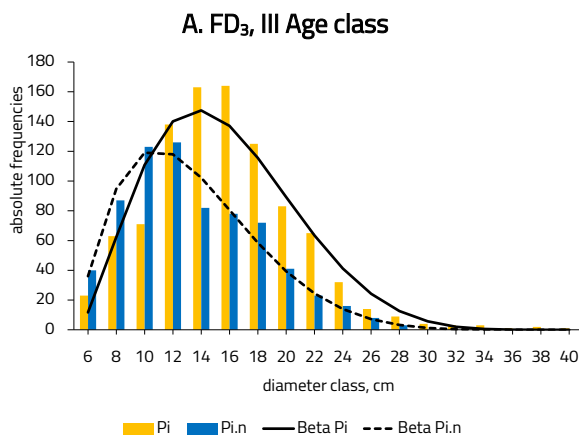


Figure 4.2 Adjustment of experimental distributions using the theoretical *Beta* frequency function

By applying the Kolmogorov-Smirnov (K-S) goodness-of-fit test, the analyzed pine stands were found to follow the theoretical Beta distribution law in all cases examined. The Chi-square (χ^2) test indicated significant differences between the distributions.

The structure of stands in relation to tree height

The distribution of the number of trees across height classes follows well-known distribution laws, with the shape of the theoretical frequency curves for height differing from those for diameter (Fig. 4.3A, 4.3B, 4.3C, 4.3D). The experimental distributions exhibited a right-skewed negative asymmetry, which is opposite to the asymmetry observed in diameter distributions.

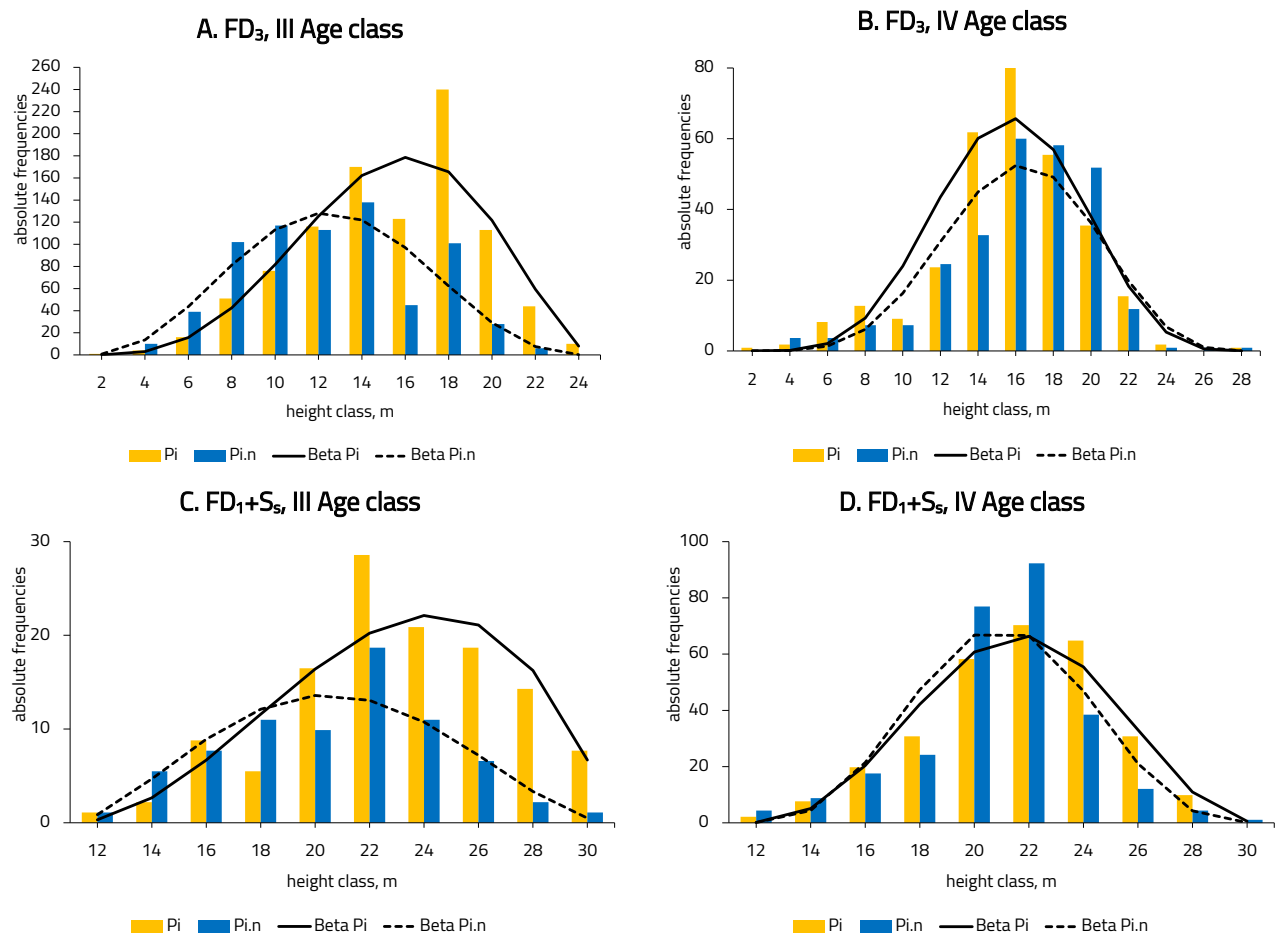


Figure 4.3 Adjustment of experimental distributions using the theoretical Beta frequency function.

The Kolmogorov-Smirnov (K-S) and Chi-square (χ^2) goodness-of-fit tests indicated that the theoretical Beta function is suitable for fitting the experimental distributions, with significant differences observed at the distribution level.

Structure of the stands in relation to tree volume

The experimental distributions exhibit a pronounced positive left skewness in the case of volumes (Fig. 4.4A, 4.4B, 4.4C, 4.4D).

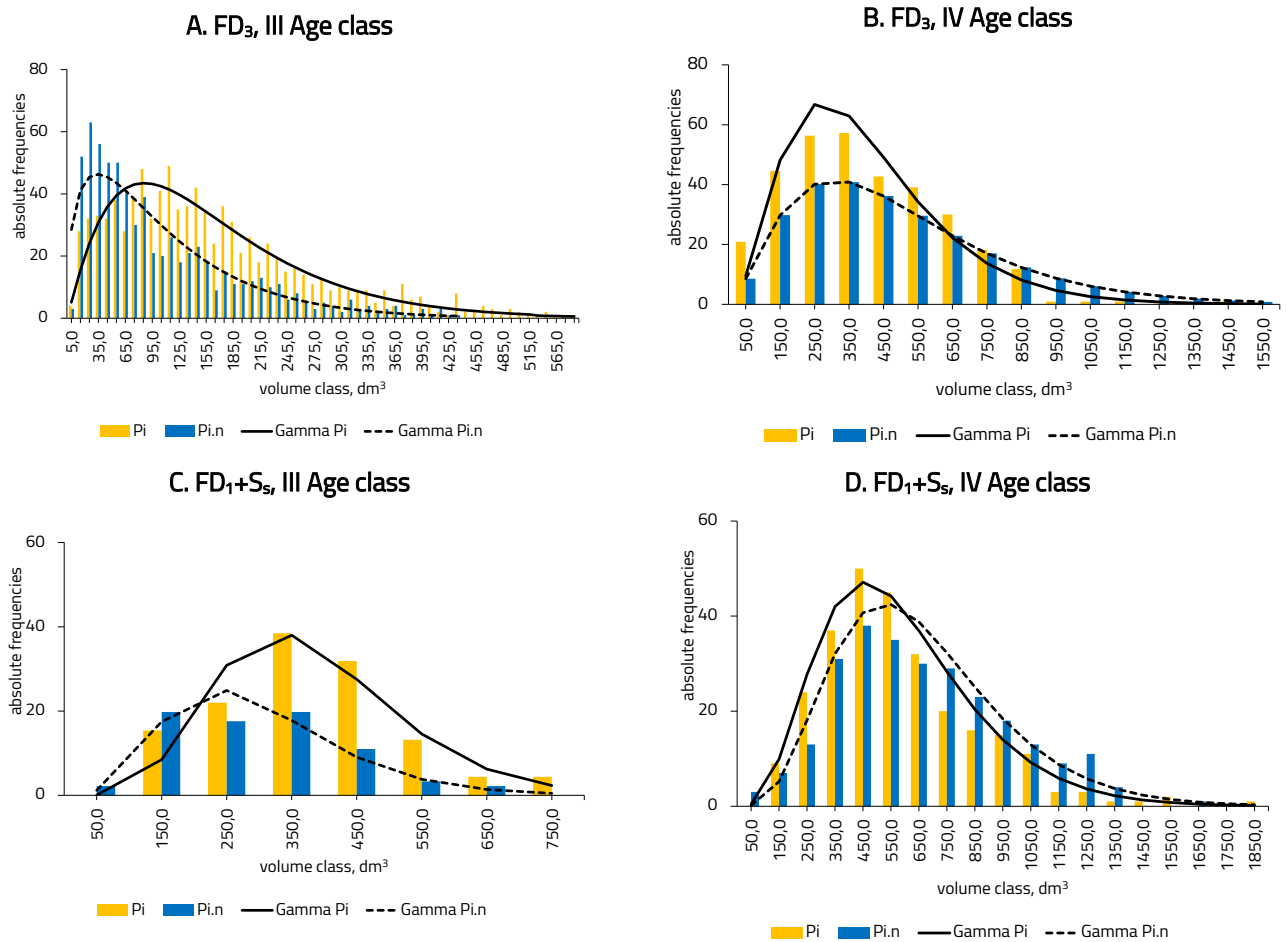
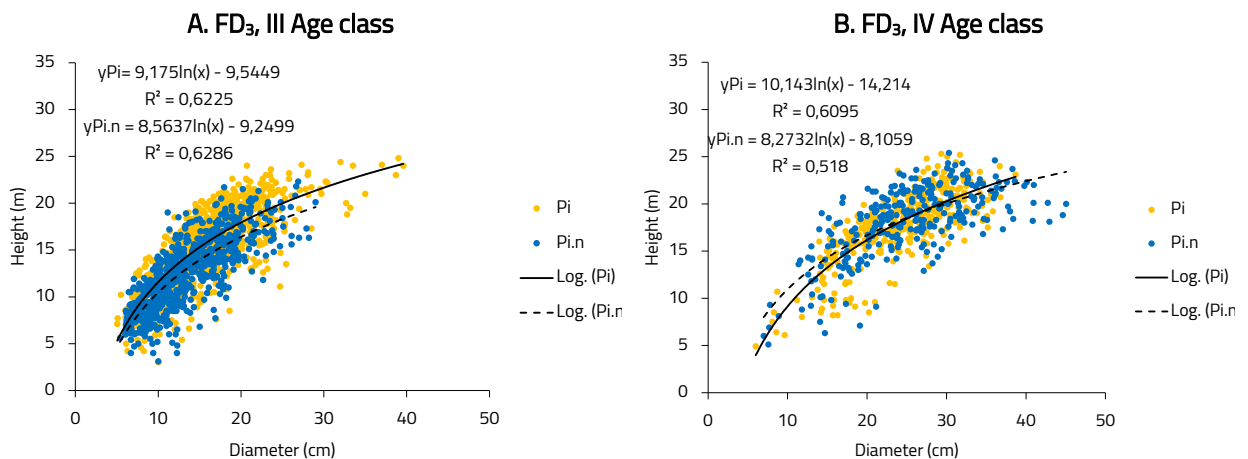


Figure 4.4 Adjustment of experimental distributions using the theoretical Gamma frequency function.

In the case of the distribution of the number of trees by volume classes, the adjustment of the experimental distributions using the theoretical Gamma function proved to be the most suitable, exhibiting a high degree of flexibility according to the K-S test. The χ^2 test indicated significant differences between the experimental and theoretical distributions for both analyzed pine species.

Diameter-Height Relationship

From the analysis of the *diameter-height relationship*, it was observed that tree heights increase proportionally with diameter, with a tendency for the growth rate to stabilize around larger diameter classes (Fig. 4.5A, 4.5B, 4.5C, 4.5D).



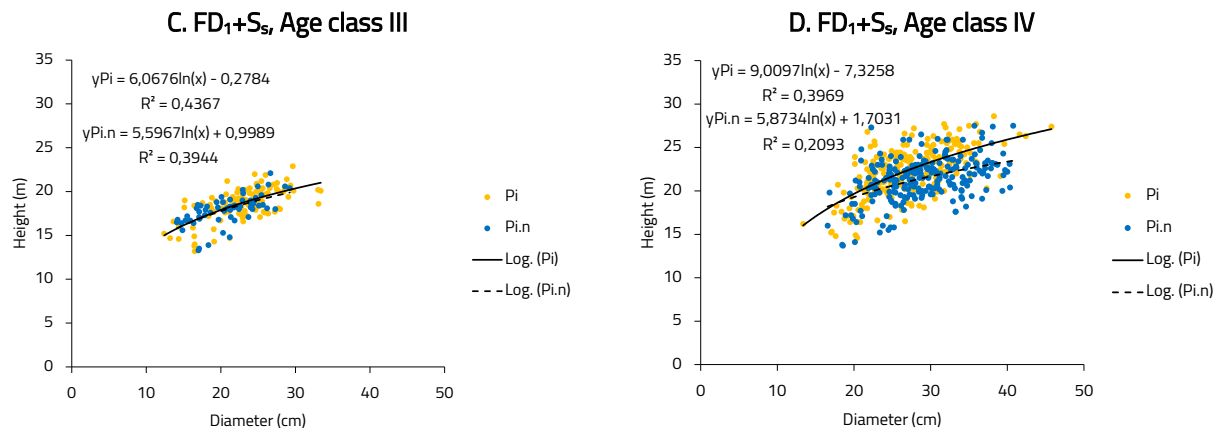


Figure 4.5 The relationship between tree diameter and height.

4.2 Evaluation of the health status of pine stands

4.2.1 Defoliation intensity and drying degree of the stands

The results indicated a high intensity of the average defoliation percentage within the populations of black pine (Figure 4.6). In contrast, the intensity of the average defoliation percentage was lower in the Scots pine populations, except for those classified within the third age class belonging to the FD₁+S_s phytoclimatic zone.

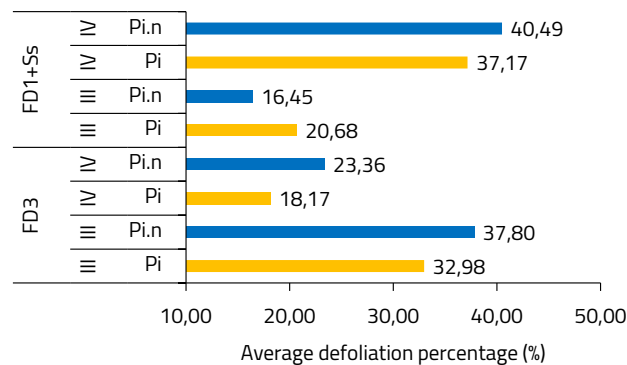


Figure 4.6 Distribution of the average defoliation percentage (%) by species, age classes, and phytoclimatic zone.

The ANOVA test confirmed the existence of significant differences between the mean defoliation percentages among the groups at a 95% confidence level, but only within the pine stands of the FD₃ phytoclimatic zone.

The average drying degree calculated for all stands located in the FD₃ phytoclimatic zone is 1.91, indicating a moderate level of drying damage (Table 4.3).

Table 4.3 Average drying degree (G_u) of pine stands affected by wind and snow in the FD₃ phytoclimatic zone

SEP	R _i	Class interval	N _t	N _i x R _i	G _u	Intensity of the average drying degree of the stand (G _u)
III Age class						
CA3	0-4	1,5-2,4	51	114	2,24	Moderately affected
CA4	0-4	1,5-2,4	88	166	1,89	Moderately affected
CA5	0-4	1,5-2,4	114	162	1,42	Moderately affected
CA6	0-4	1,5-2,4	86	188	2,19	Moderately affected
CA7	0-4	1,5-2,4	360	414	1,15	Slightly affected

SEP	R _i	Class interval	N _t	N _i x R _i	G _u	Intensity of the average drying degree of the stand (G _u)
CA8	0-4	1,5-2,4	127	258	2,03	Moderately affected
CA9	0-3	1,5-2,4	121	208	1,72	Moderately affected
CA10	0-4	1,5-2,4	65	137	2,11	Moderately affected
CA11	0-4	2,5-3,4	160	410	2,56	Severely affected
CA12	0-3	1,5-2,4	154	359	2,33	Moderately affected
CA13	0-3	2,5-3,4	58	153	2,64	Severely affected
IV Age class						
PS1	0-3	1,5-2,4	44	76	1,73	Moderately affected
PS2	0-2	0,1-1,4	32	16	0,50	Slightly affected
PS3	0-4	0,1-1,4	28	21	0,75	Slightly affected
PS4	0-4	0,1-1,4	30	37	1,23	Slightly affected
PS6	0-4	>3,5	24	117	4,88	Highly severely affected
PS7	0-4	2,5-3,4	37	91	2,46	Severely affected
PS8	0-4	0,1-1,4	26	21	0,81	Slightly affected
PS9	0-3	1,5-2,4	101	151	1,50	Moderately affected
PS10	0-4	0,1-1,4	58	36	0,62	Slightly affected
PS11	0-4	0,1-1,4	132	95	0,72	Slightly affected
RO4	0-3	1,5-2,4	32	52	1,63	Moderately affected
RO7	0-4	0,1-1,4	47	36	0,77	Slightly affected
RO9	0-3	0,1-1,4	43	56	1,30	Slightly affected
RO10	0-3	0,1-1,4	29	35	1,21	Slightly affected

Meaning of symbols: SEP- permanent experimental plot; R_i- drying class rank; N_t- number of trees in Kraft classes 1, 2, and 3"; N_i x R_i- the product of the number of trees in the defoliation classes (0-4) and the rank of the drying class (0-4).

The average drying degree calculated for all stands in the FD₁+S_s phytoclimatic zone is 1.83, indicating a moderate level of drying damage (Table 4.4).

Table 4.4 The average drying degree (G_u) of pine stands affected by wind and snow in the FD₁+S_s zone

SEP	R _i	Class interval	N _t	N _i x R _i	G _u	Intensity of the average drying degree of the stand (G _u)
III Age class						
MU12	0-4	0,1-1,4	59	76	1,29	Slightly affected
MU17	0-1	0,1-1,4	51	36	0,71	Slightly affected
MU18	0-4	0,1-1,4	43	20	0,47	Slightly affected
IV Age class						
LI6	0-4	1,5-2,4	90	146	1,62	Moderately affected
LI9	0-4	1,5-2,4	56	113	2,02	Moderately affected
LI10	0-4	1,5-2,4	136	332	2,44	Moderately affected
LI12	1-4	1,5-2,4	161	376	2,34	Moderately affected

Meaning of symbols: SEP- permanent experimental plot; R_i- drying class rank; N_t- number of trees in Kraft classes 1, 2, and 3"; N_i x R_i- the product of the number of trees in the defoliation classes (0-4) and the rank of the drying class (0-4).

4.2.2 Establishing tree defects and damage degree of the stands

The frequency of fallen, leaning, and broken trees (%) calculated for the total stands in the FD₃ phytoclimatic layer is 16.06%, indicating a moderate degree of damage characterized by fairly frequent wind and snow-induced falls and breaks (Table 4.5).

Table 4.5 The damage degree (G_v) of pine stands affected by wind and snow in the FD₃ phytoclimatic zone, calculated based on the nature and extent of damages

SEP	Mixture type	Number of trees analyzed /SEP	Number of damaged trees according to the nature of the damage					Frequency of fallen, leaning, and broken trees (%)	Degree of damage to the stand (G _v)
			A	VR	TR	VU	Î		
III Age class									
CA3	Mixture (Pi, Pi.n)	64	2	9	-	-	1	17,19	Moderately damaged
CA4	Mixture (Pi, Pi.n)	105	11	15	-	-	3	24,76	Moderately damaged
CA5	Mixture (Pi, Pi.n)	133	11	16	-	3	1	20,30	Moderately damaged
CA6	Mixture (Pi, Pi.n)	126	14	9	2	-	1	19,84	Moderately damaged
CA7	Mixture (Pi, Pi.n)	388	12	19	-	-	3	7,99	Slightly damaged
CA8	Pure (Pi)	155	23	18	-	-	1	26,45	Moderately damaged
CA9	Mixture (Pi, Pi.n)	145	10	6	-	2	-	11,03	Slightly damaged
CA10	Mixture (Pi, Pi.n)	92	3	4	-	-	-	7,61	Slightly damaged
CA11	Mixture (Pi, Pi.n)	207	20	26	-	3	3	22,22	Moderately damaged
CA12	Mixture (Pi, Pi.n)	185	14	9	8	4	1	16,76	Moderately damaged
CA13	Mixture (Pi, Pi.n)	75	3	5		1	-	10,67	Slightly damaged
Total (III)		1675	123	136	10	13	14	16,06	
%			7,34	8,12	0,60	0,78	0,84		
IV Age class									
PS1	Mixture (Pi, Pi.n)	53	5	17	-	-	-	41,51	Severely damaged
PS2	Pure (Pi)	33	3	19	-	-	-	66,67	Highly severely damaged
PS3	Pure (Pi)	29	2	4	-	-	-	20,69	Moderately damaged
PS4	Mixture (Pi, Ci)	38	5	-	-	1	-	13,16	Moderately damaged
PS6	Mixture (Pi, Ci)	55	-	4	-	-	2	7,27	Slightly damaged
PS7	Mixture (Pi, Ci)	59	2	4	-	-	1	10,17	Slightly damaged
PS8	Pure (Pi)	27	1	2	1	-	2	14,81	Moderately damaged
PS9	Pure (Pi.n)	118	21	23	-	-	-	37,29	Moderately damaged
PS10	Pure (Pi.n)	65	2	8	-	-	11	15,38	Moderately damaged

SEP	Mixture type	Number of trees analyzed /SEP	Number of damaged trees according to the nature of the damage					Frequency of fallen, leaning, and broken trees (%)	Degree of damage to the stand (G_v)
			A	VR	TR	VU	$\hat{I}$		
PS11	Mixture (Pi, Pi.n)	150	11	16	-	-	11	18,00	Moderately damaged
RO4	Mixture (Pi, Pi.n)	40	5	1	-	1	3	15,00	Moderately damaged
RO7	Mixture (Pi, Pa)	56	-	-	-	4	-	0,00	Undamaged
RO9	Pure (Pi.n)	50	6	4	-	1	8	20,00	Slightly damaged
RO10	Pure (Pi)	33	-	7	-	1	-	21,21	Moderately damaged
TOTAL (IV)		806	63	109	1	8	38	21,46	
%			7,82	13,52	0,12	0,99	4,71		
TOTAL (III+IV)		2481	186	245	11	21	52	17,82	
%			7,50	9,88	0,44	0,85	2,10		

Note: SEP- permanent experimental plot; A- leaning / hung-up; VR- broken top; TR- broken stem; VU- dead top; $\hat{I}$ - forked; Pi- Scots pine; Pi.n- black pine; Ci- bird cherry; Pa- sycamore.

The frequency of fallen, leaning, and broken trees (%) calculated across all stands in the FD_1+S_s phytoclimatic zone was 12.87%, indicating a moderate level of damage, characterized by fairly frequent wind and snow-induced falls and breaks (Table 4.6).

Table 4.6 The degree of damage (G_v) in pine stands affected by wind and snow in the FD_1+S_s phytoclimatic zone calculated based on the nature and extent of damage.

SEP	Mixture type	Number of trees analyzed /SEP	Number of damaged trees according to the nature of the damage					Frequency of fallen, leaning and broken trees (%)	Degree of damage to the stand (G _v)
			A	VR	TR	VU	Î		
III Age class									
MU12	Pure (Pi)	145	-	-	1	1	1	12,68	Moderately damaged
MU17	Pure (Pi.n)	69	-	4	-	-	5	-	Undamaged
MU18	Pure (Pi)	47	-	-	1	-	-	2,13	Slightly damaged
TOTAL (III)		261	0	4	2	1	6		
%			0,00	1,53	0,77	0,38	2,30		
IV Age class									
LI6	Pure (Pi)	165	1	3	-	3	-	3,85	Slightly damaged
LI9	Pure (Pi.n)	88	1	16	4	5	1	22,73	Moderately damaged
LI10	Mixture (Pi, Pi.n)	328	10	47	4	7	7	25,73	Severely damaged
LI12	Pure (Pi.n)	205	-	8	5	1	1	6,70	Moderately damaged
TOTAL (IV)		786	12	74	13	16	9		
%			1,53	9,41	1,65	2,04	1,15		
TOTAL (III+IV)		1047	12	78	15	17	15		
%			1,15	7,45	1,43	1,62	1,43		
Note: SEP- permanent experimental plot; A- leaning / hung-up; VR- broken top; TR- broken stem; VU- dead top; Î- forked; Pi- Scots pine; Pi.n- black pine; Ci- bird cherry; Pa- sycamore.									

4.3 Dynamics of the auxological processes of the pine stands studied, installed on degraded lands

During the conducted researches, in order to evaluate radial growth processes, a total of 20 growth forest surveys were carried out within the SEP. The codes were updated by inserting a specific authenticity symbol for each species (Table 4.7).

Table 4.7 The distribution of sample numbers across the investigated experimental plots, by species, regarding to analyze radial growth and resilience components.

Phytoclimatic zone of the stands	*SEP codification by species	Number of samples in the survey
FD ₃	CAS3	19
	CAN3	17
	CAS4	21
	CAN4	23
	CAS5	15
	CAN5	12
	CAS8	20
	CAS9	16
	CAN9	15
	CAS11	23
	CAN11	26
	PSS1	22
	PSN1	23
	PSN9	34
	RON9	24
	ROS10	17
FD ₁ +S _s	LIS10	29
	LIN12	32
	MUS12	22
	MUN17	21
Total number of growth samples		431
Total number of growth samples Scots pine (Pi)		204
Total number of growth samples black pine (Pi.n)		227

Note: *) SEP CAS3, CAN3, CAS4, CAN4, CAS5, CAN5, CAS8, CAS9, CAN9, CAS11, CAN11: "CA"- PA Caciū-Bârseşti acronym; S- code assigned to the Scots pine species; N- code assigned to the black pine species; 3, 4, 5, 8, 9, 11- identification number of the permanent experimental plot; SEP PSS1, PSN9: "PS"- PA Pârâul Sărat-Valea Sării acronym; S- code assigned to the Scots pine species; N- code assigned to the black pine species; 1, 9- identification number of the permanent experimental plot; SEP RON9, ROS10: "RO"- PA Roşoiu-Andreiaşu acronym; S- code assigned to the Scots pine species; N- code assigned to the black pine species; 9, 10- identification number of the permanent experimental plot; SEP LIS10, LIN12: "LI"- PA Livada-Râmnicu Sărat acronym; S- code assigned to the Scots pine species; N- code assigned to the black pine species; 10, 12- identification number of the permanent experimental plot; SEP MUS12, MUN17: "MU"- PA Murgeşti acronym; S- code assigned to the Scots pine species; N- code assigned to the black pine species; 12, 17- identification number of the permanent experimental plot.

4.3.1 Analysis of auxological processes through dendrochronological series of radial growth

In the encountered phytoclimatic zones, the mean tree-ring width series (TRW) of Scots pine and black pine exhibited a decreasing trend (Figure 4.7), which can be attributed to the dynamics of stem geometry higher radial growth during the juvenile stage, followed by a gradual reduction as diameter increases.

In the FD₃ phytoclimatic zone, the average radial growth (TRW) for the period 1960–2020 was 2.01 ± 1.13 mm for Scots pine and 1.92 ± 1.21 mm for black pine. In contrast, in the FD₁+S_s phytoclimatic zone, the average radial growth (TRW) of black pine was 2.48 ± 2.12 mm, which is 13.70% higher compared to Scots pine.

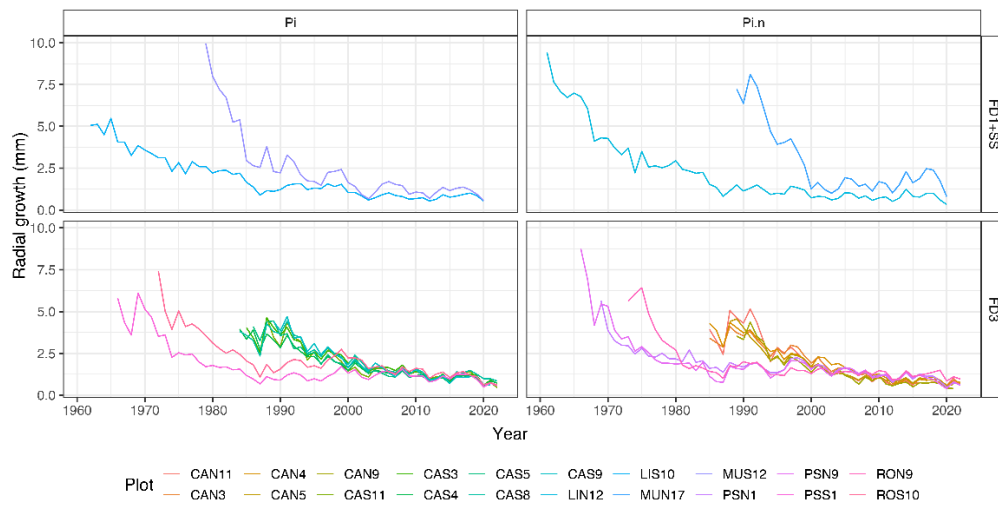


Figure 4.7 Dynamics of radial growth (TRW) at the plot level during the 1960–2020 period for the two studied pine species, in relation to the identified phytoclimatic zones. (Legend of symbols: e.g., CAS3, CAN3– “CA” indicates the experimental plot code; “S” represents the code assigned to Scots pine; “N” represents the code assigned to black pine; “3” refers to the number of the experimental plot. The same logic applies to other coding combinations.)

In the encountered phytoclimatic zones, basal area increment (BAI) follows the same pattern observed in the mean tree-ring width (TRW) series, exhibiting an increasing trend during the juvenile phase, followed by a negative trend as the trees age (Figure 4.8). In most cases, this negative trend indicates a high level of stress experienced by the trees, which may serve as an early warning signal of tree decline (Camarero et al., 2015). The basal area increment (BAI) shows an increasing trend until the year 2000, with significant fluctuations for both pine species. The growth rate was higher in Scots pine across both phytoclimatic zones studied.

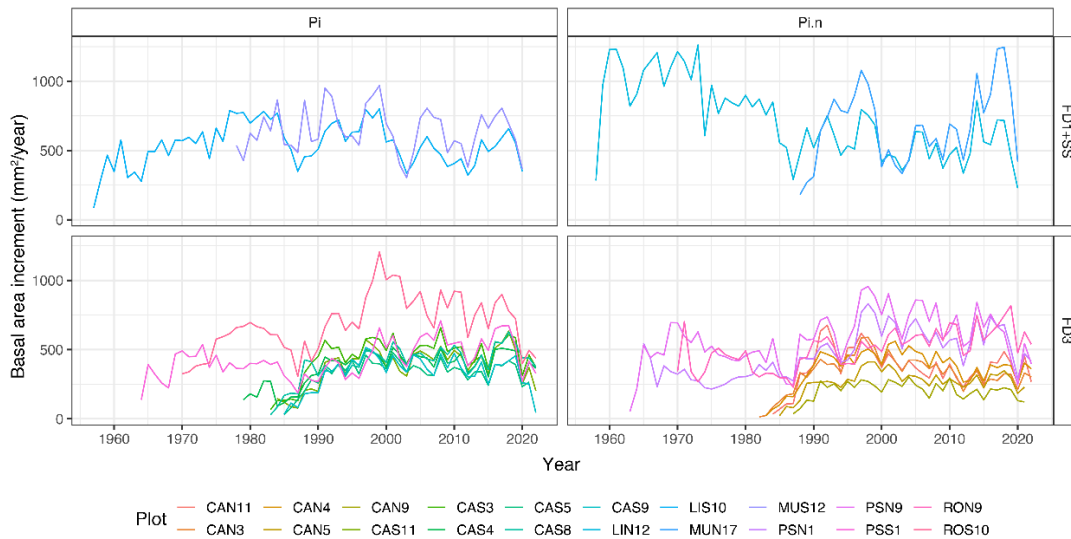


Figure 4.8 Dynamics of basal area increment (BAI) at the plot level during the 1960–2020 period for the two studied pine species in relation to the encountered phytoclimatic zones. (Legend of symbols: e.g., CAS3, CAN3 - “CA” represents the experimental plot code; “S” is the code assigned to Scots pine; “N” is the code assigned to black pine; “3” refers to the number of the experimental plot. The same logic applies to other coding combinations.)

4.3.2 Modelling of radial growth, in diameter, basal area, and volume

Growth of pine stands on degraded lands

In the FD_3 phytoclimatic zone, considering the total pine stands and excluding the influence of erosion on their growth, Scots pine recorded an average radial growth over 10 years (2011–2020) of 10.70 mm, compared to 9.17 mm for its competitor, black pine (Figure 4.9A).

On degraded lands within the FD_1+S_5 phytoclimatic zone, the situation is reversed: black pine demonstrates a superior growth capacity, registering an average radial growth over 10 years of 11.54 mm, with a mean growth rate 26.64% higher than that of Scots pine (Figure 4.9B).

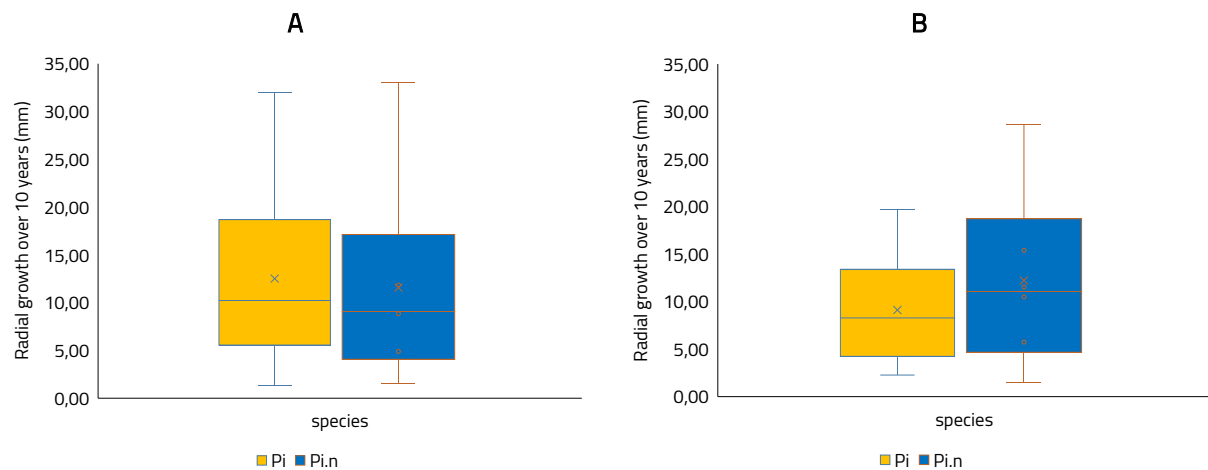


Figure 4.9 Variability of radial growth over 10 years in pine trees across all stands: A. FD_3 ; B. FD_1+S_5 .

The ANOVA test indicated the presence of significant differences between the mean radial growth of the groups formed by Scots pine and black pine ($p < 0.05$).

Basal area and volume growth of Scots pine stands established on degraded lands (Table 4.8).

In the FD_3 phytoclimatic zone, the mean basal area growth for Scots pine ranges from $0.99 \text{ m}^2 \cdot \text{ha}^{-1}$ (CAS9) to $2.87 \text{ m}^2 \cdot \text{ha}^{-1}$ (CAS3). The mean volume growth ranges from $9.19 \text{ m}^3 \cdot \text{ha}^{-1}$ (CAS9) to $32.17 \text{ m}^3 \cdot \text{ha}^{-1}$ (CAS3).

In the FD_1+S_5 phytoclimatic zone, the mean basal area growth for Scots pine varies between $0.87 \text{ m}^2 \cdot \text{ha}^{-1}$ (LIS10) and $1.42 \text{ m}^2 \cdot \text{ha}^{-1}$ (MUS12). The mean volume growth ranges from $12.40 \text{ m}^3 \cdot \text{ha}^{-1}$ (LIS10) to $22.16 \text{ m}^3 \cdot \text{ha}^{-1}$ (MUS12).

Table 4.8 Basal area and volume growth of Scots pine trees and stands in the permanent experimental plots

Phytoclimatic zone	*SEP	Species	Number of trees	Basal area growth over 10 years ($\text{m}^2 \cdot \text{ha}^{-1}$)	Mean annual basal area growth over 10 years ($\text{m}^2 \cdot \text{an}^{-1} \cdot \text{ha}^{-1}$)	Volume growth over 10 years ($\text{m}^3 \cdot \text{ha}^{-1}$)	Mean annual volume growth over 10 years ($\text{m}^3 \cdot \text{an}^{-1} \cdot \text{ha}^{-1}$)
FD_3	CAS3	Pi	19	2,87	0,29	32,17	3,22
	CAS4	Pi	21	2,00	0,20	23,73	2,37
	CAS5	Pi	15	1,86	0,19	20,36	2,04
	CAS8	Pi	20	1,82	0,18	21,21	2,12
	CAS9	Pi	16	0,99	0,10	9,19	0,92
	CAS11	Pi	23	1,68	0,17	21,67	2,17

Phytoclimatic zone	*SEP	Species	Number of trees	Basal area growth over 10 years (m ² ·ha ⁻¹)	Mean annual basal area growth over 10 years (m ² ·an ⁻¹ ·ha ⁻¹)	Volume growth over 10 years (m ³ ·ha ⁻¹)	Mean annual volume growth over 10 years (m ³ ·an ⁻¹ ·ha ⁻¹)
	PSS1	Pi	22	2,47	0,25	26,05	2,60
	ROS10	Pi	17	2,26	0,23	27,91	2,79
	TOTAL FD₃		153	1,99	0,20	22,79	2,28
FD ₁ +S _s	LIS10	Pi	29	0,87	0,09	12,40	1,24
	MUS12	Pi	21	1,42	0,14	22,16	2,22
	TOTAL FD₁+S_s		50	1,14	0,11	17,28	1,73

Basal area and volume growth of black pine stands established on degraded lands (Table 4.9).

In the FD₃ phytoclimatic zone, the mean basal area growth for black pine ranges from 0.51 m²·ha⁻¹ (CAN9) to 2.72 m²·ha⁻¹ (PSN1). The mean volume growth varies between 5.32 m³·ha⁻¹ (CAN9) and 37.64 m³·ha⁻¹ (PSN1).

In the FD₁+S_s phytoclimatic zone, the mean basal area growth for black pine ranges from 0.75 m²·ha⁻¹ (LIN12) to 4.41 m²·ha⁻¹ (MUN17). The mean volume growth varies between 13.95 m³·ha⁻¹ (LIN12) and 51.10 m³·ha⁻¹ (MUN17).

Table 4.9 Basal area and volume growth of black pine stands in the permanent experimental plots

Phytoclimatic zone	*SEP	Species	Number of trees	Basal area growth over 10 years (m ² ·ha ⁻¹)	Mean annual basal area growth over 10 years (m ² ·an ⁻¹ ·ha ⁻¹)	Volume growth over 10 years (m ³ ·ha ⁻¹)	Mean annual volume growth over 10 years (m ³ ·an ⁻¹ ·ha ⁻¹)
FD ₃	CAN3	Pi.n	17	1,71	0,17	20,59	2,06
	CAN4	Pi.n	23	1,90	0,19	22,84	2,28
	CAN5	Pi.n	12	1,46	0,15	17,46	1,75
	CAN9	Pi.n	15	0,51	0,05	5,32	0,53
	CAN11	Pi.n	26	1,50	0,15	19,87	1,99
	PSN1	Pi.n	23	2,72	0,27	37,64	3,76
	PSN9	Pi.n	34	2,33	0,23	36,79	3,68
	RON9	Pi.n	24	2,03	0,20	28,15	2,82
	TOTAL FD₃		174	1,77	0,18	23,58	2,36
FD ₁ +S _s	LIN12	Pi.n	32	0,75	0,07	13,95	1,40
	MUN17	Pi.n	21	4,41	0,44	51,10	5,11
	TOTAL FD₁+S_s		53	2,58	0,26	32,52	3,25

The influence of soil erosion on radial, basal area, and volume growth in pine trees on degraded lands

Based on the graphs in Figure 4.10A and Figure 4.10B, *in the FD₃ phytoclimatic zone*, Scots pine shows higher average values for all three growth categories compared to black pine, under both types of erosion.

In contrast, *in the FD₁+S_s phytoclimatic zone*, black pine demonstrates a greater growth capacity. This can be attributed to the species' ecological adaptability, expressed through its broader tolerance to the pedoclimatic and site-specific conditions characteristic of the analyzed area.

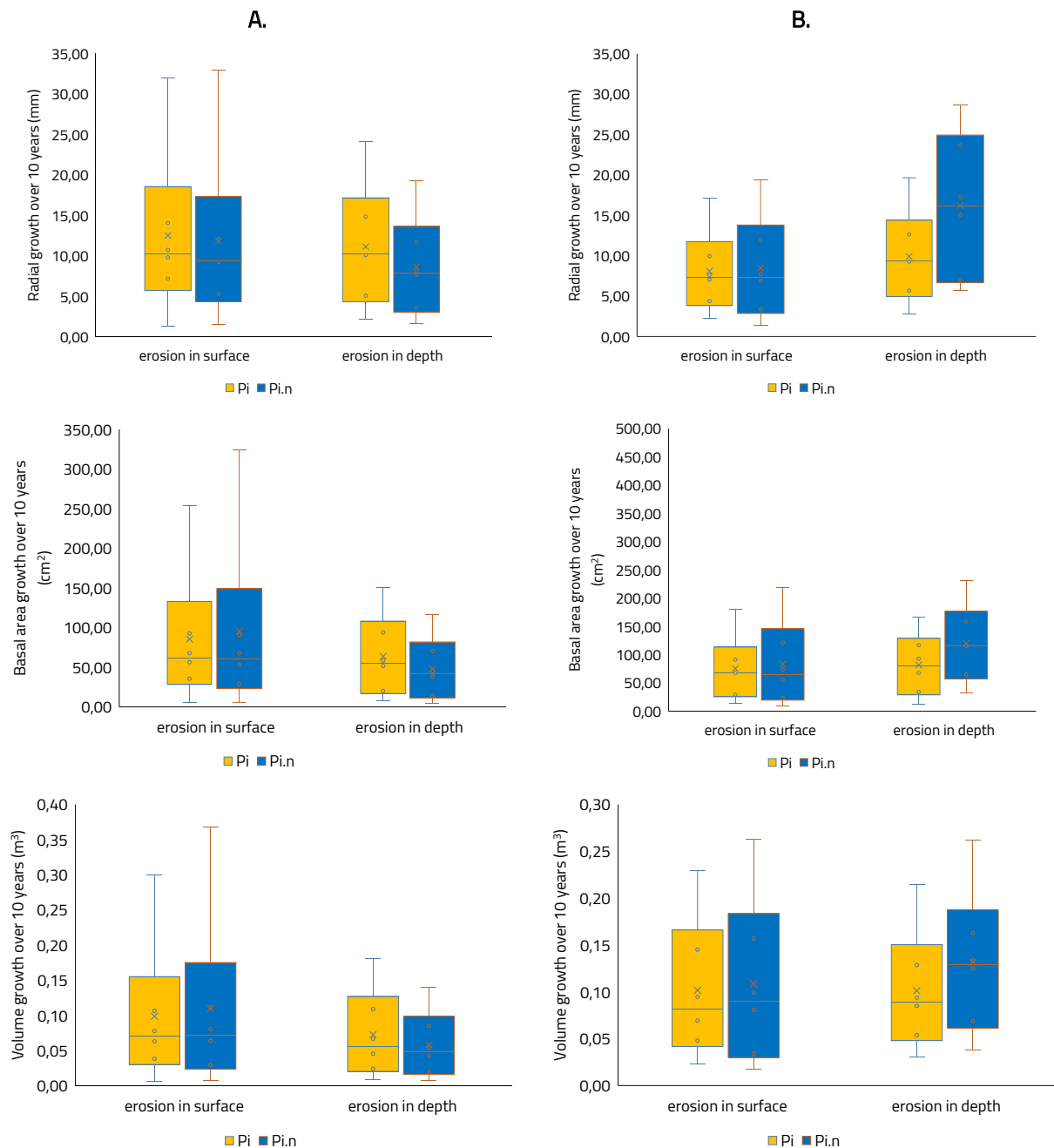


Figure 4.10 Variation in radial, basal area, and volume growth over 10 years of trees within stands, by erosion type: A. FD_3 ; B. FD_1+S_s .

As part of this doctoral thesis, the statistical analysis of growth under the main erosion types (in surface and depth erosion) was conducted for two distinct cases. The summary includes only *Case 2: Different species under similar erosion conditions*, as it was considered the most relevant result.

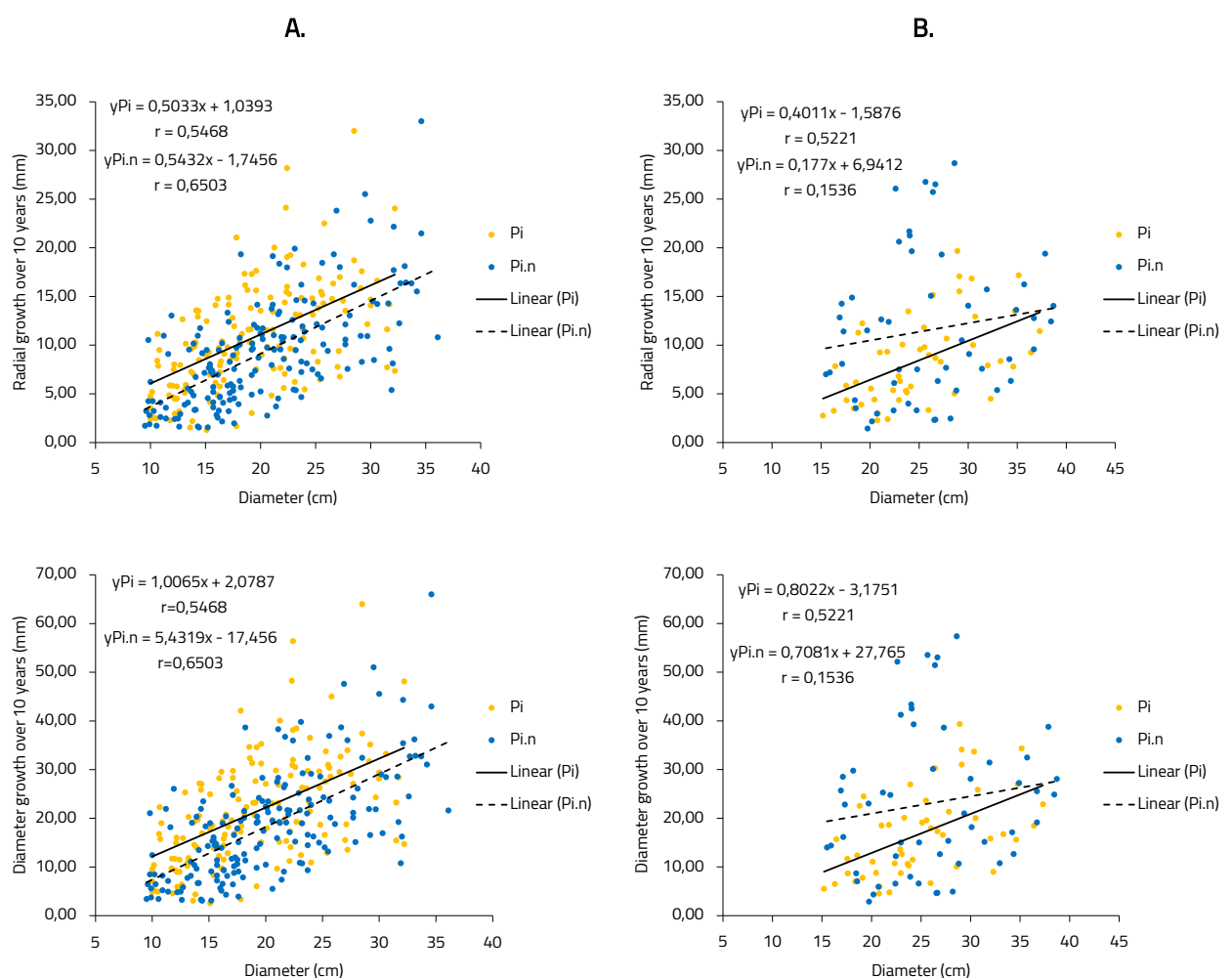
Regarding the influence of soil erosion on radial growth over 10 years of the two analyzed pine species on eroded lands in the FD_3 phytoclimatic zone, the ANOVA test indicated significant differences between the mean growth values ($p < 0.05$) on eroded lands in depth. The mean radial growth rate recorded in Scots pine was 31.17% higher than that of black pine on these lands. In contrast, on eroded lands in the FD_1+S_s phytoclimatic zone, the ANOVA test also revealed significant differences in mean growth values on eroded lands in depth, with black pine showing a 45.35% higher mean radial growth rate compared to Scots pine on these lands.

Regarding of the influence of soil erosion on basal area growth over 10 years for both species, significant differences between means were observed only on eroded lands in depth in the FD₁+S₅ phytoclimatic zone, where the mean growth rate of black pine was 41.31% higher than that recorded for Scots pine.

The influence of soil erosion on volume growth over 10 years under the same degraded land conditions did not result in statistically significant differences between mean values. The ANOVA test confirmed the existence of similarities in the volume growth patterns of the two pine species under analysis.

Modelling the growth of pine trees

An analysis of the graphs in Figures 4.11A and 4.11B confirms the general pattern whereby tree growth follows a trend line characteristic of even-aged stands, where the minimum growth values are observed in thinner trees, and growth increases proportionally with tree diameter and stem form.



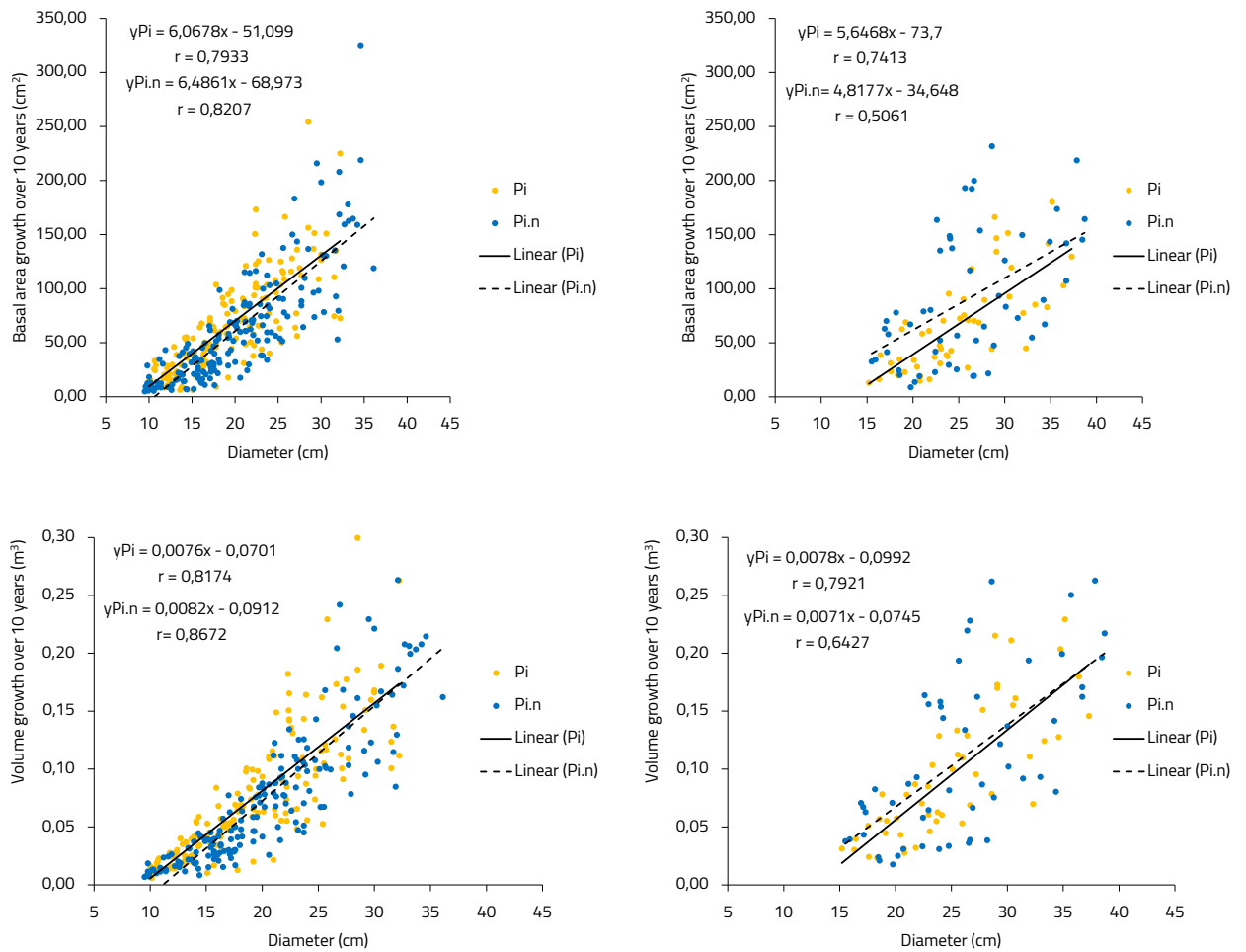


Figure 4.11 Variation in growth in relation to basal diameter for the two pine species and adjustment of experimental values using linear regression equations of the form ($ir=b_0+b_1d$): A. FD_3 ; B. FD_1+S_s .

4.3.3 Dendroclimatic models for pine species on degraded lands

Residual growth indices (RWI) were obtained by standardizing the individual growth series of the studied pine species (Figure 4.12). These indices exhibited a negative trend in the years 1974, 1987, 1989, and 2020, as well as during the most drought-affected years (2000, 2003, 2007).

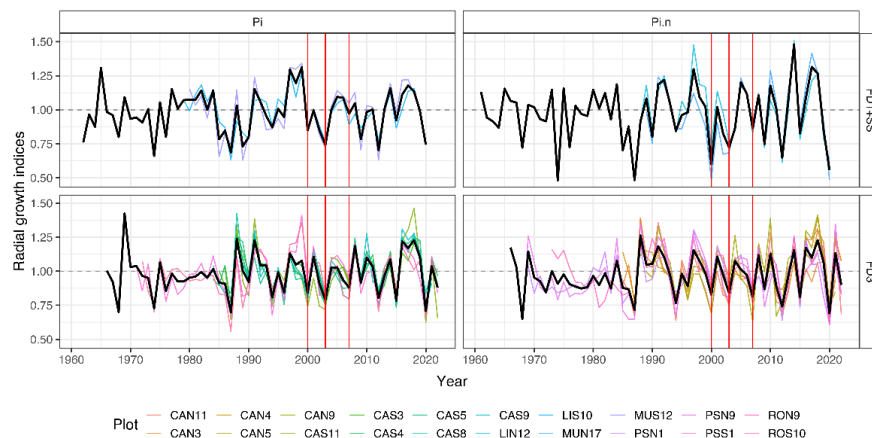


Figure 4.12 Dynamics of residual growth indices at the phytoclimatic zone level (in black) and at the plot level (in colour) during the 1960–2020 period for the two studied pine species. (Legend of symbols: e.g., CAS3, CAN3 – “CA” indicates the code of the experimental plot; “S” refers to the code assigned to Scots pine; “N” refers to the code assigned to black pine; “3” represents the experimental plot number. The same logic applies to other codes. Red vertical lines indicate the three driest years within the study period.)

Dendroclimatic models for mean and minimum monthly temperatures revealed positive and significant correlations with radial growth processes only for Scots pine during November of the previous year (Figures 4.13 and 4.14). This is likely due to the storage of non-structural carbohydrates, which supports growth at the onset of the new growing season.

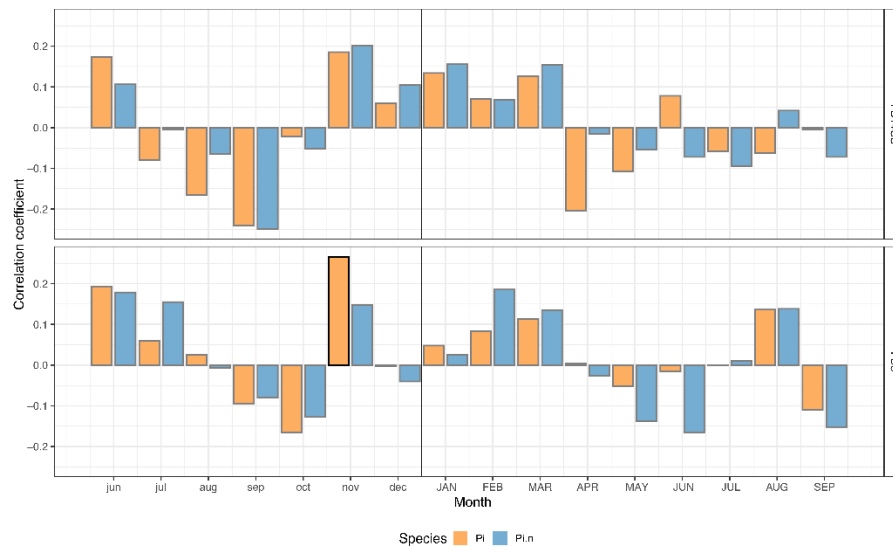


Figure 4.13 Dendroclimatic model for mean monthly temperature [climatic factor] in relation to the encountered phytoclimatic zones for Scots pine and black pine during the period 1960–2020. Statistically significant correlations are highlighted with a black box; months written in uppercase correspond to the year of ring formation, while lowercase months correspond to the previous year.

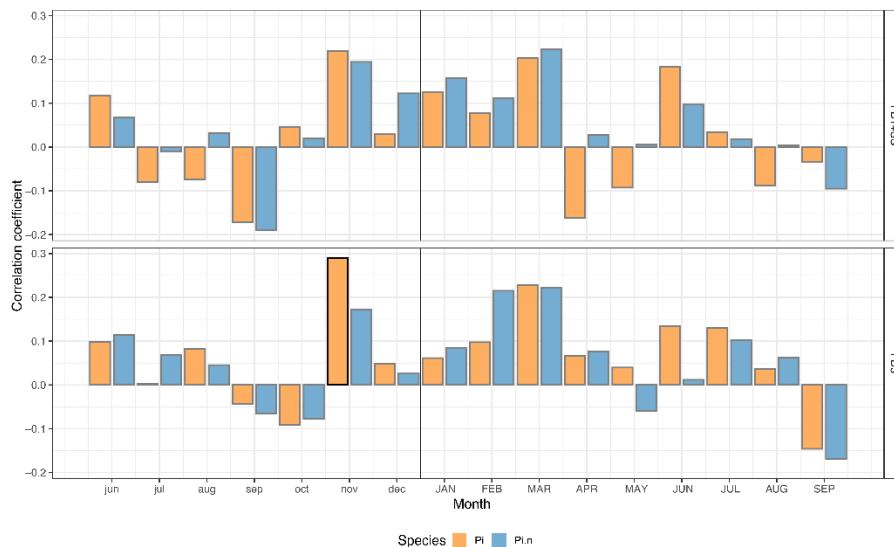


Figure 4.14 Dendroclimatic model of minimum monthly temperature [climatic factor] in relation to the phytoclimatic zones encountered for Scots pine and black pine during the period 1960–2020. Statistically significant correlations are highlighted with a black box; months written in uppercase correspond to the year of ring formation, while lowercase months correspond to the previous year.

The dendroclimatic model for maximum monthly temperature revealed inverse relationships with growth in September and October of the previous year, with significant differences observed only in September for the pine species in the FD₁+S₅ phytoclimatic zone. In September of the previous year, correlations with growth were positive, indicating that maximum temperature influenced nutrient storage, thereby promoting growth in the new growing season (Figure 4.15).

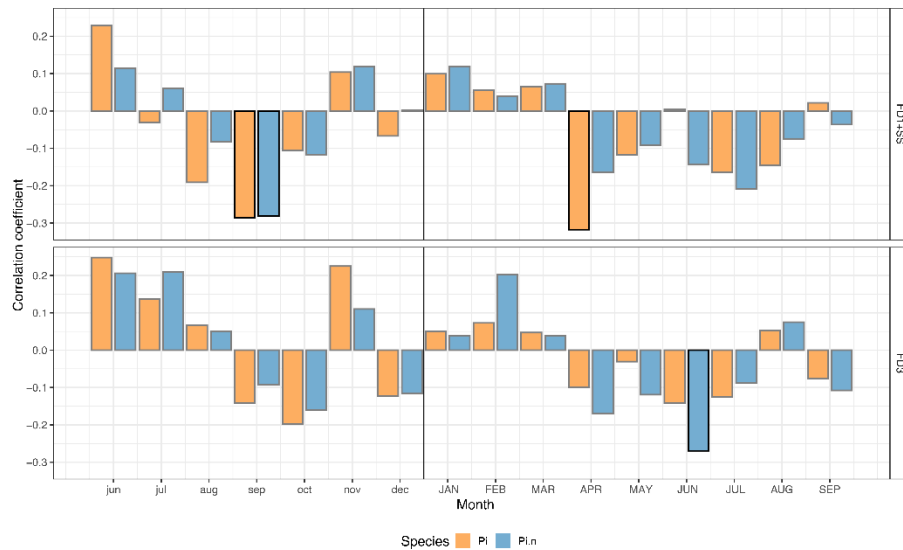


Figure 4.15 Dendroclimatic model for maximum monthly temperature [climatic factor] in relation to the phytoclimatic zones encountered for Scots pine and black pine during the period 1960–2020. Statistically significant correlations are marked with a black box; months written in uppercase correspond to the year of ring formation, while lowercase months correspond to the previous year.

The dendroclimatic model for precipitation revealed positive correlations with radial growth in November of the previous year (Figure 4.16). The amount of water stored during the previous autumn positively influenced growth at the beginning of the current growing season (March, April), as well as in June, where correlations were significant for both pine species across the encountered phytoclimatic zones.

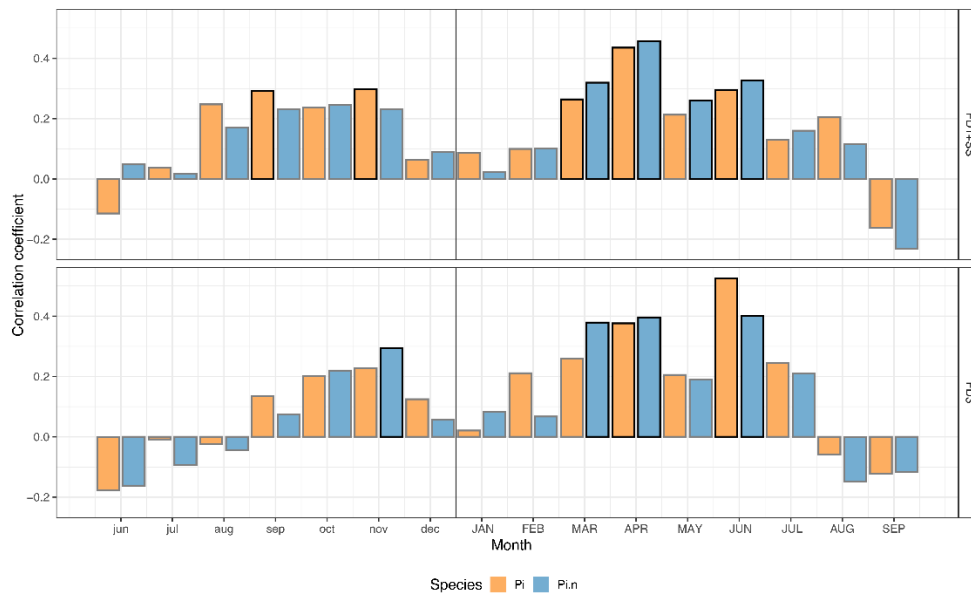


Figure 4.16 Dendroclimatic model for precipitation [climatic factor] in relation to the phytoclimatic zones encountered for Scots pine and black pine during the period 1960–2020. Statistically significant correlations are highlighted with a black box; months written in uppercase correspond to the year of ring formation, while lowercase months correspond to the previous year.

The dendroclimatic model for the water balance or soil water availability revealed positive correlations with growth in November of the previous year (Figure 4.17). The loss of soil water reserves through evapotranspiration did not affect the water balance of the previous autumn, which positively favored

growth at the beginning of the new growing season, as well as during the summer months. Positive and significant correlations were observed in April and June for the studied pine species, regardless of the phytoclimatic zone.

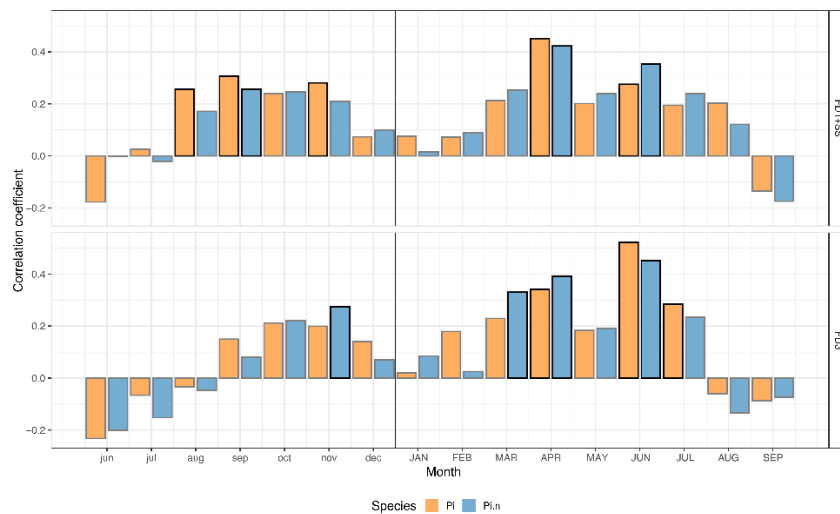
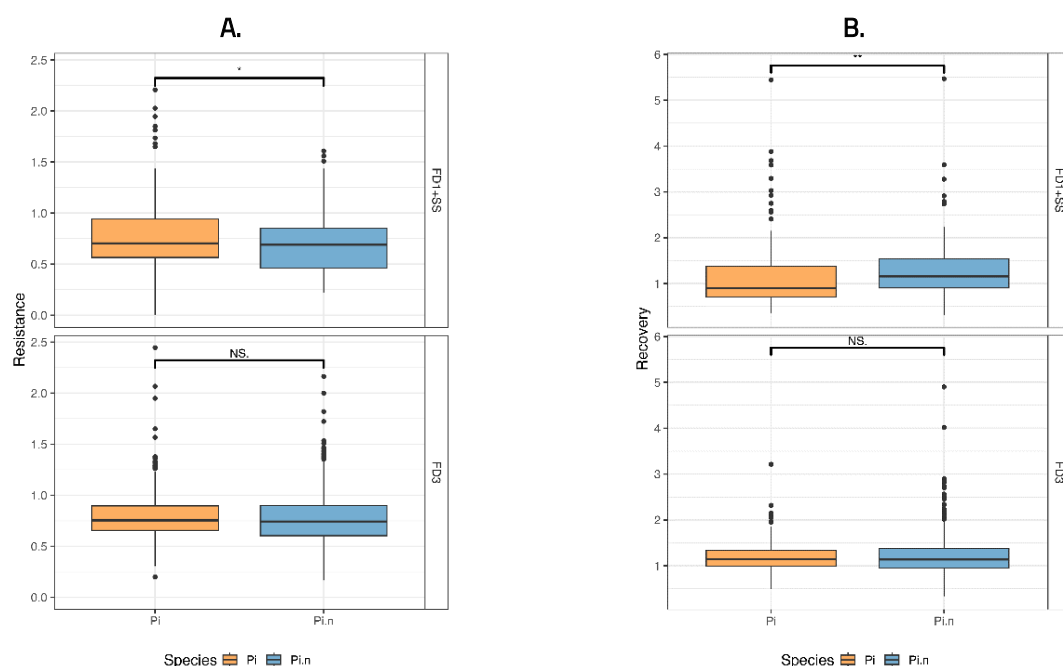


Figure 4.17 Dendroclimatic model for water balance [climatic factor] in relation to the phytoclimatic zones encountered for Scots pine and black pine during the period 1960–2020. Statistically significant correlations are highlighted with a black box; months written in uppercase correspond to the year of ring formation, while lowercase months correspond to the previous year.

4.3.4 Variability of resilience components

Resilience indices were calculated based on radial growth at the individual tree level. These indices effectively reflect the trees' responses to extreme events, in this case, drought.

The components of resilience (resistance, recovery, recovery period, and resilience), determined for all trees while excluding erosion effects (Figures 4.18A, 4.18B, 4.18C, and 4.18D), indicated that Scots pine exhibits a higher resistance capacity compared to black pine across the encountered phytoclimatic zones, being able to recover growth losses more rapidly following the drought event, with significant differences observed in resistance and distinctly significant differences in recovery.



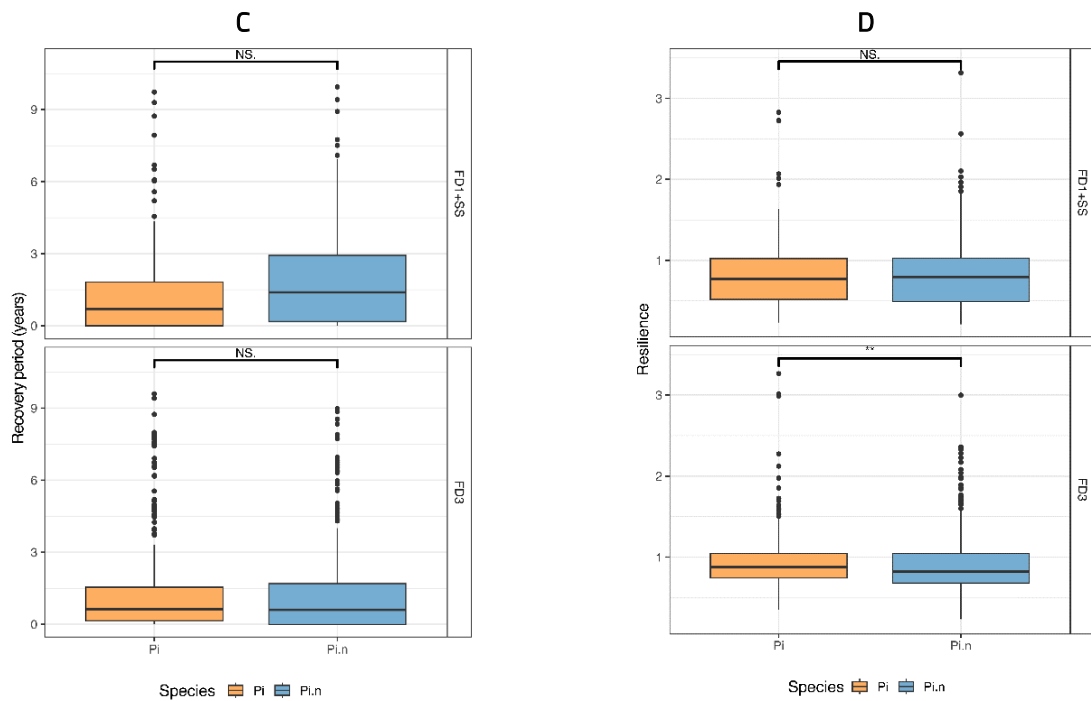


Figure 4.18 Resilience components of pine species by phytoclimatic zone for the three drought years similar to the study areas: A – resistance; B – recovery; C – recovery period; D – resilience (Symbol significance: * $p < 0.05$; ** $p < 0.01$).

Regarding the main types of erosion (in surface and in depth), the resilience components (resistance, recovery, recovery period, and resilience) assessed at the tree level showed that Scots pine exhibits a superior resistance capacity compared to black pine, regardless of the erosion type and phytoclimatic zone, managing to maintain its growth rate in post-drought periods.

Although black pine is highly tolerant to drought and wind stress (Isajev et al., 2004) due to its higher potassium content in needles, it displayed increased sensitivity in terms of resistance and recovery following the extreme drought events of 2000 and 2003, which negatively impacted its growth. One hypothesis to explain this is that drought-induced stress in black pine delays xylem formation, thereby shortening the radial growth phase and resulting in the production of fewer mature tracheids (Guada et al., 2016).

Statistical analysis using the non-parametric Wilcoxon test revealed distinct significant differences between means at the tree level only on eroded lands in depth for the recovery and resilience indices ($P=99\%$), and significant differences for resistance and recovery period indices ($P=95\%$) (Figures 4.19A–D). A possible explanation is that, with increased precipitation amounts, eroded lands in depth (gullies, landslides) possess a greater capacity to conserve and store soil moisture, especially during torrential summer rains, thereby enhancing nutrient retention and promoting growth (Lal, 2001).

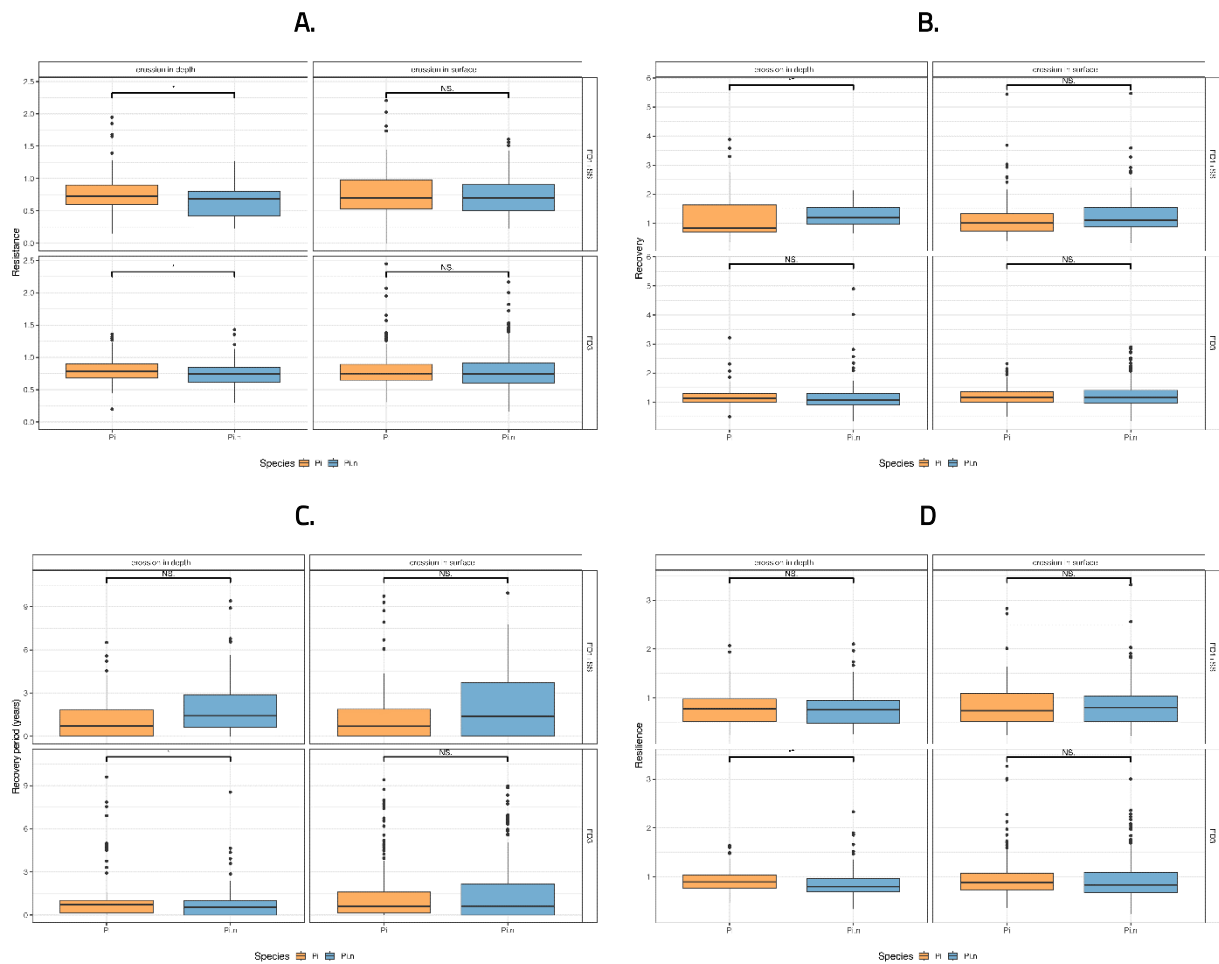


Figure 4.19 Pine resilience components according to the phytoclimatic zone and soil erosion type for the three drought years corresponding to the study areas: A – resistance; B – recovery; C – recovery period; D – resilience (Symbols: * – $p < 0.05$; ** – $p < 0.01$).

4.4 Analysis of some qualitative indicators of pine wood from degraded lands

4.4.1 Particularities regarding the density of pine wood

Results regarding the variation of wood density, aboveground biomass, and carbon stock

Within the conducted research, *wood density, aboveground biomass, and carbon stock* were evaluated for Scots pine and black pine species across two phytoclimatic zones (FD₃ and FD_{1+S₅}). The results revealed higher values for all three variables in black pine compared to Scots pine in both analyzed zones (between $443.17 \pm 41.76 \text{ kg} \cdot \text{m}^{-3}$ and $524.48 \pm 94.97 \text{ kg} \cdot \text{m}^{-3}$; between $42.75 \text{ to} \cdot \text{ha}^{-1}$ and $49.91 \text{ to} \cdot \text{ha}^{-1}$; between $21.80 \text{ to} \cdot \text{ha}^{-1}$ and $25.46 \text{ to} \cdot \text{ha}^{-1}$, versus $405.27 \pm 33.40 \text{ kg} \cdot \text{m}^{-3}$ and $454.45 \pm 67.39 \text{ kg} \cdot \text{m}^{-3}$; $29.53 \text{ to} \cdot \text{ha}^{-1}$ and $42.04 \text{ to} \cdot \text{ha}^{-1}$; $15.06 \text{ to} \cdot \text{ha}^{-1}$ and $21.44 \text{ to} \cdot \text{ha}^{-1}$). Additionally, the FD₃ phytoclimatic zone was characterized by higher mean wood densities ($454.45 \pm 67.39 \text{ kg} \cdot \text{m}^{-3}$ for Scots pine and $524.48 \pm 94.97 \text{ kg} \cdot \text{m}^{-3}$ for black pine), as well as elevated levels of biomass and carbon stock ($42.04 \text{ to} \cdot \text{ha}^{-1}$ for Scots pine and $49.91 \text{ to} \cdot \text{ha}^{-1}$ for black pine; $21.44 \text{ to} \cdot \text{ha}^{-1}$ for Scots pine and $25.46 \text{ to} \cdot \text{ha}^{-1}$ for black pine), suggesting more favorable ecological conditions for stand development. These results contribute to a better understanding of the carbon sequestration potential in forest ecosystems within the studied phytoclimatic zones.

Wood density varied depending on the type of erosion and species, with black pine exhibiting higher mean values than Scots pine on both eroded lands in surface (518.06 vs. 456.69 kg·m⁻³) and in depth (545.67 vs. 444.14 kg·m⁻³), highlighting a superior adaptability of this species under the less productive site conditions found in the studied phytoclimatic zones (Fig. 4.20, Fig. 4.21).

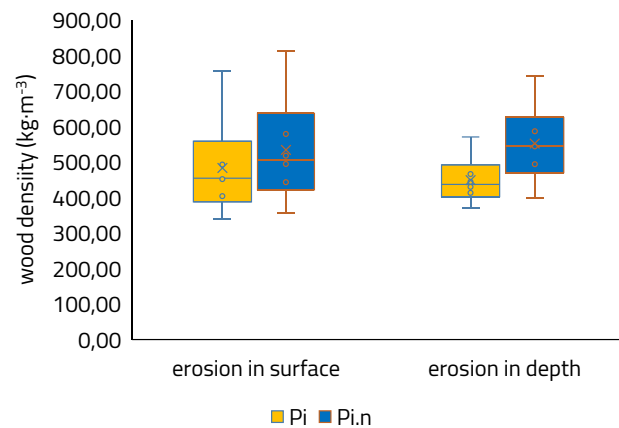


Figure 4.20 Variation of wood density in Scots pine and Black Pine on sites with different forms of erosion (plots from pine stands located in the FD₃ phytoclimatic zone).

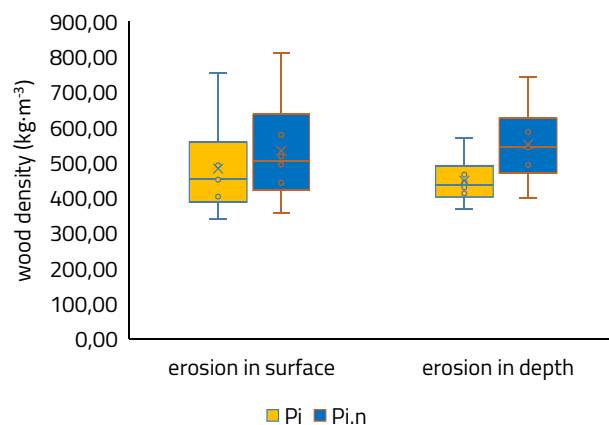


Figure 4.21 Variation of wood density in Scots pine and Black Pine on sites with different forms of erosion (plots from pine stands located in the FD₁+S_s phytoclimatic zone).

The ANOVA statistical test revealed significant differences between means in the FD₃ phytoclimatic zone, where wood density variability is more pronounced. In contrast, in the FD₁+S_s phytoclimatic zone, significant differences were observed only on eroded lands in surface.

Modelling of wood density and derived quantitative indicators (aboveground biomass, carbon stock)

The modelling of individual experimental values of wood density and associated quantitative indicators revealed significant relationships with the trees' diameter at breast height, using linear regression and Pearson's correlation coefficients. The results demonstrated positive and direct correlations, indicating that as the diameter increases, the values of wood density and its derived variables increase proportionally (Fig. 4.22A, Fig. 4.22B). The most significant correlations were identified in stands from the FD₃ phytoclimatic zone, confirming the direct link between the dimensional growth of the trees and the qualitative characteristics of the wood.

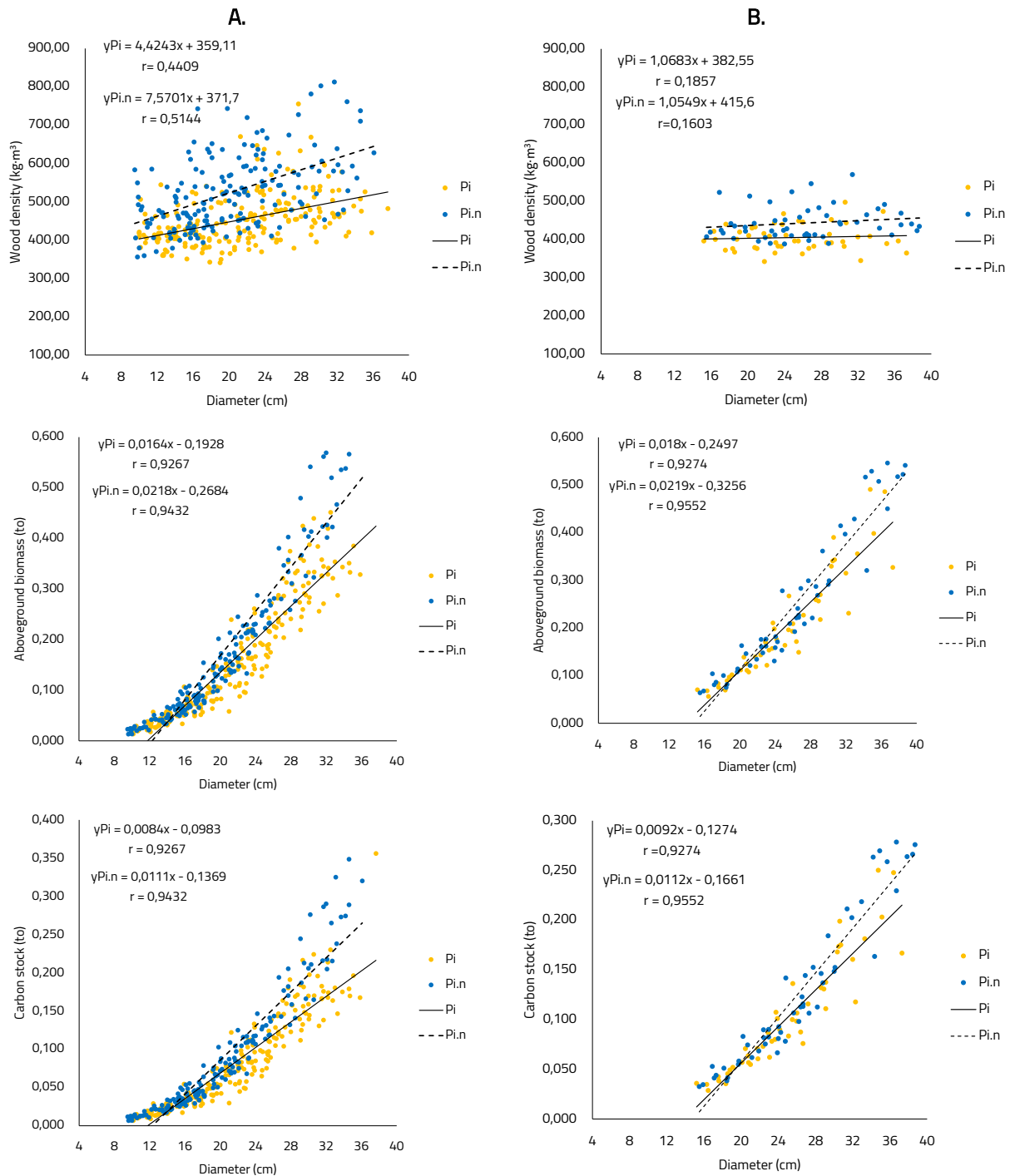


Figure 4.22 Modelling of selected qualitative wood indicators in relation to tree diameter using linear regression equations: A. FD_3 ; B. FD_1+S_5 .

Wood density represents one of the most important physical properties of wood, directly influencing its mechanical strength and serving as a key indicator in assessing its quality and utilization potential (Kantieva et al., 2021). This property varies depending on species, anatomical structure, environmental conditions, and silvicultural interventions (Brichta et al., 2023). Studies indicate that black pine generally has a higher density than Scots pine, due to a greater proportion of latewood and its capacity for structural adaptation (Pazdrowski, 2004). Variations observed at the level of the sampling plots reflect the genetic influence, type of erosion, and local ecological conditions (Thornquist, 1993).

4.4.2 Particularities regarding resistance to micro-drilling in pine species

Results regarding the variation of wood resistance measured by micro-drilling

The average wood resistance measured by micro-drilling showed higher values for black pine (ranging from $41.78 \pm 8.09\%$ to $42.66 \pm 7.13\%$) compared to Scots pine (ranging from $30.83 \pm 8.47\%$ to $33.67 \pm 7.59\%$) across the studied phytoclimatic zones. These differences confirm the superior mechanical properties of black pine wood, reflecting a more compact internal structure and a higher proportion of latewood, regardless of environmental conditions (Pazdrowski, 2004).

Wood resistance to micro-drilling varied significantly depending on species, *erosion type*, and *phytoclimatic zone*. In the FD_3 phytoclimatic zone, mean values were higher on eroded lands in depth compared to eroded land in surface, with black pine consistently exhibiting greater resistance than Scots pine (45.07% vs. 35.38% erosion in depth; 40.96% vs. 32.79% erosion in surface) (Figure 4.23).

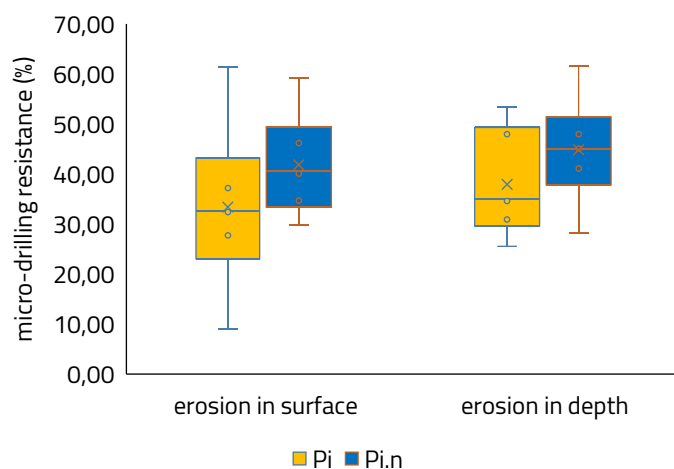


Figure 4.23 Variation in micro-drilling resistance within samples of Scots pine and black pine trees on sites exhibiting different forms of erosion, located in the FD_3 phytoclimatic zone.

The variation of wood resistance with micro-drilling depth depends on the internal structure of the wood (Fundova et al., 2018). Along the micro-drilling path, intervals of decreased wood resistance appear, influenced by the wood density of the annual rings in the transversal wood section (Krzemień et al., 2015). A distinct trend of increasing micro-drilling resistance towards the heartwood was observed in the transverse section, more pronounced in black pine, reflecting the higher average wood density of this species (Fig. 4.24A, 4.24B).

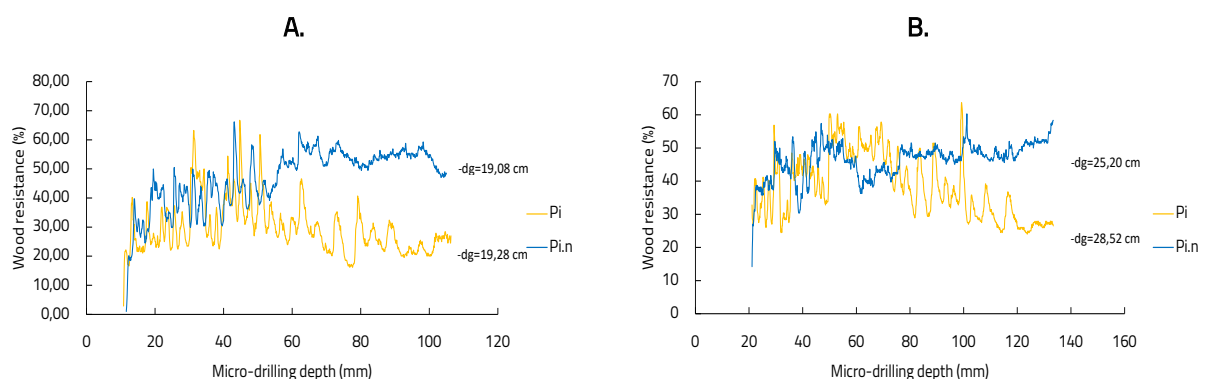


Figure 4.24 Variation of micro-drilling resistance in average trees: A. PA Căciu-Bârsești (CA); B. PA Roșoiu-Andreiașu (RO).

In the FD_1+S_s phytoclimatic zone, differences between species persisted; however, resistance values were generally lower, especially for Scots pine, which exhibited the lowest values on eroded lands in depth (29.03%) (Figure 4.25). These results underscore the superior mechanical properties of black pine under poor site conditions, indicating greater structural strength and better adaptability in degraded forest ecosystems (Figure 4.26).

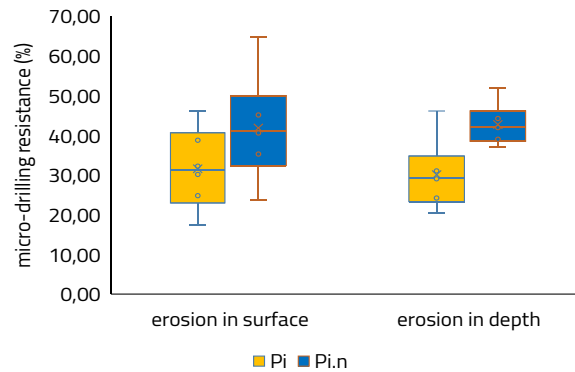


Figure 4.25 Variation of micro-drilling resistance within plots with Scots pine and black pine tree on lands with different erosion types located in the FD_1+S_s phytoclimatic zone.

In the FD_1+S_s phytoclimatic zone, micro-drilling resistance profiles revealed a high predisposition for the occurrence of internal defects, especially in Scots pine trees (Figure 4.26B). These defects indicate the presence of characteristics affecting the internal wood structure, such as resin pockets, decay and so on (Figure 4.26C).

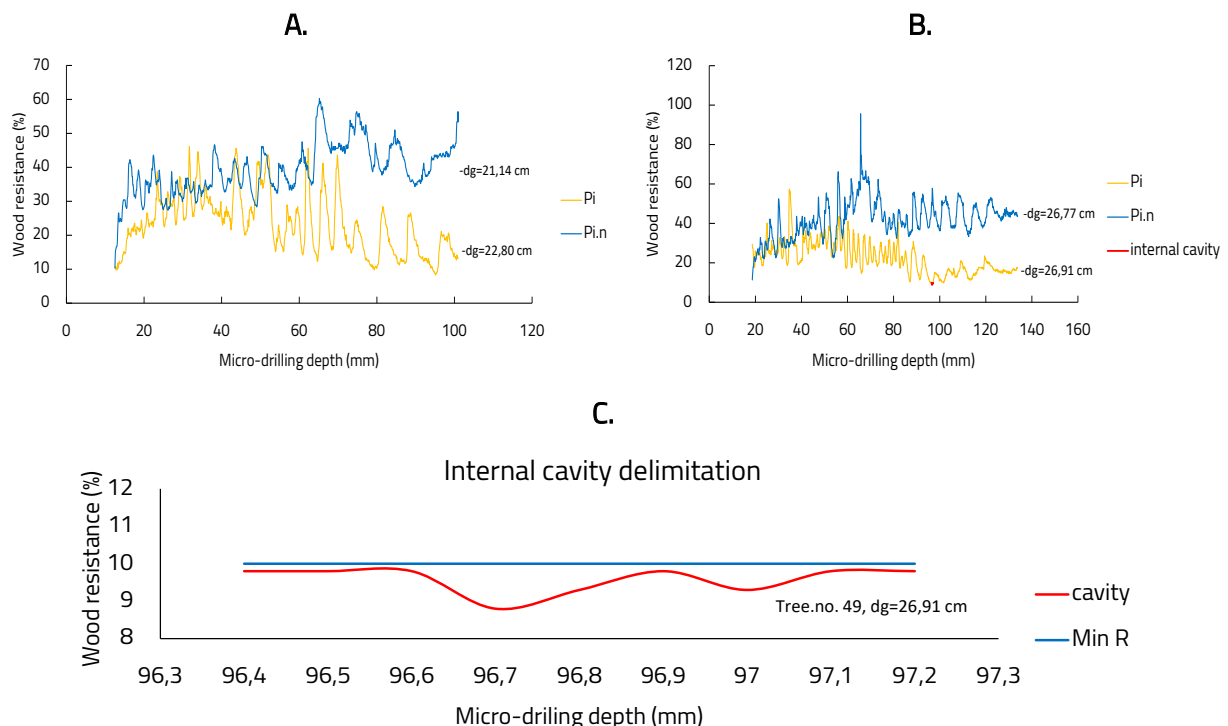


Figure 4.26 Variation of micro-drilling resistance in average trees: A. PA Murgești (MU); B. PA Livada-Râmnicu Sărat (LI); C. Delimitation of potential decay zones (specific case for average trees from PA Livada-Râmnicu Sărat)

The ANOVA test confirmed the existence of significant differences between the mean wood resistance values calculated for the pine species ($p < 0.05$), regardless of erosion type and phytoclimatic zone.

Modelling wood resistance to micro-drilling in relation to wood density

The results highlighted a positive and direct correlative relationship between wood density and resistance to micro-drilling, indicating an interdependent association between the two variables (Fig. 4.27A, Fig. 4.27B). Statistically significant correlations ($p < 0.05$) were observed only for Scots pine trees from the FD₃ phytoclimatic zone.

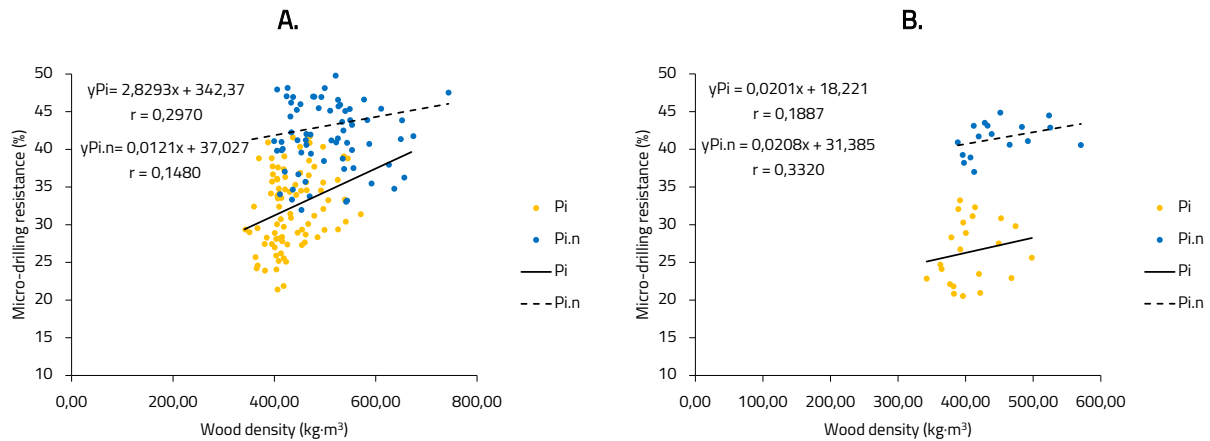


Figure 4.27 Modelling wood resistance to micro-drilling as a function of wood density using linear regression equations: A. FD₃; B. FD₁+S_s.

4.4.3 Particularities regarding sound velocity in pine species

Results regarding the variation of sound propagation velocity through the cross-section of trees

The average velocity of sound propagation through wood exhibited specific variations in function of species and phytoclimatic zone.

Overall, higher values were recorded for black pine (ranging from $1342.08 \pm 107.60 \text{ m}\cdot\text{s}^{-1}$ to $1392.52 \pm 131.80 \text{ m}\cdot\text{s}^{-1}$) compared to Scots pine ($1283.87 \pm 144.33 \text{ m}\cdot\text{s}^{-1}$ to $1298.97 \pm 116.36 \text{ m}\cdot\text{s}^{-1}$) across the studied phytoclimatic zones and the showed differences reflect the direct influence of environmental conditions and dimensional attributes of trees on the acoustic properties of wood.

The analysis of average sound velocity on degraded lands eroded both in surface and depth within the investigated phytoclimatic zones, highlighted significant variations linked to species and degradation type (see Fig. 4.28 and Fig. 4.29). Sound propagation velocity was constantly higher in the case of black pine, a pattern attributable to higher wood density of this species, influencing positively the acoustic wood material behaviour.

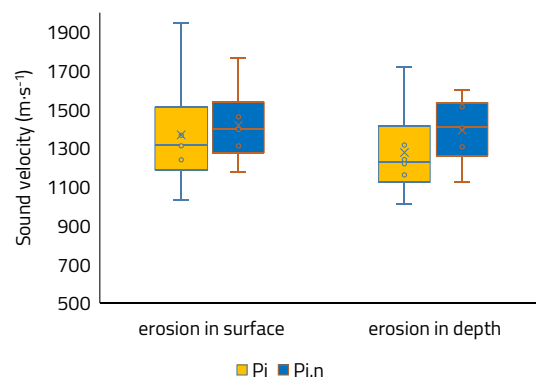


Figure 4.28 Variation in sound propagation velocity in wood from sample plots of Scots Pine and black pine trees on lands with different erosion forms within the FD₃ phytoclimatic zone.

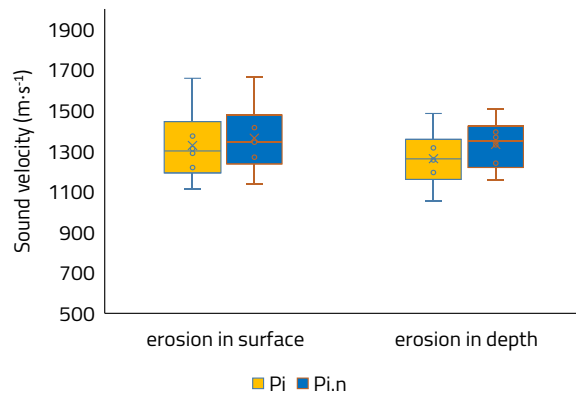


Figure 4.29 Variation in sound propagation velocity in wood from sample plots of Scots Pine and black pine trees on lands with different erosion forms within the FD_1+S_s phytoclimatic zone.

The ANOVA test revealed statistically significant differences between the mean values of sound propagation velocity for the studied pine species ($p < 0.05$), particularly under degraded lands conditions from the FD_3 phytoclimatic zone, with significantly higher sound velocity increases in the case of black pine species.

Modelling sound velocity in relation to wood density

The analysis of the relationship between wood density and sound velocity revealed a direct correlation, confirmed through linear regression modelling, which proved suitable for estimating the interdependence between the two variables (Fig. 4.30A, Fig. 4.30B). Statistically significant results were obtained in pine stands located in the FD_3 phytoclimatic zone, indicating that higher wood density is associated with increased sound velocity. In contrast, in the FD_1+S_s phytoclimatic zone, the relationships remained positive but were not statistically significant, likely due to a smaller sample size and the influence of abiotic factors that contributed to increased variability in the physical-mechanical properties of the wood. The acoustic analysis also demonstrated its effectiveness in the early detection of internal wood defects, with the values recorded for both Scots pine and black pine trees indicating a generally healthy wood condition (sound velocities $>1200 \text{ m} \cdot \text{s}^{-1}$) (Gezer et al., 2015). Sound wave propagation is highly sensitive to the presence of structural defects such as decay, as well as internal factors like knots or compression wood (Sasaki et al., 1998). These findings confirm the applicability of method in forestry, offering important research insights for risk management related to internal wood degradation, and contributing to the improvement of stability and wood quality.

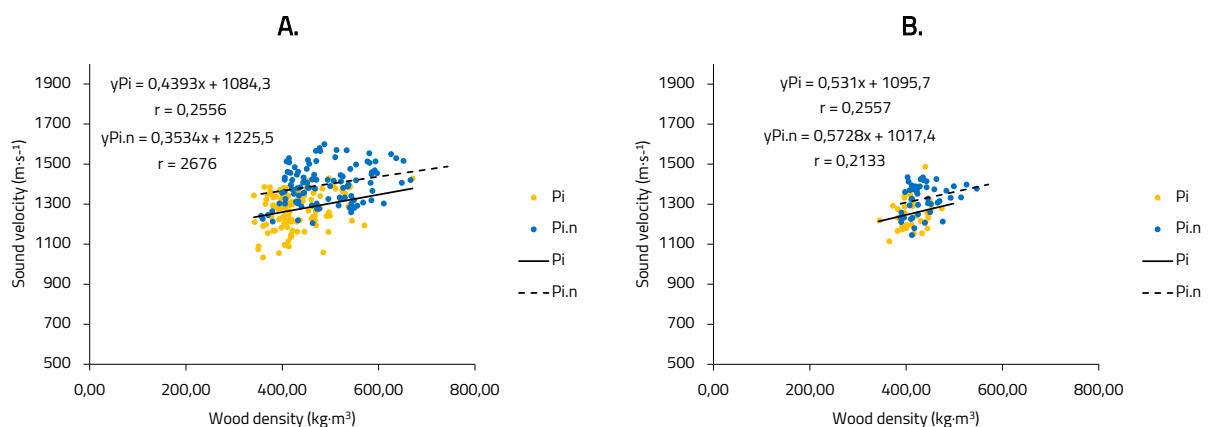


Figure 4.30 Modelling sound velocity in wood as a function of wood density using linear regression equations: A. FD_3 ; B. FD_1+S_s .

5. CONCLUSIONS

Following the research conducted, the processing of information, and the analysis of the results obtained within this doctoral thesis, pertinent and scientifically grounded conclusions can be formulated, contributing to the development of knowledge both regarding the structure, health status, and auxology of pine trees and stands established on degraded lands in the Curvature Subcarpathians, as well as certain physical and mechanical indicators of the wood of the component trees.

Regarding stand structure in relation to tree diameter, the theoretical Beta frequency curves exhibited clear left-skewed positive asymmetry in pine stands of the III age class (41–60 years), due to the concentration of a large number of trees in the lower diameter classes. This pattern is typical of poor site and vegetation conditions characteristic of degraded lands (such as shallow soil, steep slopes, unstable slope configurations and so on.). In contrast, in stands classified within the IV age class (61–80 years), there is a tendency toward a relatively normal distribution of the experimental values

Regarding height, a slight tendency was observed for pine trees to migrate from lower positional classes to higher ones, due to the natural thinning process that subsequently favored increased light penetration and the expansion of the vital growth space, positively impacting the development of important dimensional characteristics (diameter and height) through photosynthesis. In contrast to the previously described situation, in stands within the III age class (41–60 years), the theoretical Beta frequency curves showed clear negative right-skewed asymmetry. Similarly, in pine stands classified in the IV age class (61–80 years), the same tendency toward a relatively normal distribution of experimental values is observed, these being more stable and dynamically balanced.

Regarding the tree volume, the theoretical Gamma frequency curves showed clear positive left skewness, similar to the case of diameters for both age classes, highlighting the inability of these stands to accumulate large volumes, a fact caused by the limited site conditions as well as the terrain orography, which favored the accelerated development of erosion processes.

By comparing the experimental distributions with the theoretical ones, significant differences were found at the level of both analyzed pine species (Scots pine and black pine), the Kolmogorov-Smirnov (K-S) and Chi-square (χ^2) conformity tests indicated that the Beta functions (in the case of diameters and heights) and the Gamma functions (in the case of volumes) are the most appropriate for fitting the experimental values, having a high degree of plasticity. Also, through the analysis of the dynamics of the structure of the pine stands, examined using the structural indices Camino and Gini, specific features of a homogeneous even-aged structure were highlighted in terms of the number of trees and basal area, thus providing important indicators for their future evolution.

Regarding the health assessment of pine stands, the average defoliation percentage for the two analyzed pine species exhibits varying intensity depending on the age of the stands and the phytoclimatic zone. Thus, in pine stands located within the FD₃ phytoclimatic zone, the average defoliation percentage was higher in mixed stands composed of Scots pine and black pine, with defoliation intensity being significantly greater within black pine populations. This aspect correlates with the relatively low participation rate of black pine in the composition, as well as with structural indicator values lower than those recorded for Scots pine stands. In this context, the degree of competition between the two species is manifested through a high frequency of suppression ratios, leading to an increased average defoliation percentage for black pine populations, due to the gradual

migration of trees from higher Kraft social classes to lower ones. Similarly, the average defoliation percentage remains elevated in pure stands of Scots pine and black pine within the phytoclimatic zone defined by the internal forest steppe and the hill oak forests (FD₁+S_s). The intensity of defoliation varies depending on species and stand age, with the most affected being those in the IV age class, predominantly black pine populations; however, statistical differences between means are not significant.

After the average drying degree (G_u), the Scots pine and black pine stands belonging to the two phytoclimatic zones (FD₃, FD₁+S_s) were moderately affected by drying, with a higher variation in intensity in the pine stands located in the FD₃ phytoclimatic zone, ranging from slightly to very strongly affected. This aspect can be explained by the increased variability of the defoliation percentage in stands with stocking and density indices close to the value of 1, a cause attributed to the generally lower social class position, associated with the action of damaging abiotic factors (wind, snow) and inter- and intraspecific competition ratios, which over time have led to the deterioration of the health status of these stands.

After the degree of damage (G_v), Scots pine and black pine stands belonging to the two phytoclimatic zones (FD₃, FD₁+S_s) were moderately affected by damage, with fairly frequent occurrences of windthrow and breakage caused by wind and snow. The variation in the degree of damage increased with the advancing age of the stands, with damage intensity ranging from slight to very severe in stands of the IV age class (61–80 years), where isolated and very frequent windthrows and breakages were recorded, particularly noticeable in the upper third of the stems. The fairly frequent and very frequent damages observed in the stem formation of the analyzed pine trees increase alongside the harsh growth site conditions characteristic of degraded land. The interaction between ecological and climate-soil factors negatively influences the behavior and health status of pine stands artificially established on degraded lands, providing scientific rationale for the success of their ecological restoration.

Regarding the dynamics of the auxological processes of pine stands on degraded lands, fundamental research represents a main objective in forest monitoring. Auxological indicators were determined at the level of experimental plots, based on growth core sampling conducted within these plots, with physiological and auxological information identified within the annual growth ring. *Analysis of radial growth processes through dendrochronological series showed that* the growth dynamics of pine trees belonging to the two species (Scots pine and Black pine) presented a decreasing trend in the studied areas, explained by the stem geometry and the developmental phases of the trees (higher radial growth during the juvenile period, followed by a gradual reduction with increasing diameter). From 1960 to 2020, in the FD₃ phytoclimatic zone, the mean radial growth rate (TRW) improved in growth cores belonging to Scots pine, being higher compared to those of Black pine. In contrast, in the phytoclimatic zone defined by the internal forest steppe and the hill oak forests (FD₁+S_s), the mean radial growth rate in growth cores belonging to Black pine was higher compared to those of Scots pine.

Regarding the dynamics of basal area increment (BAI) growth processes, the growth curve showed an increasing trend during the juvenile growth period, followed by lower growth rates correlated with drought years. The basal area increment (BAI) exhibited a negative trend starting in 2003 for both pine species (Scots pine and Black pine), indicating a high level of stress to which the trees were exposed. This negative trend may also represent an early warning signal of tree decline. Higher basal area

increment (BAI) rates were observed in growth cores from Scots pine trees in stands classified within the FD₃ phytoclimatic zone, and in Black pine trees from stands classified within the internal forest steppe and the hill oak forests (FD₁+S₅). BAI fluctuations were more numerous in the growth cores from Black pine trees, while higher BAI rate increases after 2000 were noted in cores from Scots pine trees.

Within pine stands on degraded lands during the analysis period 2011-2020 showed a higher *average radial growth rate over the last 10 years* in the growth cores from Scots pine trees in the FD₃ phytoclimatic zone, which also led to an increase in BAI rates after 2000, this species demonstrating a better adaptability to the shallow site conditions specific to this area. In contrast, in internal forest steppe zone and the hill oak forests (FD₁+S₅), the average radial growth rate over the last 10 years was higher in the growth cores from Black pine trees, Scots pine trees being much more susceptible to stress factors in this area, indicating a decline in growth during the 2011-2020 analysis period.

In the FD₃ phytoclimatic zone, the *average basal area growth rate* was higher in the growth samples of Scots pine compared to those from the FD₁+S₅ phytoclimatic zone, while it was higher in the growth samples of black pine belonging to the FD₁+S₅ phytoclimatic zone compared to those from the FD₃ zone, both pine species (Scots pine and black pine) exhibiting different behavior concerning the accumulation of woody biomass in relation to the ecological conditions of the species and the growth fluctuations correlated with climatic factors.

At the same time, the values obtained for *volume growths*, both at the tree level and at the stand level, indicate a better productivity of Scots pine stands in FD₃, respectively of black pine stands in FD₁+S₅, due to the high variability of individual radial growth values, as a result of intense inter- and intraspecific competition processes, the diversified conditions of micro-sites identified through site mapping, but also due to the action of damaging abiotic factors, which on the one hand led to the reduction in the number of trees in certain concentration points within the stands, and on the other hand caused physiological destabilization at the foliar apparatus level through multiple damages recorded in the upper third of the stem. Certainly, the production of these stands is not entirely influenced by the individual values of radial growth, but depends on a combination of factors involved in its evaluation, the most important being species, age, and productivity class.

Regarding the evolution of radial growth processes by erosion types, in the samples from the FD₃ phytoclimatic zone, Scots pine trees exhibited a higher average radial growth rate compared to black pine trees on both types of erosion, with the differences between means being statistically significant at a 95% confidence level only on eroded lands in depth. In contrast, in the samples conducted in internal forest steppe zone and the hill oak forests (FD₁+S₅), black pine trees showed a higher average radial growth rate than Scots pine on both types of erosion, with significant differences between means recorded only on eroded lands in depth. Referring to the samples taken from the two studied zones, the basal area growth and volume growth determined by the indirect method follow the same rule, according to which radial growth values are uniformly distributed according to a linear regression equation of the form $y = a \cdot x + b$, specific to even-aged stands, where the experimental growth values increase directly proportional to the tree diameter and stem geometry. Similarly, basal area and volume growths varied according to the ecological requirements of the species, age, and productivity classes, under the influence of climatic factors (temperature, precipitation) which led to significant accumulations of woody biomass, especially on eroded lands in depth.

Regarding the influence of temperatures (monthly averages, minimum, maximum), precipitations, and water balance on the radial growth processes of the trees, dendroclimatic models have highlighted that:

- *In the case of average monthly temperature*, most correlations were positive and significant with the radial growth processes for Scots pine trees from the forest surveys carried out in the FD₃ phytoclimatic zone, as well as for black pine trees from the forest surveys conducted in internal forest steppe zone and the hill oak forests (FD₁+S₅). The two species react similarly through positive correlations at the beginning of the new growth season of the current year in the forest surveys from the FD₃ zone, however, Scots pine trees are more predisposed to the analyzed climatic factor in the FD₁+S₅ zone, with correlations being negative at the start of the growing season of the current year. These elements indicate a differentiation between the two pine species analyzed regarding their growth response to average monthly temperatures.
- *The minimum monthly temperature* in November of the year preceding the formation of the annual ring correlates positively and significantly with the radial growth processes in both pine species. In the current year, minimum temperatures in September showed a negative correlation.
- In the case of *maximum monthly temperature*, most correlations with radial growth processes were negative during the summer months of the current year, especially for trees of the black pine species in the forest surveys conducted in the FD₃ phytoclimatic zone. In contrast, in the forest surveys carried out in the internal forest-steppe zone and hill oak forests (FD₁+S₅), negative correlations with growth processes were recorded for Scots pine trees, with growth loss being greater in this case.
- *The monthly precipitation amount* from the autumn of the previous year led to an acceleration of the radial growth processes in the current year for both pine species, with positive and significant correlations observed in April and June of the current year. Negative correlations were, however, evident in August of both the previous and current years, as well as in September of the current year, with growth being strongly negatively influenced by this climatic factor.
- *The water balance (soil water availability)* shows a similar pattern to that of the monthly precipitation amount, with the water reserve stored in the autumn of the previous year leading to positive correlations in the current year with radial growth processes due to its amplification.

Regarding the response of trees during drought years (2000, 2003, 2007), quantified by resilience indices, a clear differentiation was observed in the resistance and recovery capacity of the two pine species in relation to the phytoclimatic zone and erosion type. According to the obtained results, Scots pine trees showed a higher capacity for resistance and recovery compared to black pine trees after drought, regardless of the phytoclimatic zone and erosion type during the three drought years, signaling clearly that the resilience of this species is not conditioned by the site factor, but by its ecological requirements and the involvement of climatic factors which activate certain physiological self-regulation functions. Despite the fact that black pine demonstrated significantly superior growth compared to Scots pine in growth samples conducted in low altitude areas, it still exhibits high sensitivity regarding resistance and recovery after drought events, being much more prone to physiological decline. Against the backdrop of this sensitivity, a scientifically supported hypothesis is strictly related to the delayed formation of wood during the stress factor, involving a reduction in the duration of radial growth processes and the formation of a reduced number of mature tracheids.

Regarding the analysis of qualitative indicators of a physico-mechanical nature (density, resistance to micro-drilling, velocity of sound through wood), clearly superior particularities were highlighted in the internal structure of black pine wood compared to that of Scots pine, the former demonstrating a high resistance capacity to the mechanical action of various disruptive factors:

- *Regarding wood density,* the results indicated a high probability of significant differences between the mean wood density on eroded lands in depth in the forest surveys conducted in FD₃, with greater amplitudes observed for the black pine species. This is attributed to its higher capacity to form earlywood and latewood compared to Scots pine, leading to increased density and hardness. Furthermore, both Scots pine and black pine trees recorded higher density values for individuals in the lower diameter classes, a fact explained by the presence of additional stress factors that accelerated radial growth processes and implicitly increased density, strength, and hardness
- *Regarding wood resistance to micro-drilling,* it was observed that the experimental values increased directly proportional to the wood density values in the reference cross-section of the trees, especially on eroded lands in depth, with significant differences between the means for the two analyzed pine species. The results indicated higher micro-drilling resistance values in black pine trees, confirming the hypothesis of a greater formation proportion of latewood and intermediate wood, which subsequently generated additional resistance forces to micro-drilling.
- *Regarding the velocity of sound propagation through wood,* the results indicated high experimental values in the reference cross-section of black pine trees compared to Scots pine, with significant differences between the means especially on eroded lands in depth. The trend was increasing alongside the increase in wood density. The high variability of sound velocity values may be caused by physical changes in the wood, constituting reaction wood (compression and tension wood), but a pronounced degree of impairment may be caused by a series of influencing factors present in the internal wood structure (internal knots, moisture content, compression wood and so on.).

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Through the research conducted within the doctoral thesis, new scientific information was obtained regarding the dynamics of the structure of Scots pine and black pine stands, their health status in the context of climate change, the dynamics of radial growth processes and the way radial growth is influenced by climatic factors, the resistance and recovery capacity of the two pine species following alternating drought periods and under conditions of active soil erosion, as well as the evaluation of pine wood quality in its internal structure using modern methods for determining its physical-mechanical properties. The general conclusion of the research results obtained through the elaboration of the doctoral thesis is that pine stands on degraded lands established artificially, despite the poorly productive site conditions and severe climatic factors, still manage, through their capacity to adapt to these conditions, to successfully fulfill their functions and ecosystem services specific to these types of stands. The results indicated a better adaptability of Scots pine regarding the climatic and edaphic conditions of degraded lands, having a better capacity for growth, resistance, and recovery under stress factors compared to black pine, its sensitivity to the severe effects of these factors being low. In contrast, black pine presented superior qualitative characteristics, being much more resistant to the mechanical forces exerted by harmful abiotic factors.

In this context, it is necessary to develop additional silvicultural measures aimed at ensuring sustainable management of artificial pine plantations, especially those of black pine on degraded lands in the Subcarpathian Bend area. These measures should focus on regulating structural dynamics through timely application of special conservation treatments, monitoring the evolution of natural regenerations over time, promoting seedling patches in a controlled manner, as well as periodic analysis through forest surveys of the physical and chemical properties of the soil, in order to establish scientific rationales for the successful ecological reconstruction of these plantations in the future.

6. ORIGINAL CONTRIBUTIONS

Based on the research carried out during the elaboration of the doctoral thesis, the obtained results, and the formulated conclusions, significant original scientific contributions can be stated. These mainly refer to the achievement of indicators that captured the *organisation and functioning of pine stands on degraded lands* under the influence of stress factors of competitive and site nature, *their current health status, the dynamics of growth of pine trees and stands*, adaptation to current climatic scenarios through *resistance, recovery, and resilience capacities* following drought events, as well as the state of certain qualitative physical-mechanical wood indicators, thus making an important contribution to the sustainable management of these forests by reducing soil erosion impact, conserving biodiversity, and mitigating risks arising from natural calamities. These personal contributions are presented as follows:

- ❖ The realisation for the first time in our country, for the studied area, through the quantification of specific indicators, an up-to-date analysis of the structure of Scots pine and black pine stands established in two phytoclimatic zones (FD_3 and FD_1+S_5) and distinct age classes (III and IV).
- ❖ Modelling the current structure of the studied pine stands, separately by species, age classes, and phytoclimatic zones, using appropriate theoretical functions with a high degree of plasticity in fitting the experimental values.
- ❖ Evaluation and pioneering analysis of the health status of Scots pine and black pine stands established in two phytoclimatic zones (FD_3 and FD_1+S_5), expressed through average percentage of drying, average degree of drying, and degree of damage, used within the forest health research and monitoring system.
- ❖ Analysis of the silvo-productive potential of Scots pine and black pine stands by establishing auxological indicators for the period 2011–2020 and highlighting the superior physiological characteristics of the pine species through distinct statistical comparisons based on the main erosion types (in surface and in depth) and phytoclimatic zones.
- ❖ Elaboration, for the first time, of dendrochronological series based on radial growth for Scots pine and black pine species used in the ecological reconstruction of degraded lands in two distinct phytoclimatic zones, covering the period from 1960 to 2020.
- ❖ Analysis of the influence of climatic factors on the radial growth processes of pine trees through dendroclimatic models developed separately for each species and for the investigated phytoclimatic zones.
- ❖ Quantification of the response of Scots pine and black pine trees to current climate scenarios using resilience indices (resistance, recovery, recovery period, and resilience), followed by statistical comparison of these indices across species and main erosion types (in surface and in depth), reflecting their capacity for resistance and recovery after drought events.

- ❖ Evaluation of the wood quality of standing pine trees at the reference cross-section (1.30 m) through the determination of qualitative physical-mechanical indicators of pine wood (density, resistance to micro-drilling, and sound propagation velocity through wood).
- ❖ Estimation of the internal structure quality of Scots pine and black pine wood, with implications both for managing the risk of potential damages occurring in the tree's cross-section and for developing preventive measures to limit the spread of defects that threaten the stability and physiological properties of the pine species.
- ❖ Comparative statistical analysis of qualitative physico-mechanical wood indicators of Scots pine and black pine, differentiated by main erosion types (in surface and depth erosion) and by phytoclimatic zones within the Subcarpathians of the Curvature region.
- ❖ Identification of differentiations in the dynamics of quantitative and qualitative indicators of the two pine species on degraded lands, and the establishment of new research premises aimed at optimizing the stand structure and promoting the use of pine species in afforestation compositions on such lands.

7. DISSEMINATION OF RESULTS

A. Works related to the doctoral thesis, published in ISI-indexed journals

1. Constandache, C., **Tudor, C.**, Vlad, R., Dincă, L., & POPOVICI, L. (2021). The productivity of pine stands on degraded lands. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 10. <https://landreclamationjournal.usamv.ro/pdf/2021/Art11.pdf> (corresponding author)
2. Constandache, C., **Tudor, C.**, Popovici, L., & Dincă, L. (2022). Ecological reconstruction of the stands affected by drought from meadows of inland rivers. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 11. <https://www.landreclamationjournal.usamv.ro/pdf/2022/Art9.pdf> (corresponding author)
3. Constandache, C., **Tudor, C.**, Popovici, L., & Radu, V. (2023). The state and behavior of some forestry cultures installed on degraded lands in the forest-steppe site. Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering, 12. <https://landreclamationjournal.usamv.ro/pdf/2023/Art28.pdf> (corresponding author)
4. Cristinel, C., **Ciprian, T.**, Popovici, L., Radu, V., Crișan, V., & Dincă, L. C. (2024). Structural characteristics of the pine stands on degraded lands in the south-east of Romania, in the context of climate changes. Applied Sciences, 14(18), 8127. <https://doi.org/10.3390/app14188127> (corresponding author)
5. Constandache, C., **Tudor, C.**, & Popovici, L. (2025). Indicators of the Structural and Compositional Diversity of Stands on Degraded Lands in the Vrancea Area. BOOK OF ABSTRACTS - Section 5: Land Reclamation, Earth Observation & Surveying, Environmental Engineering International Conference "Agriculture for Life, Life for Agriculture", University of Agronomic Sciences and Veterinary Medicine of Bucharest Bucharest, Romania- article accepted, pending publication (corresponding author) https://agricultureforlife.usamv.ro/images/2025/Book_of_Abstracts/Land_Reclamation_Book_of_Abstracts_2025.pdf
6. **Tudor, C.**, Constandache, C., Dinca, L., Murariu, G., Badea, N.O., Tudose, N.C., & Marin M. (2025). Pines as a Solution for Degraded Lands: Carbon Sequestration and Ecological Restoration. Forest Landscape Restoration (FLR) and Carbon Storage Dynamics, Submitted on: 16 Jun 2025- accepted for publication (first author) <https://www.frontiersin.org/journals/forests-and-global-change>

B. Works related to the doctoral thesis, published in BDI-indexed journals

1. **Tudor, C.**, Constandache, C., Popovici, L., & Vlad, R. (2022). The characteristics of some pine stands from outside the habitat, affected by drying. Lucrări Științifice Seria Horticultură, USV Iași, 65(1), 85–90 (first author)
2. **Tudor, C.**, Constandache, C., Popovici, L., Ivan, V., & Badea, N. O. (2023). Health state and behaviour of pine stands on degraded lands in the Vrancea Subcarpathians. Revista de Silvicultură și Cinegetică, 28(53). <https://journals.indexcopernicus.com/api/file/viewByFileId/1928477> (first author)
3. Pleșca, B.I., **Tudor, C.**, Frink, J.P., Constandache, C., Popovici, L., Pleșca, I.M. (2025). O stațiune nouă de Quercus pubescens Willd. în Subcarpații Vrancei: importantă resursă genetică pentru reconstrucția terenurilor degradate. Revista Pădurilor, 140(1), 3-20. <https://www.revistapadurilor.com/wp-content/uploads/2025/05/01-Plesca-et-al.pdf>

4. **Tudor, C.**, Constandache, C., Popovici, L., Badea, N.O. (2025). Investigations on the structure of pine stands on degraded lands. *Revista de Silvicultură și Cinegetică*, nr. 56- article accepted, pending publication (first author) <https://www.progresulsilvic.ro/#>

C. Works outside the doctoral thesis domain, published in ISI-indexed journals

1. Tereșneu, C. C., **Tudor, C.**, & Vasilescu, M. M. (2022). Laser caliper reliability in upper-stem diameter measurements by multiple users. *Forests*, 13(9), 1522. <https://doi.org/10.3390/f13091522>
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D. Works outside the doctoral thesis domain, published in BDI-indexed journals

1. Moldovan, M., Tăut, I., Șimonca, V., Constandache, C., Popovici, L., & **Tudor, C.** (2023). Studies regarding the identification of some solutions for the renaturation of forest lands which have been used for the growing of pheasants. *Current Trends in Natural Sciences*, 12(23), 118-125. <https://doi.org/10.47068/ctns.2023.v12i23.013>

E. Participation in International Conferences

1. Constandache, C., **Tudor, C.**, Vlad, R., Dincă, L., & Popovici, L. (2021). The productivity of pine stands on degraded lands. The International Conference of the University of Agronomic Sciences and Veterinary Medicine of Bucharest "Agriculture for Life, Life for Agriculture", June 3-5, 2021, Bucharest, Romania- oral presentation;
2. Constandache, C., **Tudor, C.**, Popovici, L., & Dincă, L. (2022). Ecological reconstruction of the stands affected by drought from meadows of inland rivers. The International Conference of the University of Agronomic Sciences and Veterinary Medicine of Bucharest "Agriculture for Life, Life for Agriculture", June 2-4, 2022, Bucharest, Romania- oral presentation;
3. **Tudor, C.**, Constandache, C., Popovici, L. (2022). The influence of the structure on the health state of the pine stands installed on the degraded lands in the Vrancea Subcarpathians. 10th International Symposium Forest and Sustainable Development, October 14-15, 2022, Brașov, Romania- poster presentation;
4. Constandache, C., **Tudor, C.**, Popovici, L., & Radu, V. (2023). The state and behavior of some forestry cultures installed on degraded lands in the forest-steppe site. The International Conference of the University of Agronomic Sciences and Veterinary Medicine of Bucharest "Agriculture for Life, Life for Agriculture", June 8-10, 2023, Bucharest, Romania- oral presentation;
5. **Tudor, C.**, Constandache, C., Popovici, L., Ivan, V., & Badea, N. O. (2023). Health state and behaviour of pine stands on degraded lands in the Vrancea Subcarpathians. 90th "Marin Drăcea" INCDS Anniversary International Scientific Conference "Forest science for people and societal challenges" October 2-5, 2023, Bucharest, Romania- oral presentation;
6. Constandache, C., **Tudor, C.**, Aga, V., & Popovici, L. (2024). Ecological restoration of Norway spruce stands affected by drying from outside the natural range. The International Conference of the University of Agronomic Sciences and Veterinary Medicine of Bucharest "Agriculture for Life, Life for Agriculture", June 6-8, 2024, Bucharest, Romania- poster presentation;

7. Pleșca, B.I., **Tudor, C.**, Frink, J.P., Constandache, C., Popovici, L., Pleșca, I.M. (2024). A new site with *Quercus pubescens* Willd. in the Vrancea Subcarpathians: an important forest genetic resource for reconstructing degraded lands. 11th International Symposium Forest and Sustainable Development, October 17-18, 2024, Brașov, Romania- poster presentation;
8. **Tudor, C.**, Constandache, C., Popovici, L., Aga, V. (2024). The health state of some pine stands and their behaviour on degraded lands from forest steppe site of Subcarpathians of Curvature 11th International Symposium Forest and Sustainable Development, October 17-18, 2024, Brașov, Romania- poster presentation.
9. Constandache, C., **Tudor, C.**, & Popovici, L. (2025). Indicators of the Structural and Compositional Diversity of Stands on Degraded Lands in the Vrancea Area. The International Conference of the University of Agronomic Sciences and Veterinary Medicine of Bucharest "Agriculture for Life, Life for Agriculture", June 5-7, 2025, Bucharest, Romania- poster presentation.

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SCURT REZUMAT

Plantațiile artificiale de pin realizate pe terenurile degradate, în afara arealului natural sunt ecosisteme forestiere cu un rol extrem de important în combaterea proceselor active de degradare, asigurând un complex de funcții eco-protective ale unor obiecte de interes economic și social importante. În condițiile schimbărilor climatice actuale, aceste arborete sunt supuse unui declin fiziologic incipient, fiind necesare măsuri silvotehnice urgente de natură să conducă la obținerea unor arborete rezilente climatic. Totodată, pe fondul scenariilor climatice severe care au indus seceta, a intensificării proceselor de degradare la nivelul solului și a acțiunii combinate a unor factori abiotici vătămători, pinetele

artificiale au suferit modificări importante în structura lor, generând o vulnerabilitate ridicată la acești factori de risc. Având în vedere tendința de creștere a temperaturii, reducerea cantității de precipitații, creșterea evapotranspirației potențiale și a intensificării proceselor de degradare, este necesară și oportună monitorizarea intensivă a stării de sănătate a acestor păduri și a evoluției lor în dinamica structurală și auxologică, pentru a preveni și gestiona durabil riscurile apărute în cazul producerii unor dezastre naturale.

Cercetările realizate în cadrul tezei de doctorat reprezintă un prim demers în sprijinul acestui deziderat, fiind urmărită studierea modului de organizare și de funcționare ale acestor arborete de pin instalate pe terenurile degradate, prin utilizarea unor tehnici de modelare a structurii arboretelor, a principalilor indicatori de monitorizare a stării de sănătate, a metodelor de aprofundare dendrocronologică și dendroclimatică prin furnizarea de modele de creștere standardizate și a identificării factorilor climatici care influențează creșterea în anul prioritar formării inelelor anuale (anul precedent) și a anului formării efective ale inelelor anuale (anul curent), analiza răspunsului oferit de arborii de pin silvestru și pin negru la evenimente de secetă, prin cuantificarea indicatorilor de reziliență, precum și prin furnizarea unor date preliminare ale calității lemnului obținute prin tehnologii moderne care pot dezvălui noi concepte viitoare de dezvoltare a unor modele de testare a calității lemnului.

Cercetările au evidențiat o reziliență mai bună a pinului silvestru în timpul secetei, reușind să își mențină creșterea de referință și să o recupereze mai repede față de pinul negru în special pe terenurile erodate în adâncime (ravene, alunecări de teren). În contrast, pinul negru a dovedit creșteri semnificativ mai mari în perioada de analiză 2011-2020 față de pinul silvestru, însă acesta prezintă o sensibilitate ridicată în timpul episoadelor de secetă, fiind mult mai predispus la un posibil scenariu de declin fiziologic. Totodată, acumulările de creștere cu tendință accentuată de formare a mai multor traheide în zonele cu lemn târziu, a favorizat obținerea unor însușiri calitative superioare de natura fizico-mecanică ale lemnului de pin negru, făcându-l mai puțin vulnerabil la apariția incipientă a unor factori favorizanți ai dezastrelor naturale și mult mai valoros din punct de vedere economic.

Mesajul esențial transmis prin teza de doctorat este acela de a orienta viitoarele cercetări în manieră să asigure un management sustenabil al arboretelor de pin, prin crearea unor raționamente științifice din domeniul reconstrucției ecologice care să favorizeze creșterea capacității de rezistență ale arboretelor de pin pe terenurile degradate prin promovarea speciilor care prezintă reziliență climatică ridicată, în vederea asigurării cu continuitate a funcțiilor eco-protective pe terenurile afectate de degradare.

SHORT SUMMARY

Artificial pine plantations established on degraded lands, outside their natural range, are forest ecosystems with an extremely important role in combating active degradation processes, ensuring a complex of eco-protective functions for economically and socially important assets. Under current climate change conditions, these stands are experiencing early physiological decline, making it necessary to implement urgent silvicultural measures aimed at achieving climate-resilient forest stands.

Moreover, against the backdrop of severe climate scenarios that have induced drought, intensified soil degradation processes, and the combined action of harmful abiotic factors, artificial pine forests have undergone significant structural changes, leading to increased vulnerability to these risk factors.

Given the trends of rising temperatures, decreasing precipitation levels, increasing potential evapotranspiration, and the intensification of degradation processes, it is both necessary and timely to conduct intensive monitoring of the health status of these forests and their structural and growth dynamics, in order to sustainably prevent and manage risks associated with natural disasters.

The research carried out within this doctoral thesis represents a first step in support of this goal, aiming to study the organisation and functioning of these pine stands established on degraded lands, through the use of modelling techniques for stand structure, key indicators for monitoring forest health, dendrochronological and dendroclimatic analysis methods, by providing standardized growth models and identifying the climatic factors influencing growth in the year preceding the formation of annual rings (the previous year) and in the actual year of ring formation (the current year). It also includes an analysis of the response of Scots pine and black pine trees to drought events by quantifying resilience indicators, as well as the provision of preliminary data on wood quality obtained using modern technologies that may reveal new concepts for future development of wood quality testing models.

The research highlighted a better resilience of Scots pine during drought, managing to maintain its reference growth and recover more quickly compared to black pine, especially on eroded lands in depth (gullies, landslides). In contrast, black pine exhibited significantly higher growth during the 2011–2020 analysis period compared to Scots pine, but it shows high sensitivity during drought episodes, making it more prone to potential physiological decline. At the same time, the increased growth tendency through the formation of more tracheids in latewood areas has favored superior physical-mechanical wood properties in black pine, making it less vulnerable to the early emergence of factors contributing to natural disasters and more valuable from an economic perspective.

The essential message conveyed by the doctoral thesis is to guide future research towards ensuring the sustainable management of pine stands, through the creation of scientific reasoning in the field of ecological reconstruction that supports the enhancement of the resilience capacity of pine forests on degraded lands by promoting species with high climate resilience, in order to continuously ensure the eco-protective functions of lands affected by degradation.