SILVA WORLD

2022 Volume 1 Issue 1
e-ISSN: 2822-6127

PRENSİP
silvaworld.org

SILVAWORLD

2022 ● VOLUME 1 ● ISSUE 1

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SILVAWORLD

2022 ● VOLUME 1 ● ISSUE 1

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SilvaWorld (2022), *1*(1), 1-15 https://doi.org/10.29329/silva.2022.462.01

http://silvaworld.org

SilvaWorld

e-ISSN: 2822-6127

https://prensip.gen.tr

RESEARCH ARTICLE

Mortality and Growth in a Sessile Oak [*Quercus petraea* (Matt.) Liebl.]-Dominated Young Stand Managed through Silvicultural Operations of Different Types and Intensities

Valeriu-Norocel Nicolescu[1*] • Diana-Cristina Șimon[2] • Alexandru-Mihai Goia[1] • Cornelia Buzatu-Goanță[3]

[1]Transylvania University of Brașov, Faculty of Silviculture and Forest Engineering, Department of Silviculture, Brașov/Romania
[2]University of Eastern Finland, Master's Degree Programme in European Forestry, Joensuu/Finland
[3]Banat's University of Agricultural Sciences and Veterinary Medicine "King Michael I of Romania", Faculty of Horticulture and Forestry, Timişoara/Romania

ARTICLE INFO

Article History
Received: 08.08.2022
Accepted: 29.08.2022
First Published: 14.09.2022

Keywords
Sessile oak
Cleaning-respacing
Stand silviculture
Crop tree silviculture
Mortality
Growth

ABSTRACT

A small-scale R&D project, including a block with four plots (P1-4) of 200 m^2, was established in 2001 in a 15-year-old sessile oak-dominated stand, regenerated naturally through the application of group shelterwood cutting. In each plot, "potential" final crop trees were selected, based on *vigour-quality-distribution* criteria, and painted. Silvicultural interventions (cleaning-respacing and thinning), of different types and intensities were performed in P1-3 (P4 was kept as control) as well as P5 (500 m^2), established in 2009, in 2001, 2004, and 2009. The mortality intensity between 2001 and 2019 was the highest in P4 and the lowest in P1, with the minimum stand density. Sessile oak showed the highest mortality, followed by Hungarian oak and Turkey oak. The fastest diameter growers were the "potential" final crop trees, their quadratic mean diameter (QMD) reaching values close to 20 cm at 35 (30-40) years in the plots with the lowest stand density. In all plots, trees have reached heights corresponding to the QMD of ca. 15 m, which are typical to a sessile oak stand of high productivity (production class II). The best solution for managing sessile oak young and medium-aged stands seems to be a "dynamic", crop tree silviculture, with the most valuable individuals selected as "potential" final crop trees at the end of thicket stage. These trees should be favoured by subsequent heavy intensity thinning from above, in order to produce timber with as uniform as possible radial increments of 2-3 mm, as requested by veneer and high-quality saw log buyers.

Please cite this paper as follows:

Nicolescu, V. N., Şimon, D. C., Goia, A. M., & Goanță, C. B. (2022). Mortality and growth in a sessile oak [*Quercus petraea* (Matt.) Liebl.]-dominated young stand managed through silvicultural operations of different types and intensities. *SilvaWorld*, *1*(1), 1-15. https://doi.org/10.29329/silva.2022.462.01

Introduction

Oaks (*Quercus* spp.) are the most important broadleaved trees in Europe (cover ca. 21 million ha), of which pedunculate oak (*Q. robur* L.) and sessile oak [*Q. petraea* (Matt.) Liebl.] are the most common, occurring widely across most of Europe, from Scandinavia to the Iberian Peninsula (Lemaire, 2010; Eaton et al., 2016).

In Romania, sessile oak is the dominant oak species. It covers 588,161 ha (over 8 per cent of national forest land, and over 52% of all *Quercus* species), has a mean volume of 284

* Corresponding author
E-mail address: nvnicolescu@unitbv.ro

m^3 ha^{-1} and produces 7.3 m^3 ha^{-1} yr^{-1} on average (Marin, 2015). It grows in both pure and mixed stands (is a *social species*, more than pedunculate oak) with other oak species (e.g., pedunculate oak; Turkey oak, *Q. cerris* L.; Hungarian oak, *Q. frainetto* Ten.) as well as European beech, *Fagus sylvatica* L.; hornbeam, *Carpinus betulus* L.; maples, *Acer* spp.; common ash, *Fraxinus excelsior* L.; etc. (Negulescu & Săvulescu, 1957; Stănescu, 1979; Stănescu et al., 1997).

Sessile oak is a light-demanding species, but can withstand more shade than pedunculate oak, especially in youth (Ciumac, 1965; Haralamb, 1967; Petrescu, 1971). Consequently, it is regenerated under group shelterwood systems, with large gaps (up to 1.5 x mean height), and the regeneration period is recommended to be short (5-7 years) (Purcelean & Ciumac, 1965; Ciumac, 1967; Haralamb, 1967; Dămăceanu, 1984). In resulting natural regenerations, the intensity of natural mortality is high in the first years i.e., 40-50% of the initial number of seedlings in the second year (Purcelean & Ciumac, 1965; Ciumac, 1967). However, the stand density can be still high (up to 30,000 stems ha^{-1}) at the end of sapling-beginning of thicket stage (Dămăceanu, 1984). Such dense, uniform and single-layered stands, predominantly pure, with tall but slim individuals, are prone to snow bending (Petrescu, 1971).

Sessile oak is a slow-grower in the first decade (it grows in height 10-20 cm yr^{-1} during this period), when the growth is concentrated in the root system. The height growth activates afterwards and reaches up to 50 cm yr^{-1} between 10 and 25 years (Negulescu & Săvulescu, 1957; Haralamb, 1967; Stănescu et al., 1997).

The silvicultural model of Romanian sessile oak stands, imposed by the current technical norms (Anonymous, 2000a), is mostly a *stand silviculture* and includes:

- Cleaning-respacing, started when dominant height (H_{dom}) is 8-10 m (age 15-20 years). It is a *negative selection* (removal of suppressed and poorly formed trees without considering the growth of remaining ones), with moderate intensity, and keeping a canopy cover of minimum 80% (75% in stands with rich understory), and

- Thinning, started when H_{dom} is 12-13 m (age 25-30 years). They are intermediate (from above and from below) and act as *positive selection* [competing trees are removed, to maximize the growth of the best ones (Kerr & Haufe, 2011)]. The intensity of thinning (per cent of standing volume) ranges between 14 (age 21-30 years) and 6 (age 71-80 years), the age when the application of thinning halts as required by the technical norms. Canopy cover after thinning at least 80%.

In valuable sessile oak stands, the same norms recommend (so it is not mandatory) to select (at 30-40 years of age) and paint 200-300 "candidate" final crop trees ha^{-1}, based on the *vitality (vigour)* (the thickest and tallest, part of crown classes I and II, with large crowns) – *quality* (straight, vertical, healthy, without forking, wounds, insect attacks, etc.) - *distribution (spacing)* (as regularly spaced as possible) criteria, in order to reach a stand density of 90-100 trees ha^{-1} final crop trees at rotation age. In this context, one should mention that, under the current norms, with moderate-low intensity interventions halting at early ages, the target density is impossible to be reached and the sessile oak stands have 250-400 trees ha^{-1} at rotation age. This density is much higher than the one recommended in other European countries: Maximum 100 trees ha^{-1} [70-100 in Belgium (Bary-Lenger & Nebout, 1993; Wouters et al., 2000); 80-100 in Austria (Hochbichler, 1993), France (CRPF Aquitaine, 2005), and Germany (Kenk, 1984, Spiecker, 2021); 100 in Switzerland (Schütz, 1993) , Ireland (Joyce et al., 1998; Horgan et al., 2003), and France (CRPF Bourgogne, 2012)], but decreasing to 50-60 trees ha^{-1} [Czech Republic (Dobrovolný & Macháček, 2012)], 50-70 trees ha^{-1} [Sweden (Löf et al., 2016)], 60-70 trees ha^{-1} [France (Sevrin, 1997; Allegrini & Depierre, 2000; Jarret, 2004; Allegrini, 2010; Lemaire, 2010; Le Nail & Decucq, 2021)], 40-80 trees ha^{-1} [Belgium (Balleux, 2005)] or even 30-40 (5) trees ha^{-1} (Baar, 2008, 2010).

The rotation age in sessile oak stands of Romania for wood production depends on target wood assortment: between 120 and 140 years for sawlogs and between 160 and 200 years for veneer logs (Anonymous, 2000b).

Taking into account these circumstances, as well as the interest to: (i) *Reduce the management costs at young ages* and to (ii) *Reduce the rotation age*, in parallel with the *production of top-quality and large diameter sessile oak trees*, a small-scale research and demonstration (R&D) project was launched in Valea Mare Forest District (F. D.) in 2001. The target of this study was to compare two options: *Stand silviculture* vs. *single-tree oriented silviculture*, the latter option including interventions focusing around "potential", followed by "genuine" final crop trees in order to provide them a *free-growth state* at crown level since young ages (end of thicket-beginning of pole stages of development).

Materials and Methods

The R&D work was carried out in sub-compartment 71E (44°50'42.91"N, 25°21'02.36 E), part of Working Circle IV Râncăciov, Valea Mare Forest District, Dâmbovița County Branch of National Forest Administration-ROMSILVA (Figure 1)**.**

The main characteristics of this sub-compartment are as follows:

a. Site - Area: 6.7 ha; Elevation: 290 m; Plateau; Soil: Luvisol, of high fertility for sessile oak stands; Ground flora: *Carex pilosa*. Climate: D.f.b.x. type; Annual mean temperature: 9.9 °C, Annual mean precipitation: 688 mm, Aridity (de Martonne) index: 35.

Figure 1. Location of research area

b. Stand (current data) - Species composition: over 90% sessile oak with scattered individuals of Hungarian oak, Turkey oak, hornbeam, European beech, field maple (*Acer campestre* L.), etc.; Mean age: 35 years (range 30-40 years), following the application of group shelterwood cuttings; Production class: II; Rotation age: 130 years; Production target: Sawn timber (d.b.h. at least 48 cm).

The fieldwork started in 2001 and consisted of the following interventions and works:

Year 2001: Establishment of a R&D block of 1,500 m^2 (30 x 50 m), with 4 plots, each of 200 m^2 (20 x 10 m) in each corner. In all plots, "*potential*" final crop trees (7 trees per plot, 350 trees ha^{-1}, at 5-7 m distance) were selected and painted, based on the *vitality (vigour)–quality-distribution (spacing)* criteria. In plot 3, all "potential" final crop trees are of sessile oak, in plot 4 two out of seven trees are of Hungarian oak, and in plots 1 and 2 two out of seven trees are of Turkey oak. All the other "potential" final crop trees (five individuals per plot) in these three plots are of sessile oak. In plots 1-3, cleaning-respacing of different types and intensities were carried out while plot 4 was kept as control.

Year 2004: A further intervention of cleaning-respacing was performed solely in plot 2.

Year 2009: New interventions (thinning) were performed in plots 1, 2, and 3. Establishment of a new R&D plot (no. 5) of 500 m^2 (25 x 20 m), where *potential* final crop trees (17 individuals of sessile oak, 340 trees ha^{-1}) were selected and painted using the same criteria as above. A cleaning-respacing was performed, targeting the *free-growth state* of such trees at crown level.

2001, 2004, 2009, 2019: Measurement of diameter at breast height (dbh), using a Haglöf caliper (precision 0.1 cm), and of four crown radii, at 90 degrees between them, using a metal ribbon (precision 0.5 cm), in all plots.

2001, 2004, 2009, 2015: Measurement of total height (h) using a Romanian hypsometer (precision 10 cm) in all plots.

2017: Assessment of presence of epicormic branches (e.g., length, diameter at insertion point, height of lowest epicormic, etc.), in all plots.

The field data were processed during the office work using Microsoft Excel and the main outputs are: Quadratic mean diameter (d_g), *dbh* increment, basal area (*G*), height corresponding to the quadratic mean diameter (h_g), mean crown diameter, correlation between initial *dbh* (2009) and *dbh* increment (2009-2019), correlation between *dbh* and mean crown diameter (2019).

Results

Characteristics of Silvicultural Interventions

As the initial stand density (between 7,250 trees ha^{-1} in plot 1 and 9,100 trees ha^{-1} in plot 3), as well as stocking (range 17.55 m^2 ha^{-1} in plot 2 - 20.65 m^2 ha^{-1} in plot 1) were very high in 2001, and no silvicultural interventions have been performed since the stand establishment, the intensity of first cleaning-respacing (2001) in plots 1-3 was *very high* (over 25%) by both number of trees (I_N) and basal area (I_G). Obviously, as the range of diameters was very wide in these plots (coefficient of variation before cleaning-respacing between 35 and 46%), this intervention was *from below*, removing mostly trees from inferior crown (Kraft) classes, 4 (sub-dominant) and 5 (suppressed) (Figure 2). Consequently, the initial (before intervention) coefficient of variation of diameters in plots 1-3, ranging between 43.43% (plot 3) and 49.39% (plot 1) [bigger than the "normal" one in even-aged stands, of 20-40% (Giurgiu, 1979)] was reduced to 20.55% (plot 3) -25.01% (plot 1) but remained very high (46.69%) in plot 4 (control).

The same type of intervention (from below) is obvious when taking into account the coefficient of variation of heights in the same plots: If the initial one (before intervention) was very high, ranging between 25.26% in plot 3 and 26.92% in plot 1 [bigger than the “normal” range in even-aged stands, of 10-20% (Giurgiu, 1979)], it was reduced to values between 9.43% in plot 3 and 12.94% in plot 2.

In 2004, another cleaning-respacing *from below* was performed only in plot 2, to create an obvious stands density and stocking difference between this plot and plot no 3.

In 2009, the third intervention (thinning of different types), with *high* (between 16 and 25%) to *very high* intensities, was carried out in plots 1-3 and 5 (Table 1).

Table 1. Types and intensities of interventions performed in plots 1-3 and 5 in 2001, 2004, and 2009

Plot no.	Intervention performed in ...								
	2001			2004			2009		
	I_N* (%)	I_G** (%)	Type of intervention	I_N (%)	I_G (%)	Type of intervention	I_N (%)	I_G (%)	Type of intervention
1	69.66	39.80	*From below*	-	-	-	41.86	39.30	*From above (détourage)* (Figure 3)
2	57.86	31.00	*From below*	14.93	8.54	*From below*	30.36	21.01	*From below*
3	63.74	34.52	*From below*	-	-	-	28.79	21.60	*Intermediate (mostly from below)*
5	-	-	-	-	-	-	37.50	35.12	*Intermediate (mostly from above) (détourage)*

I_N* = intensity by number of trees; I_G** = intensity by basal area

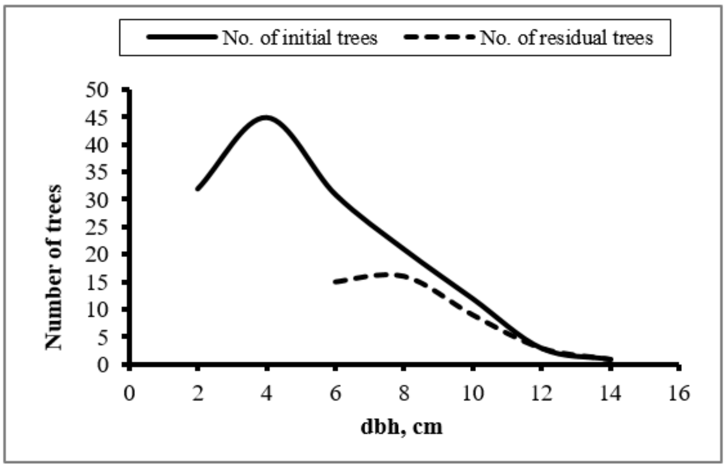


Figure 2. Typical intervention *from below* performed in plot 1 in 2001

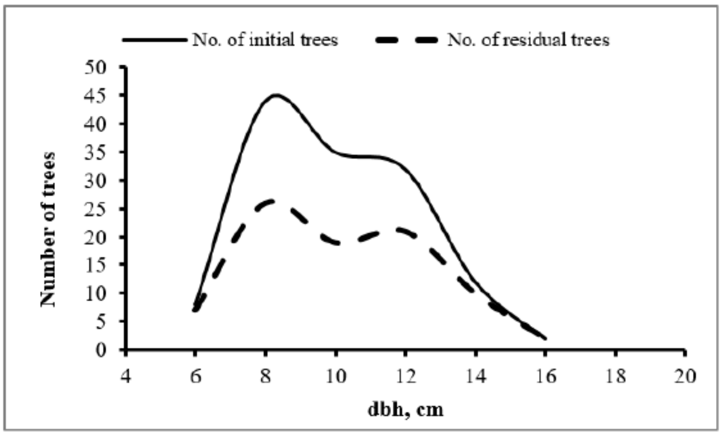


Figure 3. Intermediate (*mostly from above*) (*détourage*) intervention performed in plot 5 in 2009

Natural Mortality and Evolution of Species Composition

The natural mortality of trees (sessile oak: SOAK; Turkey oak: TOAK; and Hungarian oak: HOAK) in plots 1-4 between the establishment of R&D block in 2001 (residual stand) and 2019, as well as their dieback in plots 1-5 since the silvicultural intervention in 2009 (residual stand) are very variable (Table 2).

Table 2. Natural mortality of trees between 2001 and 2019 and in the 2009-2019 period

Plot no.	Initial number of trees in 2001	Natural mortality 2001-2019 (%)	Natural mortality 2009-2019 (%)	Share of natural mortality in 2001-2019 (%)			Share of natural mortality in 2001-2019 (%)		
				SOAK	**TOAK**	**HOAK**	**SOAK**	**TOAK**	**HOAK**
1	2,200	2.27	0	100.0					
2	3,350	14.93	23.08	90.00	10.00		88.89	11.11	
3	3,300	18.18	25.53	100.0			100.00		
4	8.300	83.73	61.43	75.97		24.03	67.44		32.56
5	1,750*	-	23.53		100.0		100.00		

*1,750 trees ha^{-1} in plot 5 in 2009 (year of establishment of that plot)

In both periods, the lowest natural mortality was registered in plot 1, with the lowest stand density after the intervention carried out in 2001 (2,200 tree ha^{-1}), while plot 4 (control), with the highest stand density in 2001 (8,300 trees ha^{-1}) showed the peak of natural mortality. The species most affected by natural mortality in both periods was sessile oak, with a share of dead trees between 75.97% (plot 4) and 100.00% (plots 1 and 3) in 2001-2019, and between 67.44% (plot 4) and 100.00% (plots 2 and 5) in 2009-2019. Hungarian oak contributed secondly to natural mortality in plot 4 (control) (ca. 24.03% in 2001-2019, and ca. 32.56% in 2009-2019 respectively), while Turkey oak contributed to 10-11% of dead trees in plot 2. All of them are light-demanding species, and all dead trees were part of low canopy, belonging to crown classes IV and V. In contrast, no trees of European beech (shade tolerant) or hornbeam (with intermediate shade tolerance) have died during the same periods, even being part of the same crown classes.

Natural mortality, combined with the three silvicultural interventions performed in 2001, 2004, and 2009, led to changes in species composition of different magnitudes in plots 1-5 (Table 3).

Table 3. Evolution of species composition by number of trees in plots 1-5 between 2001 and 2019

Plot no.	Species composition by number of trees in plots 1-5 between 2001 and 2019 (%)			
	2001	**2004 (after intervention)**	**2009 (after intervention)**	**2019**
1	75SOAK 14TOAK 11HOAK	75SOAK 14TOAK 11HOAK	68SOAK 20TOAK 12HOAK	68SOAK 20TOAK 12HOAK
2	90SOAK 9TOAK 1HOR	88SOAK 11TOAK 1HOR	85SOAK 13TOAK 2HOR	83SOAK 13TOAK 4HOR
3	98SOAK 2HOR	98SOAK 2 HOR	98SOAK 2HOR	97SOAK 3HOR
4	69SOAK 29HOAK 1TOAK 1HOR	66SOAK 31HOAK 2HOR 1TOAK	56SOAK 40HOAK 3HOR 1TOAK	37SOAK 52HOAK 7HOR 4TOAK
5	-	-	94SOAK 4HOAK 1HOR 1EB	95SOAK 3HOR 1HOAK 1EB

HOR = hornbeam; EB = European beech

These changes range from ± 1% sessile oak in plots 3 and 5, 7% less sessile oak in plots 1 and 2, to a reverse of species composition in plot 4 (control). In the latter plot, where Hungarian oak was less affected by natural mortality, it took over and reached 52% by number of trees in 2019, compared with 29% in 2001. As hornbeam and European beech trees have not died between 2001-2019 period, their share in species composition has increased from 1-2% (plots 2-4) in 2001 to 7% (plot 4) in 2019.

Effects of Silvicultural Interventions and Natural Mortality on Different Stand Parameters

Stand density (number of trees per hectare)

As mentioned, the stand density at the beginning of interventions (2001) in plots 1-4 was extremely high, ranging between 7,250 trees ha^{-1} (plot 1) and 9,100 trees ha^{-1} (plot 3). Under these conditions, the interventions performed in 2001 (plots 1-3), 2004 (plot 2), and 2009 (plots 1-3 and 5), combined with the *natural mortality* of trees, extremely variable as shown above, had reduced continuously the stand density to values ranging between 1,250 trees ha^{-1} (plot 1) and 1,750 trees ha^{-1} (plot 3) in 2019 (Figure 4).

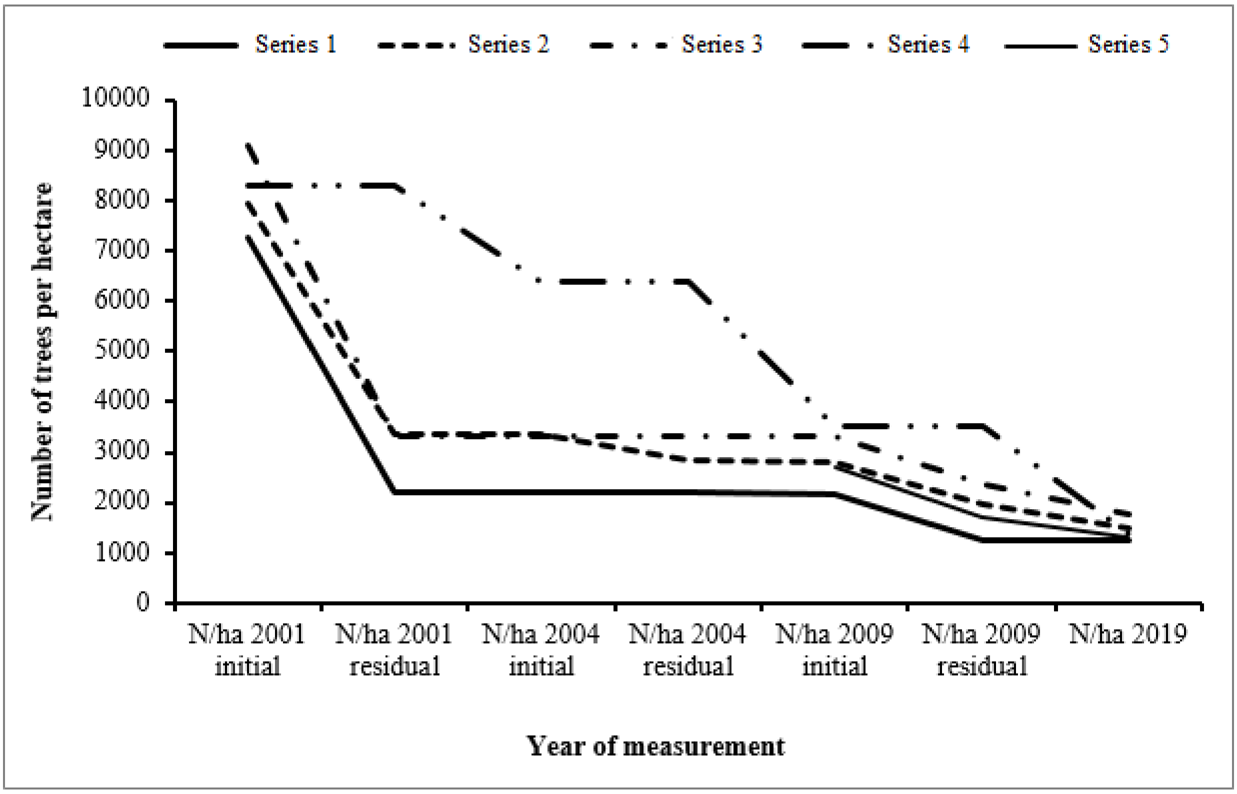


Figure 4. Evolution of stand density in plots 1 (series 1), 2 (series 2), 3 (series 3), 4 (series 4), and 5 (series 5) between 2001 and 2019

This reduction in stand density is due primarily to the three silvicultural interventions (2001, 20014, and 2009) performed in plots 1-3, where the natural mortality over the 2001-2019 period counts for less than 20%. On the contrary, the main source of reduction of stand density in plot 4 (control) in the same period is the natural dieback, accounting for over 83%.

Quadratic mean diameter (QMD) of all trees and potential final crop trees in plots 1-5

The increase of this parameter of all trees in plots 1-4 between 2001 (after intervention) and 2019 ranges between 6.30 cm (91.44%, in plot 3) and 9.10 cm (174.33%, in plot 4) (Table 4).

Table 4. Evolution of quadratic mean diameter of all trees in plots 1-4 in 2001-2019 period

Plot no.	QMD in ... (cm)				Increment of QMD between 2001 and 2019	
	2001 residual	2004 residual	2009 residual	2019	cm	%
1	8.48	9.38	11.81	15.86	7.38	87.03
2	6.78	7.79	10.36	14.26	7.48	110.32
3	6.89	7.53	9.70	13.19	6.30	91.44
4	5.22	6.16	8.77	14.32	9.10	174.33

The highest increase of QMD was found in plot 4 (control), where the reduction of stand density was not affected by silvicultural interventions but solely by natural mortality (over 83%). As almost exclusively the suppressed trees were eliminated, the increase of QMD, even occurring naturally, can be considered as "artificial".

In these circumstances, it is more relevant to consider the evolution of this parameter and its increment between 2009 and 2019 solely in trees existing in plots 1-5 in 2019 as well as in "potential" final crop trees in the same plots was taken into account (Table 5).

Table 5. Evolution of quadratic mean diameter of all trees and "potential" final crop trees in plots 1-5 between 2009 and 2019

Plot no.	QMD 2009 (cm)	QMD 2019 (cm)	Increment of QMD 2001-2019		Range of dbh increment 2009-2019 (cm)	Share of trees with min 5 cm dbh increment between 2009 and 2019 (%)
			cm	%		
a. All trees						
1	11.81	15.86	4.05	34.29	0.3-7.2	36.00
2	10.89	14.75	3.86	35.45	0.5-11.1	10.00
3	10.19	13.19	3.00	29.44	0.5-6.1	11.43
4	11.59	14.33	2.74	23.64	0.4-6.4	18.52
5	11.27	15.04	3.77	33.45	0.3-8.1	20.00
b. Potential final crop trees						
1	13.85	19.94	6.09	43.97	4.6-7.1	85.71
2	11.74	16.79	5.05	45.49	1.3-11.1	14.29
3	11.84	15.52	3.68	31.09	2.1-5.4	14.29
4	11.99	15.59	3.70	30.90	0.3-5.6	33.33
5	13.10	18.40	5.30	40.45	2.0-8.1	52.94

The absolute increase of QMD of all trees between 2009 and 2019 is maximum in plot 1 (4.05 cm), with the lowest stand density (1,250 trees ha^{-1}) in 2009, and minimum in plot 4 (control) (2.74 cm), which was overcrowded in 2009 (3,500 trees ha^{-1}). The effect of stand density is obvious in the share of trees with minimum 5 cm dbh increment between 2009 and 2019: It ranges between 10.00% (plot 2) and 36.00% (plot 1). In 2019, the proportion of trees reaching 20 cm in diameter (maximum 24.2 cm in sessile oak, 26.0 cm in Hungarian oak, and 27.9 cm in Turkey oak) ranged between 2.86% (plot 3), and 24.00% (plot 1). The majority of these trees, showing mean annual radial increments between 2.5 and 3 mm, are of sessile oak (100% in plot 5) and Turkey oak (83.33% in plot 1). All trees at least 20 cm in dbh in 2019 have grown over 10 cm in diameter between 2001 and 2019, with a maximum of 18.2 cm (Turkey oak tree in plot 2, 27.9 cm in diameter in 2019).

The effect of stand density on dbh increment is more obvious when considering solely the "potential" final crop trees, which have been favoured during the application of the three interventions in 2001, 2004 and 2009. In both absolute and relative terms, the highest increase was found in plots 1 (6.09 cm, 43.97%) and 5 (5.30 cm, 40.45%), compared to 3.68 cm (31.09%) in plot 3. In plots 1 and 5, the QMD of "potential" final crop trees is close of 20 cm, a threshold which was targeted since the beginning of this R&D project for a stand of 35 (30-40) years of age. As above, the share of "potential" final crop trees with minimum 5 cm dbh increment between 2009 and 2019 is maximum (85.71 %) in plot 1, with the minimum stand density (1,250 trees ha^{-1}) in 2009, followed by plot 5 (52.94%), with a similar stand density (1,300 trees ha^{-1}) in the same year.

In addition, one should emphasize the very important output that the increase of QMD of "potential" final crop trees between 2001 and 2019 is very variable: 6.17 cm (0.32 cm yr^{-1}, in plot 4), 7.13 cm (0.38 cm yr^{-1}, plot 3), 9.03 cm (0.47 yr^{-1}, plot 2), and 10.65 cm (0.56 cm yr^{-1}, plot 1). In plot 5, the increase of QMD between 2009 (plot establishment) and 2019 was close to the one in plot 4 (0.53 cm yr^{-1}). These results confirm the "speeding up" effect of lower stand density and silvicultural interventions [i.e., thinning from above (détourage) or intermediate thinning, mostly from above (détourage), in plots 1 and 5] on the dbh increment not only of all trees but particularly of "potential" final crop trees.

The values of QMD before and after silvicultural interventions performed in 2001, 2004, and 2009 can also be used to define their type (Table 6).

Table 6. QMD of initial trees, extracted trees and residual trees in cleaning-respacing and thinning carried out in plots 1-4 in 2001, 2004, and 2009

Plot no.	QMD in ...								
	2001			2004			2009		
	Initial trees	Extracted trees	Residual trees	Initial trees	Extracted trees	Residual trees	Initial trees	Extracted trees	Residual trees
1	6.02	4.55	8.48	9.38	-	9.38	11.56	11.21	11.82
2	5.30	3.88	6.78	7.52	5.69	7.79	9.71	7.55	10.36
3	5.12	3.77	6.89	7.53	-	7.53	9.23	7.85	9.70
4	5.22	-	5.22	6.16	-	6.16	8.77	-	8.77

In 2001 and 2004, as the QMD of extracted trees is much lower than the one of initial trees, the cleaning-respacing was definitely a negative selection, and from below. In 2009, the only thinning from below was carried out in plot 2, while its character approached an intervention from above (or détourage) or intermediate in the other plots.

Height corresponding to the quadratic mean diameter (h_g) of all trees in plots 1-4

The increase of this parameter of all trees in plots 1-4 between 2001 and 2015 (last year of height measurements) ranges between 5.21 m (53.71%, in plot 1) and 7.29 m (108.97%, in plot 4) (Table 7).

Table 7. Evolution of height corresponding to the quadratic mean diameter (h_g) of all trees in plots 1-4 in 2001-2015 period

Plot no.	h_g in ... (m)				Increment of h_g between 2001 and 2015	
	2001 residual	2004 residual	2009 residual	2015	m	%
1	9.70	10.36	12.54	14.91	5.21	53.71
2	9.30	9.67	12.22	14.84	5.54	59.57
3	9.05	9.84	12.24	14.77	5.72	63.20
4	6.69	8.25	11.31	13.98	7.29	108.97

As in case of QMD, the highest increase of h_g was found in plot 4 (control), where the reduction of stand density was affected solely by natural mortality (over 83%), eliminating almost exclusively the suppressed trees, so artificially increasing the value of h_g. In plots 1-3, regardless the type and intensity of interventions carried out in 2001, 2004, and 2009, the increase of h_g was similar in both relative (5.2-5.7 m) and absolute terms (54-63%). As the initial h_g (2001) in those plots had a quite narrow range (9.05-9.70 m), the values of h_g were similar in all plots 2015 (14.8-14.9 m).

In 2015, the values of coefficient of variation of heights, with values between 9.43% (plot 3) and 25.15% (plot 4) in 2001, after the cleaning-respacing intervention, ranged between 5.47% in plot 3 and 12.66% in plot 4. It confirms the relative uniformity of tree heights, characteristic to an even-aged, mono-layered stand, composed mostly of light-demanding species.

Mean slenderness (stability) index

The evolution of this parameter [$SI = (h/dbh)*100$] of all trees in plots 1-4 between 2001 and 2015 (last year of height measurements) indicates a continuous decrease, with values ranging between 5 and 19 (Table 8).

Table 8. Evolution of slenderness (stability) index of all trees in plots 1-4 between 2001 and 2015

Plot no.	SI in ...				Evolution (+ or -) of SI between 2001 and 2015	
	2001 residual	2004 residual	2009 residual	2015	m	%
1	114	110	106	104	10	8.77
2	137	124	118	118	19	13.87
3	131	131	126	126	5	3.82
4	128	134	129	116	12	9.38

As the natural mortality was the only factor affecting the decrease of SI in plot 4, one should not use it in interpreting the results but take into account only the evolution of SI in plots 1-3. The decrease was the most important in plot 2, as the increase in QMD was much higher than the one in h_g, while the increase of QMD and h_g were much closer in plots 1 and 3, so the decrease of SI was lower. However, the only plot where the SI shows a good stability of trees is plot 1, where it approaches the level of 100.

Correlations between different biometrical parameters

The requirement to select "potential" final crop trees at the end of thicket stage of development exclusively among the thickest (and tallest) individuals is obvious when considering the correlation between initial dbh (2009) and dbh increment between 2009 and 2019 (Figures 5a, and 5b).

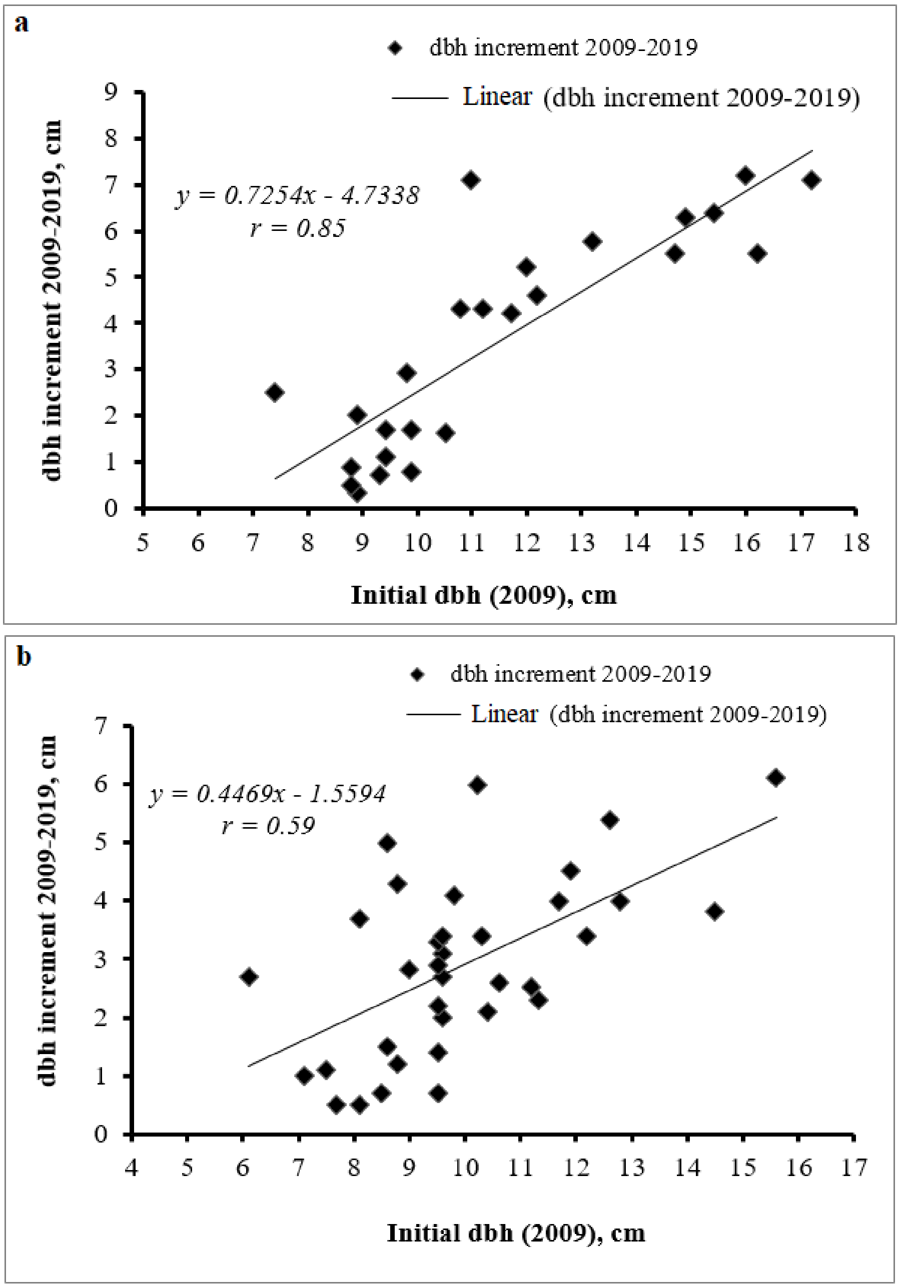


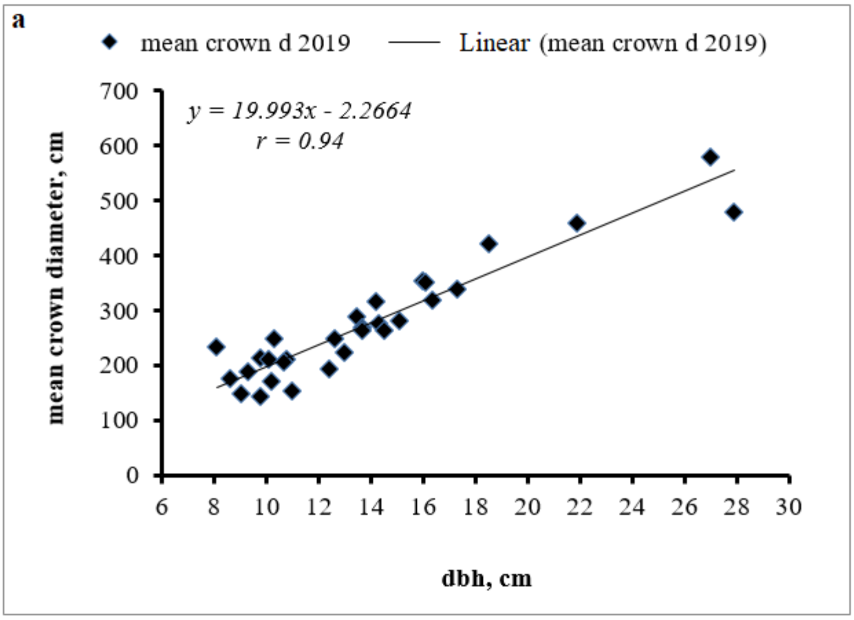
Figure 5. Correlation between initial dbh (2009) and dbh increment (2009-2019) of trees of plots 1 (a) and 3 (b)

The high values of coefficient of correlation (r) between these biometrical traits, ranging between 0.59 (plot 3) and 0.85 (plot 1), explains the need to select those valuable individuals among the thickest ones, as they are the most important growers in diameter.

This need originates also from the strong correlation between the dbh and mean crown diameter (Figure 6).

This strong correlation (r from 0.86 in plot 3 to 0.94 in plot 2) shows the need to select the “potential” final crop trees among thick (and tall) individuals, which also posses large crowns and grow quicker in dbh than thinner trees, with smaller crowns.

Such conclusion is confirmed by the relationship between stand density, QMD and mean crown diameter: The trees in plot 1, with the lowest stand density (1,250 trees ha^{-1}) in 2019, had the largest quadratic mean diameter (15.86 cm) as well as the largest crown (overall mean crown diameters 317 cm). On the other hand, trees in plot 3, with the highest stand density (1,750 trees ha^{-1} in 2019), had the smallest QMD (13.19 cm) as well as smallest crown (overall mean crown diameter 239 cm). Trees in the other three plots, with different overall mean crown diameters (285 cm in plot 5, 275 cm in plot 2, and 247 cm in plot 4), occupy intermediate positions in-between these extremes.



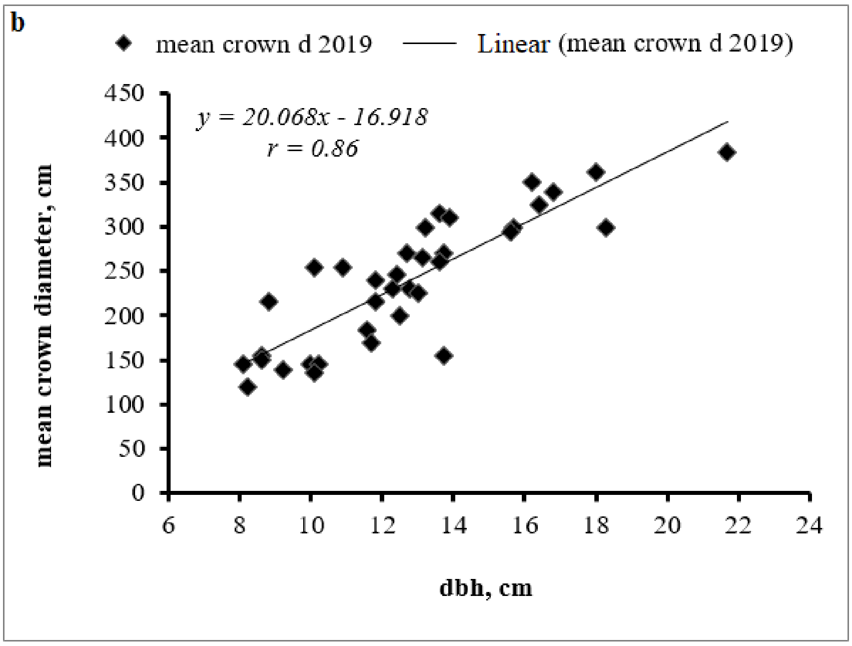


Figure 6. Correlation between dbh and mean crown diameter of trees in plots 2 (a) and 3 (b) in 2019

Stocking (basal area)

Stocking in the five plots had successive increases (between interventions) and decreases (because of silvicultural interventions as well as natural mortality of trees) in plots 1-5 between 2001 and 2019 (Figure 7).

Starting around 12 m^2 ha^{-1} in plots 1-4 after the first intervention in 2001, basal area has increased up to rather similar values (from 21.76 m^2 ha^{-1} in plot 4 to 25.63 m^2 ha^{-1} in plot 2) in all plots (including no 5) in 2019. However, the evolution of stocking between the last intervention (2009) and 2019 shows a very high variability. The increase of basal area ranges between 0.61 m^2 ha^{-1} (2.88%) in plot 4 (with the highest stand density of 3,500 trees ha^{-1} and a mortality of 61.43%) and 11.00 m^2 ha^{-1} (80.29%) in plot 1 (with the lowest stand density of 1,250 trees ha^{-1} and no mortality). In the other plots, basal area has increased 6.60 m^2 ha^{-1} (38.13%) in plot 3, 8.25 m^2 ha^{-1} (55.55%) in plot 5, and 9.24 m^2 ha^{-1} (56.38%) in plot 2.

The effect of different types of intervention on individual trees was also assessed in terms of occurrence of *epicormic branches*, a major threat in oaks (more on pedunculate than on sessile) to produce top-quality wood for A-class lumber, veneer and solid furniture. In plots 1-4, the share of trees with epicormics in 2017 ranged between 20% (plot 3) and 40% (plot 1); sessile oak, as well as Hungarian oak trees were the most affected. However, the "potential" final crop trees, with the largest diameters, heights and crowns, have been the least affected (maximum one tree per plot) (Table 9).

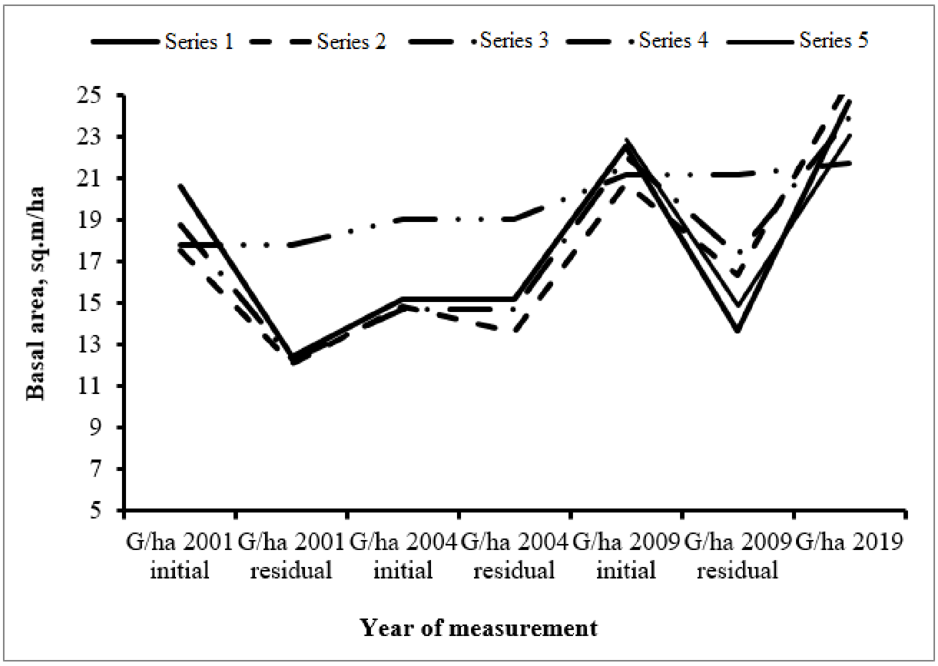


Figure 7. Evolution of stocking (basal area) in plot 1 (series 1), plot 2 (series 2), ..., plot 5 (series 5) between 2001 and 2019

Table 9. Occurrence of epicormic branches in plots 1-4

Plot no	Total number of trees	No and % of trees with epicormics	Of which		Number of "potential" final crop trees	Of which with epicormics	
			SOAK	Others (HOAK, EB, HOR)		No.	%
1	25	10/40	7	3	7	1	14
2	35	9/26	9	-	7	-	-
3	41	8/20	7	1	1	1	14
4	33	12/36	4	8	6	1	17

HOAK = Hungarian oak, EB = European beech, HOR = hornbeam

In plot 5, 21 trees (30% of all trees, of which 17 of sessile oak, the rest of Hungarian oak, hornbeam and European beech) out of 70 showed epicormic branches. As in plots 1-4, only one "potential" final crop tree out of 17 (6%) showed epicormics.

Across the five plots, these branches occurred mostly on slender trees with small and unbalanced crowns, from the lower canopy (Kraft classes IV and V). There was a very small proportion of epicormics on "potential" final crop trees, which grow vigorously, and have large diameters and crowns.

Discussion and Conclusion

In the young sessile oak thicket, as no silvicultural interventions have been carried out since the establishment, the stand density and stocking were very high (N = 7,250-9,100 trees ha^{-1}; G = 17.55-20.65 m^2 ha^{-1}) in 2001 so there was a clear need for cleaning-respacing. Taking into account the high variability of diameters and qualities, this intervention was a negative selection, removing the smaller and badly formed trees, and heavy (intensity 57-69% by number of trees N and 31-39% by basal area G). Such intensities are higher in terms of N and similar in terms of G with the levels of 40% (by N) and 35% (by G) described by Ciumac (1969).

Following the second major intervention (2009), not as heavy as the one in 2001 (intensity 28-41% by N and 21-39% by G), the stand density was reduced to 1,250-2,350 trees ha^{-1}. The minimum stand density in 2009 is similar to the one recommended in countries like France [1,100-1,200 trees ha^{-1} (Sardin, 2008; Sardin & Mothe, 2010; Anonymous, 2022)], Belgium [ca. 1,200 trees ha^{-1} (Baar, 2010)] or Ireland [1,000-1,300 trees ha^{-1} (Joyce et al., 1998)] but much lower than the one proposed in Romania [2000-4000 trees ha^{-1} (Ciumac, 1975), 2,100-2,400 trees ha^{-1} (Anonymous, 2000a)] at the same age. Reducing the stand density to those levels is also a valid strategy to increase the forest resilience to drought (Zamora-Pereira et al., 2021). Sessile oak's annual tree-ring width depends strongly on the water availability of summer months in the actual year of ring formation (Móricz et al., 2021).

Stocking after the interventions performed in 2009 (13-17 m^2 ha^{-1}) is similar to the one recommended in France [14.2 m^2 ha^{-1} (Jarret, 2004), 14.7 m^2 ha^{-1} in "dynamic" silviculture and

16.8 m^2 ha^{-1} in "classical" silviculture (Sardin, 2008)] and Belgium [14-18 m^2 ha^{-1} (Balleux, 2005)] under similar stand conditions.

The mortality process, affecting mostly trees in lower crown classes (IV and V), confirms the low shade tolerance of all oak species, with sessile oak as most affected. Its higher needs for light lead even to the change of species composition in favour of more shade tolerant Hungarian oak (Negulescu & Săvulescu, 1957; Stănescu, 1979), as in case of plot 4 (control). However, natural mortality has not affected at all the shade-tolerant (European beech) or intermediate shade-tolerant (hornbeam) species, their share in species composition increasing lightly, with positive effects on biodiversity.

The evolution of QMD (range 13-15 cm in 2019) in both all trees as well as "potential" final crop trees, especially after the intervention in 2009, has confirmed the positive effect of lower stand density on diameter increment. Plot 1, with the lowest stand density, had shown the largest increase in QMD, "potential" final crop trees in this plot, as well as in plot 5, being close to 20 cm in QMD, and showing a mean radial increment up to 2.5-3 mm yr^{-1}. This value is similar to the target radial increment of sessile oak in France [2-2.5 mm yr^{-1} (Jarret, 1996)], Austria [2.5 mm yr^{-1} (Hochbichler, 1993)], Belgium [maximum 3 mm yr^{-1} (Bary-Lenger & Nebout, 1993)], Switzerland [2-2.5 mm yr^{-1} (Schütz, 1993)]. Interestingly, in France, the quality standards for A-class sawlogs allows for radial increments of maximum 4 mm yr^{-1} (Baylot & Vautherin, 1992). Lemaire (2010) mentions that all users of high-quality logs for veneer and barrel production require wood with uniform/regular and wide growth rings (2-4 mm) or even wider (over 4 mm). Turkey oak, which grows quicker in youth in both height and diameter than all other native oaks (Negulescu & Săvulescu, 1957; Haralamb, 1967; Stănescu, 1979), has reached the largest diameter in 2019 (27.9 cm).

The height corresponding to QMD, with values of ca. 9 m in plots 1-3 in 2001, has grown similarly until 2015, as mostly being the effect of site potential over the trees not of stand density/stocking after silvicultural interventions, reaching ca. 15 m in 2015. This value characterizes fully the high growing potential of local site conditions, as the stand belongs to the production class II [h_g 14.1 m at 35 years of age (Giurgiu & Drăghiciu, 2004)].

The positive effect of lower stand density on trees was also confirmed by the reduction of slenderness (stability) index in all plots; however, the only plot where its values approach 100 is no. 1, with the maximum QMD and height corresponding to QMD.

The basal area, with a series of increases and decreases owing to silvicultural interventions and diameter increment (plots 1-3), as well as a continuing increase in plot 4 (control), has reached values over 21 m^2 ha^{-1} in 2019. This is higher than the values considered as "critical" [14-18 m^2 ha^{-1} (Balleux, 2005)] in order to avoid any loss in increment and resulting wood volume.

Sessile oak is considered a species particularly prone to the occurrence of epicormic branches (Colin et al., 2010), a major defect reducing the quality class of sawlogs. In the EU standards, the quality of sessile oak sawlogs is reduced from A to B or even C, if the knots are larger than 15 mm in diameter (Baylot & Vautherin, 1992; Anonymous, 1997). In our R&D experiment, silvicultural interventions have not had a major detrimental effect on the production of epicormic branches. This is especially true in case of "potential" final crop trees, vigorous and growing vigorously, with large crowns, less prone to the occurrence of epicormics and which should be favoured by heavy crown thinning (Courraud, 1987; Schütz, 1990; Sevrin, 1997; Joyce et al., 1998; Colin et al., 2010).

The results of this R&D work show that, in the "dynamic" silviculture, the positive selection (and painting) of "potential" final crop trees, at the end of thicket stage (during the last cleaning-respacing, when mean height is 6-8 m), followed by a heavy intervention around their crowns, as proposed in other European countries such as France (Allegrini & Depierre, 2000; CRPF Aquitaine, 2005; Allegrini, 2010; Deleuze & Renaud, 2010; Le Nail & Decucq, 2021) and Belgium (Wouters et al., 2000; Baar, 2008), is a feasible option. The number of such trees (ca. 300 individuals ha^{-1}), selected and painted based on the *vigour-quality-spacing* criteria, should be 2-3 (4) times the number of trees which will presumably form the final stand at the rotation age (final crop trees) (Petrescu, 1971; Kerr & Evans, 1993; Savill et al., 1997; CRPF Aquitaine, 2005; Colin et al., 2010). By selecting and painting them, therefore making such trees more visible and easier to locate, the further tree marking for thinning is facilitated, and both silviculturists and loggers are helped in their efforts to protect the most valuable trees and produce high-quality, healthy, and large trees (Lanier, 1979).

Obviously, the "potential" final crop trees should be favoured by further interventions with crown thinning (full or partial), removing the most aggressive competitors at crown level, in order to provide the "genuine" final crop trees, selected as early as the first (sometimes second) thinning, a free-growth state. Consequently, the crown development and correlated diameter increment are speed up (Baar, 2010; Lëtzebuerger Privatbësch, 2011; CRPF Bourgogne, 2012; Dobrovolný & Macháček, 2012; Le Nail & Decucq, 2021), confirming the fact that, in young and medium-aged oak stands, the bigger trees grow usually much faster than the smaller ones (Gadow & Hui, 1999). Or, in other words, the taller the initial tree size compared with neighbours (e.g., quantified by the initial percentile), the better the primary individual growth potential and the perspective of a tree (Pretzsch, 2021).

Interestingly, the application of crown thinning in oak stands is not a new issue; it was advocated by Broilliard (1881) and used in French forests ever since; in Romania, such thinning in sessile oak stands was proposed by Ciumac (1965, 1969), after stating that all “genuine” final crop trees belong to the upper storey so need to be released from competition, but never formalised and used in practice.

Taking into account all these outputs, what means/instruments should we use in the control of early silviculture of sessile oak stands in Romania, instead of mandatory canopy cover (80%) after intervention? In this respect, based on our results, as well as other works in the same field, two options are to be considered:

a. The use of stand density, of maximum 2,000 stems ha^{-1} after the last cleaning-respacing (when mean height is 6-8 cm) and 1,100-1,300 trees ha^{-1} following the application of first thinning (mean height 11-13 m), as also proposed in countries such as France (Jarret, 2004; Sardin, 2008; Sardin & Mothe, 2010).

b. The use of an even level of stocking (critical basal area) throughout the whole life of the stand, at the level of 14-18 m^2 ha^{-1} after each intervention (Sardin, 2008; Sardin & Mothe, 2010). A higher level of basal area after intervention (23-25 m^2 ha^{-1} on average), as proposed in the UK (Kerr & Haufe, 2011), seems to be too high for our sessile oak stands.

However, our opinion is that, in valuable stands (i.e., production classes I and II), targeting sawlog or veneer log production, the selection and painting of at least “genuine” final crop trees in Romanian oak (sessile, pedunculate) stands must become mandatory. This solution was proposed in Romania long ago (e.g., Anonymous, 1956; Ciumac, 1973), but never put into practice as being only recommended.

We fully agree with Lemaire (2010), Sardin (2008), Sardin and Mothe (2010), Le Nail and Decucq (2021) that, in favourable site conditions, the use of a “dynamic” silviculture is the best option.

On the other hand, the use of “détourage” in managing pole stage stands, by focusing exclusively around the upper crowns of the most valuable crop trees, is definitely a solution, but only for one or two interventions, followed by crown thinning, as also proposed by Lemaire (2010) and Sardin (2008). However, such intensive intervention should favour solely trees with large crowns, part of the “genuine” final crop trees group, selected and painted among the “potential” final crop trees at the end of thicket stage.

Sessile oak silviculture requires a lot of silvicultural investment at early ages but the future results in economic terms are striking so all efforts are worthwhile.

Acknowledgment

The authors wish to thank their colleagues and friends from the Dâmbovița Branch of National Forest Administration-ROMSILVA for their help during the fieldwork phase of the R&D project.

Conflict of Interest

The authors declare that they have no conflict of interest.

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SilvaWorld
http://silvaworld.org
e-ISSN: 2822-6127
PRENSIP
https://prensip.gen.tr

RESEARCH ARTICLE

Comparison of Basal Area and Trees Abundance for Estimating Tree Diversity in Beech Forests (Case Study: Guilan, Masal, Northern Iran)

Amer Mirzazadeh[1*] • Hassan Pourbabaei[2] • Mehrdad Ghodskhah Daryaei[2] • Amireslam Bonyad[2]

[1]University of Guilan, Faculty of Natural Resources, PhD Programme in Forest Sciences, Sowme`eh Sara/Iran
[2]University of Guilan, Faculty of Natural Resources, Department of Forestry, Sowme`eh Sara/Iran

ARTICLE INFO

Article History
Received: 08.08.2022
Accepted: 31.08.2022
First Published: 14.09.2022

Keywords
Diversity indices
Error percentage
Evenness indices
Masal

ABSTRACT

Measuring tree species diversity is necessary to manage forest resources sustainably and to better understand the economic consequences to changes in species diversity due to management. This research aimed at comparing the basal area and trees abundance for evaluating tree species diversity in oriental beech (*Fagus orientalis* Lipsky) forests (Guilan, Masal, Northern Iran). For this study, compartment 515 was selected, and then data were collected through the random-systematic method with a grid dimension of 150×150 m in an area of 50 ha, and lozenge shape with the sizes of 400; 800; 1,000; 1,200; 1,600; 2,000; 2,500; and 5,000 m^2 was established. In total, 160 sampling plots were taken. In each plot, the diameter at breast height (DBH≥7.5 cm) of all trees was measured. Diversity and evenness indices were estimated applying different variables (the basal area and the trees abundance) separately. The results elucidated that the error percentage of Mac Arthur's N_1, Hill's N_2 indices, and Simpson's evenness, was lower using basal area compare to the trees abundance. The result of Camargo, Nee, and Smith-Wilson evenness indices revealed that the error percentage by using the trees abundance was lower than the amount of basal area. We recommend using the basal area for estimating tree species diversity.

Please cite this paper as follows:
Mirzazadeh, A., Pourbabaei, H., Daryaei, M. G., & Bonyad, A. (2022). Comparison of basal area and trees abundance for estimating tree diversity in beech forests (case study: Guilan, Masal, Northern Iran). *SilvaWorld*, *1*(1), 16-22. https://doi.org/10.29329/silva.2022.462.02

Introduction

Investigation of the relationship between natural resource development and environmental degradation can aid to manage the ecological implications (Ahmed et al., 2020). Protection of biodiversity is one of the most critical issues in natural resources on Earth (Mirzaei et al., 2019). Measuring of woody species diversity facilitates to estimation of the economical results in biodiversity. Trees are an influential factor on other components in forests. Therefore, increasing the tree species diversity can reduce the effects of drought, and is crucial to access precise information about tree species and plant communities (Grossiord, 2018). Oriental beech (*Fagus orientalis* Lipsky) is one of the commercial species in the north of Iran, which is used in different woody crop industries (Alavi et al., 2020). The most important point of environmental protection is keeping the local species in an area that can be accomplished through the acknowledgment of biodiversity, and estimation strategies (Nesper et al., 2017). Mirzaei et al. (2019) studied the effects of inventory grids on tree species diversity in semi-arid area of Iran, which indicated that based on using criteria $E\%^2 \times T$, with a grid dimension of 200×100m (25 plots)

* Corresponding author
E-mail address: mirzazadehamer@gmail.com

was selected as the most appropriate one for measuring the tree species diversity. Etemad et al. (2014) utilized quadrat plots sizes of 100, 225, 400, and 1,600 m^2 for studying the tree species diversity in Zagros forests in Iran; and these authors revealed that the quadrat plots 1,600 m^2 and 400 m^2 were the most appropriate sizes for determining the tree species diversity. On the other hand, estimating the woody diversity by using a software provided the possibility for quickly evaluating with a reasonable error and efficiency. The usual way for assessing the diversity is applying of the basal area, the trees abundance, and the cover percentage, which are used for trees, shrubs, and herbaceous plants, respectively. Moreover, characteristics such as the volume of trees and basal area have been used to estimate different parameters. In another research by using 26 sample plots of 1,000 m^2 were used to evaluate and compare the characteristics of frequency, the basal area, and the volume of trees in estimating of tree species diversity. The results indicated that the quantity of diversity and evenness indices using the trees abundance is higher than utilizing the volume or basal area to estimate the indices (Mirzaei et al., 2016). In another research, in Kalaleh region of Golestan province (Iran), the characteristics of standing volume and tree density (trees abundance per hectare) were estimated with sample plots of 200, 600, 800, and 1,000 m^2, circle and square shapes, and full inventory. The results revealed that the size of 400 m^2 with circular and square shapes had the lower percentage of sampling error (Ghiasi et al., 2020).

Zohrevandi et al. (2016) in order to select the optimal sample plot size by studying of woody species diversity in Zagros forests (Iran), sizes of 1,000; 1,500; and 2,000 m^2 were utilized. The results showed that the size of 1,000 m^2 had the lowest error percentage of the forest inventory. Neumann and Starlinger (2001) concluded that the Shannon-Wiener diversity index is the most appropriate index to evaluate the tree species diversity. The main aim of this study was to compare the accuracy of the tree species diversity and its evenness by applying basal area, and the trees abundance in different areas of the sample plot in order to determine the best characteristic and the optimal sample plot size in the beech forest of the Hyrcanian regions in northern Iran.

Materials and Methods

Study Area

This study was carried out in the northern forests of Iran that are known as Hyrcanian regions. The total of the study area was 50 hectares, and located between 48°55′19″ to 49°02′00″ longitude and 37°14′00″ to 37°19′20″ N latitude. Elevation ranges between 300 to 200 m above sea level and the study area has a mean slope of 35%, and an East aspect. The mean annual precipitation is 1,530 mm and the mean annual temperature is 16.5 ºC. The bedrock is limestone, shale, and acidic sandstone, and pH is approximately 5.5-6.5. The forests in the study area consist of deciduous broad-leaved trees of different ages that vary in composition from pure beech to mixtures of oriental beech with other hardwood species. These forests were previously impacted by disturbances from overgrazing, harvesting by forest dwellers, and illegal logging for supplying logs and firewood, all of which have influenced the quantity and quality of forests. Conversely, the study area has been strictly protected for 16 years (Anonymous, 2016).

Method

Initially, a map of the study area was utilized to establish an inventory grid of 150×150 m, in a 50 ha area of the compartment. Eight concentric lozenge sampling plots with sizes 400; 800; 1,000; 1,200; 1,600; 2,000; 2,500; and 5,000 m^2 were established for each sampling point. In total, 160 sampling plots were measured. In each plot, species, number of species, trees abundance, and diameter at breast height (DBH≥7.5 cm) were measured and recorded. For study of tree species diversity, the eight diversity, and evenness indices were utilized with the formulas (Table 1).

Data analysis

The total basal area of each tree in each sample plot size was calculated using MS Excel software. To calculate the diversity, the data related to the basal area, and the trees abundance in each plot was measured separately, and entered into the Ecological Methodology software. In this software, Shannon-Wiener, Simpson, McArthur N_1, and Hill N_2 diversity indices, as well as Camargo, Simpson, Nee, and Smith-Wilson evenness indices were calculated (Table 1). The standard deviation, standard error, and error percentage related to each of the diversity, and evenness indices were calculated for basal area, and the trees abundance. In this research, the error percentage was estimated in each of the two parameters (variables), which used as a criterion for choosing the best parameters for evaluating the tree species diversity.

Results

In this research, three species were identified, which included *Fagus orientalis*, *Carpinus betulus* L., and *Alnus subcordata* C. A. Mey. *F. orientalis* in 8 different areas of the sample plot size showed that the highest, and the lowest percentage of the abundance in the size of 2,000 and 5,000 m^2, with the amount of 91.8 and 83.2%, respectively, in comparison with *C. betulus* and *A. subcordata*. The percentage of abundance of the *C. betulus* in all the sample plots was higher than the *A. subcordata*, and its lowest and highest values were 6.4 and 13.7%, respectively, in the sample plots of 1,200 and 5,000 m^2. The lowest and highest percentages of *A. subcordata* in all sample plots were 2.4, and 4.6% in the size of 1,000 and 400 m^2 (Table 2)

Table 1. Diversity and evenness indices with equations

Index	Equation
Simpson (1-D)	$1 - D = 1 - \sum_{i=1}^{s}\left[\frac{n_i(n_i - 1)}{N(N-1)}\right]$
Shannon-Wiener (H΄)	$H' = \sum_{i=1}^{s}(P_i)\,(log_2 P_i)$
Hill (N_2)	$\frac{1}{D} = \frac{1}{\sum p_i^2}$
Mc Arthur (N_1)	$N_1 = e^{H'}$
Camargo (E')	$E' = 1..0 - \left(\sum_{i=1}^{s}\sum_{j=i+1}^{s}\left[\left\lvert P_i - P_j\right\rvert / S\right]\right)$
Smith-Wilson (E_{var})	$E_{var} = 1 - \left(\frac{2}{\pi}\right)\left[arctan\left\{\frac{\sum\left(log_e(n_i) - \sum log_e(n_j)/s\right)^2}{s}\right\}\right]$
Simpson ($\mathbf{E_{1/\hat{D}}}$)	$E_{1/\hat{D}} = \frac{1/\hat{D}}{S}$
Nee (E_Q)	$E_Q = \frac{-2}{\pi\ \mathrm{arctan}\ (b)}$

D is dominance index, n_i = the number of individuals of the i^{th} species, N = total number of all individuals, H' = Shanon-Wiener, P_i = the relative frequency of the i^{th} species, P_j = the relative frequency of the j^{th} species, N_1 = an equal number of common species that create diversity similar to the H', E' = Camargo, S = the total number of species, b = the gradient of dominance - diversity curves, e = 2.71828.

Table 2. The trees density based on sample plot size, and species

Abundant Percentage of the Total Species (%)			The Number of Species			
F. orientalis	***C. betulus***	***A. subcordata***	***F. orientalis***	***C. betulus***	***A. subcordata***	**Plot size (m^2)**
87.2	8.0	4.6	412	38	22	400
89.8	7.0	3.0	788	62	27	800
90.8	6.5	2.5	1,048	76	30	1,000
91.1	6.4	2.4	1,375	97	37	1,200
90.60	6.7	2.6	1,781	133	52	1,600
91.8	7.4	2.6	2,154	179	63	2,000
88.9	8.4	2.6	2,543	242	75	2,500
83.2	13.7	2.9	3,438	570	123	5,000

Results with Shannon-Wiener Diversity Index error revealed that the lowest error percentage by using the basal area compared to the trees abundance was related to size of 2,000 and 1,000 m^2, with 5.5 and 25.8%, respectively. In another side, both of the plot sizes had the lowest error percentage by applying the error percentage of the trees abundance (Table 3). The sizes of 400; 800; 1,200; 2,500; and 5,000 m^2 had the lowest error percentage by utilizing the trees abundance. Totally, the size of 2,000 m^2 by using the basal area had the lowest error percentage of Shannon-Wiener index. The results of Simpson diversity Index elucidated that the lowest error percentage in size of 5,000; 2,000; and 1,000 m^2 was measured by using the basal area, which was 12.2, 18.9, and 32.1%, respectively. The lowest error percentage by applying the sizes of 400; 800; 1,200; 1,600; and 2,500 related to the use of the trees abundance variable. Totally, the size 5,000 m^2 had a reasonable error percentage by utilizing Simpson diversity index. The lowest error percentage of Mc Artor's N_1 index was related to size of 2,000; 5,000; 1,000; and 800 m^2, respectively, with 0.5, 6.6, 7.6 and 7.8%, respectively, which calculated using basal area, respectively, and the least percentage of error in other sizes was using the trees abundance. Totally, the plot size 2,000 m^2 had the lowest error percentage by applying Mc Artor's N_1 index. The results of the Hill N_2 index indicated that the lowest error percentage by size of 2,000; 5,000; and 1,000 m^2, with the amount of 3.8, 5.4 and 6.7%, respectively, which was calculated using basal area. In addition, the plot size of 400; 800; 1,200; 1,600; and 2,500 m^2 had the reasonable amount of error percentage by utilizing of the trees abundance. Totally, the size of 2,000 m^2 elucidated the lowest error percentage by applying the basal area (Table 3).

Table 3. Inventory error (E%) of diversity indices in different plot sizes

Diversity Indices								
Hill (N_2)		Mc-Arthur (N_1)		Simpson		Shannon-Wiener		
Basal area	Trees abundance	Basal area	Trees abundance	Basal area	Trees abundance	Basal area	Trees abundance	Plot size (m^2)
18.6	18.0	18.3	17.9	36.7	33.1	30.7	28.1	400
7.3	7.2	7.8	8.2	32.5	30.9	25.6	24.7	800
6.7	6.9	7.6	8.4	32.1	32.2	25.8	27.0	1,000
6.4	5.9	7.6	7.4	30.4	28.4	24.7	23.7	1,200
6.5	5.2	6.9	6.5	25.8	23.5	20.7	18.7	1,600
3.8	5.3	5.0	6.7	18.9	23.8	5.5	18.7	2,000
5.8	5.3	6.9	6.3	25.9	22.2	21.6	17.2	2,500
5.4	6.7	6.6	7.0	18.2	19.1	15.7	15.2	5,000

The right and left columns are the error percentage using the basal area, and the trees abundance in different plot size.

The results of the Camargo evenness index showed that the lowest percentage in all sample plot sizes related to the size of 5,000 m^2, which was obtained by using the trees abundance, and the amount was 1.5%. Moreover, the lowest error percentage in all of the sample plot sizes was measured by using the basal area in size of 2,500 m^2 with an amount of 7.5%, and in the other seven sample plot sizes, the lowest error percentage was related to the applying of the trees abundance (Table 4). The lowest error percentage of Simpson's evenness index in the size of 2,500 and 5,000 m^2 was 7.7 and 5.3%, respectively, which was related to the use of the basal area in the estimation of Simpson's evenness index. In summary, the lowest error percentage in the other sample plot sizes was calculated using the trees abundance. Totally, the size of 5,000 m^2 utilizing the basal area had the lowest error percentage in all of the sample plot sizes by using this index, and comparing the basal area with the trees abundance. The results with Nee's evenness index elucidated that the lowest error percentage using the basal area with size of 2,500 m^2 was 10.4%. On the other hand, the lowest error percentage in different plot sizes was calculated using the trees abundance. The reasonable error percentage in all of the sample plot sizes was also related to the calculation with the trees abundance, which was 7.5%. The lowest error percentage of the Smith-Wilson evenness index, like the Nee's evenness index, was related to the basal area in size of 2,500 m^2, which was 20.0%. Meanwhile, in the other plot size applying the trees abundance has the lower error percentage. The size of 2,000 m^2 using the trees abundance showed that the lowest error percentage in all of sample plots sizes and comparison the basal area with the trees abundance (Table 4).

Table 4. Inventory error (E%) of evenness indices in different plot sizes

Evenness Indices								
Smith-Wilson		Simpson		Nee		Camargo		
Basal area	Trees abundance	Basal area	Trees abundance	Basal area	Trees abundance	Basal area	Trees abundance	Plot size (m^2)
30.9	29.6	37.2	27.1	18.6	18.0	18.0	17.6	400
33.3	25.7	24.6	19.5	9.9	9.3	9.0	8.2	800
32.8	16.9	12.6	10.1	6.3	5.8	6.1	5.5	1,000
25.9	17.0	13.4	8.7	8.7	7.8	8.3	7.3	1,200
21.8	15.2	11.4	8.0	8.7	8.5	8.3	7.9	1,600
24.8	13.9	12.7	7.5	8.8	7.7	8.4	7.2	2,000
20.0	20.7	10.4	10.7	7.8	8.8	7.5	8.1	2,500
23.1	14.4	12.3	8.6	5.3	6.3	5.2	5.1	5,000

The right and left columns are the error percentage using the basal area, and the trees abundance in different plot size.

Discussion

In this research, the amount of the tree species diversity was estimated by applying the basal area and the trees abundance variable. The edaphic and climatic conditions were suitable for the growth of other species. However, the Oriental beech have the maximum crown and its shade-tolerance abilities and mechanisms which prevents the growth of other species, especially light-demanding species. According to, the results (Table 2), the lowest frequency percentage of oriental beech compared to other tree species with amount of 83.24% was related to the size of 5,000 m^2. However, the highest frequency of beech with a value of 91.8% is related to the plot size of 2,000 m^2. Subsequently, more than 80% of the species composition was related to oriental beech in all of 8 plot sizes. Hence, the investigated area was a pure stand of oriental beech.

In this research, the criteria for comparing the basal area, and the trees abundance was the statistical error percentage of each diversity and evenness indices.

According to the results of Shannon-Wiener diversity index, the plot size of 2,000 m^2 applying the basal area with an acceptable error percentage was more suitable than the evaluating based on the trees abundance. The plot size of 2,000 m^2 was reasonable, and also no difference with the error percentage in size of 5000 m^2 based on amount. In estimating the Simpson's diversity index based on both variables (the basal area and trees abundance) the size of 5,000 was the most suitable plot size with the lowest percentage. Conversely, the amount evaluated with the basal area had a lower error percent compared to the trees abundance. Comparison of both ways to calculate Simpson's diversity index error, the results of the basal area in all of the sample plot sizes elucidated that the size of 1,000 and 2,000 m^2 had the lowest error percentage compared to the same size by using the trees abundance.

However, the size of 400; 800; 1,200; and 1,600 m^2 had the lowest error percentage by utilizing the trees abundance. In the calculation of MacArthur's N_1 diversity index, the plot size of 2,000 and 2,500 m^2 were measured with the basal area and the trees abundance as the most reasonable error percentage respectively. On the other hand, the size of 2,000 m^2 with the lower error percentage and the area is smaller that affects the time and cost of forest inventory which seems more appropriate.

In addition, the calculations revealed that among the eight investigated plot sizes, the numbers of sample plots with a lower error percentage using the basal area and the trees abundance are equal. In calculating Hill's N_2 index, the plot size 2,000 m^2 had a lesser error percentage was more suitable in comparison with the size of 1,600 m^2 by applying of the trees abundance.

The results of Zohrevandi et al. (2016) in Zagros forests in Iran was different from the results of the present research the reason can be attributed to the lower density of trees and shrubs in Zagro forests compared to the northern forests of Iran. In addition, by size of 1,000; 2,000; and 5,000 m^2, the statistical error percentage with the basal area is lesser than the same sample plot sizes using the trees abundance variable. The results of four diversity indicators showed that the lowest error percentage was related to the estimation of the basal area.

Moreover, Hill's N_2 index had the lowest error percentage among the diversity indices evaluated in this research. However, our result is inconsistent with the conclusion of Neumann and Starlinger (2001), who utilized the Shannon-Wiener index as the best way to measure diversity. Hill's N_2 index is derived from Simpson's diversity index. Likewise, Simpson's index gives the highest return to species with more abundant, and is more sensitive with the presence of these species (Daly et al., 2018; Zohrevandi et al., 2016).

In the studied area, oriental beech was more abundant than other species in all plot sizes. This factor effects on the results of the error percentage of N_2 index. The results of Mirzaei et al. (2016) also had the same conclusion similar to our results, and showed that using the basal area is more appropriate for investigating the trees diversity. The results of Kapos (2005) also revealed that the applying the basal area is reasonable and more accurate to evaluate the tree stand diversity that is economical and commercial or the tree species that need preservation. On the other hand, the aforementioned results indicated that the basal area is able to be suitable to study the structure of the stand. Our study area was also a protected forest and consisted of oriental beech that has economical and commercial scope. Totally, the results revealed that utilizing the basal area in estimating of diversity indices had a lower error percentage, and in the calculation with the evenness indicators using the trees abundance had a more appropriate accuracy, and a lower error percentage. Conversely, considering that the diversity indicators simultaneously richness, and evenness are used in the measurement. The basal area is also used to calculate the evenness indices. Therefore, it can be concluded that the basal area is applicable to simultaneously study the indicators of diversity and evenness.

The results of Table 4 show that size of 5,000 m^2 using the Camargo evenness index with both variables (basal area and trees abundance) had the lowest error percentage, but the same plot size related to the calculation with the trees abundance had a lower and total error percentage; therefore, in analysis of this index can use the trees abundance. On the other side, the estimation of the evenness value with this index indicated that only the size of 2,500 m^2 had a lesser error percentage compared to the same sample plot size using the basal area. In the other seven plots sizes, the lower error percentage was related to the calculation with the trees abundance, was revealed that the error percentage with this sample size and Camargo evenness index in most of the sample plots is lower and acceptable based on the criteria of this research. Conversely, it should be considered that to measure diversity indices, the combination of richness, and evenness is used simultaneously, and the value of trees can be based on the biomass of each tree and the effect of biomass in the stand, calculated (Yuan et al., 2018). In other words, in the evaluating with diversity indices, the results are not impacted by the evenness factor, and the richness or the trees abundance had greatly impacted on the conclusion (Darcha et al., 2015; Mekonenet al., 2015; Guisande et al., 2017; Sintayehu et al., 2020).

The plot size of 1,000 and 5,000 m^2 had the lowest error percentage of Simpson's evenness index by applying the trees abundance and basal area, respectively. The size of 1,000 m^2 with a smaller area and less time had an acceptable error percentage in comparison with the size of 5,000 m^2, and considering due to its effect of both factors on reducing or increasing the statistical cost and time, this sample plot size is reasonable by utilizing the trees abundance to calculate Simpson's evenness index. The results of the comparison of similar sample plot sizes in using variables showed that the size of 5,000 and 2,500 m^2 had the lowest error percentage in the estimating with the basal area, and in different plot sizes, the lower error percentage is related to the calculation with the trees abundance. The results with Nee and Smith-Wilson's evenness indices elucidated that the size of 2,000 and 2,500 m^2 had the lowest error percentage in the measurement with the trees abundance and basal area, respectively.

In addition, the trees abundance variable showed lower error percentage in comparison to the total error percentage; therefore, in calculating both evenness indices, it is more appropriate to use the trees abundance on these results. The comparison of similar sample plot sizes using both variables showed that in calculation of Nee, and Smith-Wilson evenness indices, the error percentage in size of 2,500 m^2 by applying the basal area had a reasonable percentage in evaluating the trees abundance. Furthermore, using the basal area the size of 2,500 m^2 had the lowest error percentage in all of the plot sizes. The reason can be the effect of the biomass of trees on the calculation with the basal area that the value of each tree is considered proportional to its impact in the stand, that the error percentage of the evenness indices is affected by the small diameter trees and the impact of measurement in stand forest with a similar value (Ali et al., 2016; Zhang et al., 2017; Ali & Yan, 2017).

Similar research conducted on the evenness of plant species indicated that evenness is strongly influenced by the type of variable or measurement characteristic, so the distribution of trees in diameter classes has the most significant effect on the calculation of evenness indices (Orwin et al., 2014; Ribas et al., 2015).

Conflict of Interest

The authors declare that they have no conflict of interest.

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SilvaWorld
http://silvaworld.org
e-ISSN: 2822-6127
PRENSIP
https://prensip.gen.tr

RESEARCH ARTICLE

Determination of Some Soil Properties on Penetration Resistance and Consistency Limits

Bülent Turgut[1*] • Aktan Hangişi[2]

[1]Karadeniz Technical University, Faculty of Forestry, Department of Soil and Ecology, Trabzon/Turkey
[2]Artvin Çoruh University, Faculty of Forestry, Department of Soil and Ecology, Artvin/Turkey

ARTICLE INFO

Article History
Received: 28.08.2022
Accepted: 14.09.2022
First Published: 21.09.2022

Keywords
Liquid limit
Plastic limit
Plasticity index
Compaction
Pasture

ABSTRACT

Atterberg limits and penetration resistance are the factors that affect the mechanical behavior of soil. In this study, it was investigated the direct and indirect effect of some soil properties such as particle size distribution, moisture and organic matter content, aggregation rate, aggregate stability, and clay activity index on penetration resistance, liquid limit, plastic limit, and plasticity index and revealing the change of all studied properties along with the soil layers. A pasture was selected as the study area and 20 sample points were determined randomly. Penetration resistance (PR) was measured with a penetrologger at these points and soil samples were taken from three different soil layers (0-25, 25-50, and 50-75 cm). The analyses were carried out to determine the soil properties in the laboratory. One-way variance analysis (ANOVA) was used to determine the variation of the soil properties along with the sample layers, and the path analysis was used to determine the direct-indirect effects of the properties affecting the penetration resistance, liquid limit, plastic limit, and plasticity index. The path analysis results showed that clay content directly affected the penetration resistance with the highest coefficient, and organic matter content affected the aggregation rate. The clay content had the highest direct effect, and the organic matter content had the highest indirect effect on the penetration resistance. The highest direct effect coefficient was obtained from organic matter in the plastic limit and liquid limit, while the aggregation rate was in the plasticity index.

Please cite this paper as follows:

Turgut, B., & Hangişi, A. (2022). Determination of some soil properties on penetration resistance and consistency limits. *SilvaWorld, 1*(1), 23-32. https://doi.org/10.29329/silva.2022.462.03

Introduction

Fine-grained soils display significant changes in states of consistency depending on the water content (Dhir et al., 2017). To quantify these changes, Atterberg developed a series of limits relative to the water content of these types of soils (Brown Jr., 2016). The liquid limit and plastic limit are associated with the plasticity of soils and are used to calculate the plasticity index, which is the measure of the sensitivity of the soil to change in its moisture content. Researchers suggested the Atterberg limits as an indicator to evaluate the soil vulnerability to erosion, the mechanical behavior to tillage, and resistance to compaction (Yalcin, 2007; Seybold et al., 2008; Xia et al., 2019). Previously studies showed that it is a positive correlation between Atterberg limits and the resistance to dispersion rate (Rienks et al., 2000; Igwe & Ejiofor, 2005).

The value of the Atterberg limits depends on several factors, including particle size distribution, the quantity and type of clay mineral, the organic matter content, and the type of absorbed cation (Terzaghi et al., 1996; Glendinning et al., 2015; Huvaj & Uyeturk, 2018). In many studies, it was stated that increasing organic matter and clay content also causes an increase in Atterberg limits (Aksakal et al., 2013; Qu et al., 2014).

Penetration resistance is a term used to describe soil compaction and is identified as a force to advance a cone of a

* Corresponding author
E-mail address: bulentturgut@ktu.edu.tr

specific base size into the soil. Penetration resistance of soils is an important parameter that influences root growth and water movement, and a penetrometer is used to measure its value in the field (Van Quang et al., 2012). High penetration resistance (>2 MPa) directly affects root growth and indirectly impedes aeration and water movement, causing negative effects on plant growth. The most important properties affecting penetration resistance are soil moisture, organic matter content and grain size distribution (Sivarajan et al., 2018; Hargreaves et al., 2019).

This study was conducted to determine the change of the penetration resistance, Atterberg limits, particle size distribution, aggregate stability, aggregation rate, moisture content and organic matter content depending on soil depth, to calculate the direct and indirect effect coefficients of properties on penetration resistance and Atterberg limits.

Materials and Methods

This study was conducted in a natural pasture used before as agricultural land in Artvin province (Figure 1). Artvin located in the East-North part of Turkiye is characterized topographically with deep valley and high mountains. Forest and seminatural areas cover 86% of Artvin. According to the Thornthwaite climate classification system, the study area is described as semi-humid with 690 mm total precipitation and 12.3°C mean temperature. The plant composition of the study area is predominantly *Trifolium pretense* L., *Bromus inermis* Leyys., and *Oxalis acetosella* L. The altitude of the study area is 570 m and the average slope is 1%.

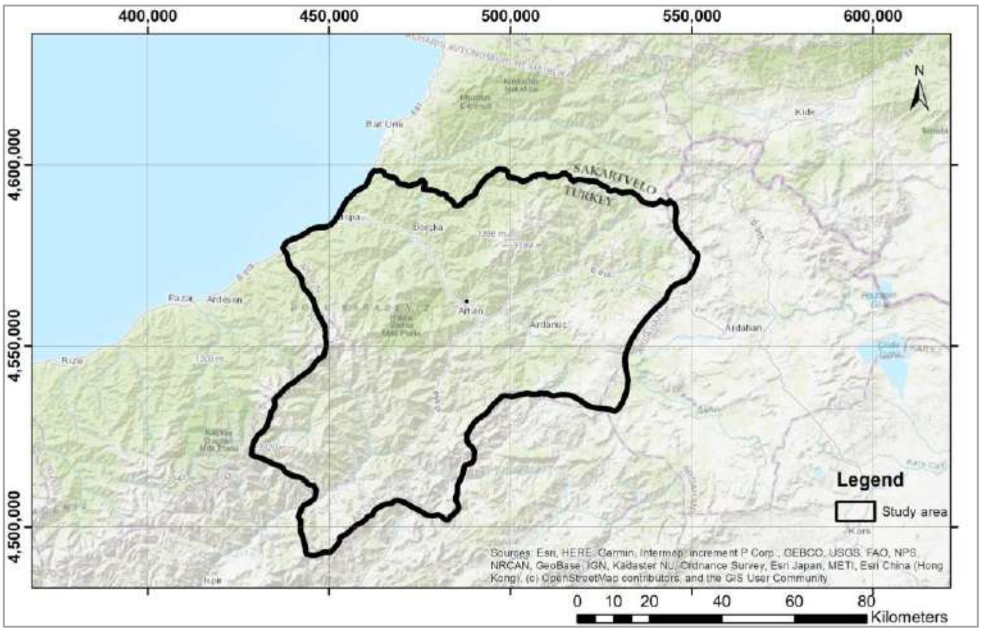

Figure 1. Geographic position of the study area

Penetration resistance was measured in the field with a digital penetrologger and soil samples were taken from 0-25 cm (K_1), 25-50 cm (K_2), and 50-75 cm (K_3) depths of randomly selected 20 points. After drying and sieving process, moisture content was determined with the gravimetric method. Bouyoucos hydrometer method was used for particle size distribution (Gee & Bauder, 1986). The plastic limit was determined as the gravimetric water content at which a rolled thread of molded soil with a diameter of 3 mm just begins to crack. The liquid limit was determined using the Casagrande liquid limit apparatus. The plasticity index was calculated as differences between the liquid and the plastic limit. Organic matter content was determined by the Walkley-Black method (Schnitzer, 1982). Aggregate stability was determined with the Yoder wet-sieving method (Kemper & Rosenau, 1986). Aggregation rate was calculated by equation 1 (Turgut & Ates, 2017). Clay activity index was calculated by the following equation 2 (Wagner, 2013).

$$AR = \frac{AW}{T} \quad (1)$$

AR: Aggregation rate, *AW*: Total aggregate obtained from wet sieving, *T*: Soil samples weight.

$$a_c = \frac{I_p}{CC} \quad (2)$$

a_c: Clay activity index, I_p: Plasticity index, *CC*: Clay content.

The ANOVA was used to determine the differences along with the sampling layers in terms of the properties. The Path analysis was used to determine the direct and indirect effect of properties on penetration resistance and Atterberg limits. JMP 5.0 was used to ANOVA and AMOS for Path analysis.

Results and Discussion

The descriptive statistics were given in Table 1. The particle size distribution of the soils showed that the common texture classes in the study area were silty loam, clayey loam, silty clay loam and clay (Figure 2). Penetration resistance measurements showed that there was no severe compaction problem in the study area (<2 MPa). It was determined that the moisture content of the soil in the study area was within the limits of usefulness and organic matter content was low. Due to the structural evaluation, it can be said that the aggregation rate and the resistance of the aggregates to the dispersing effect of water were high. According to Dahms and Fritz (1998), the study area was classified as clayey with very high plasticity.

Table 1. Descriptive statistics of studied properties

Properties	Minimum	Maximum	Mean	Coefficient of variation
Clay (%)	10.15	51.71	23.53±11.54	49.06
Silt (%)	33.33	64.88	53.03±9.22	17.39
Sand (%)	13.25	35.20	23.44±4.35	18.57
Organic matter (%)	0.72	4.25	1.99±1.04	52.36
Aggregation rate (%)	55.75	92.00	80.20±6.49	8.10
Aggregate stability (%)	57.60	85.57	72.90±6.33	8.68
Penetration resistance (MPa)	0.81	2.48	1.46±0.43	29.74
Clay activity index	0.39	2.87	1.16±0.55	47.41
Plastic limit	18.52	46.15	33.88±6.28	18.55
Liquid limit	49.33	66.76	56.05±3.91	6.98
Plasticity index	13.80	35.17	22.17±5.13	23.14

Comparison of Layers in terms of Soil Properties

The clay contents of the surface layer (K_1) were lower significantly than K_2 and K_3, which may be due to the leaching of clay from the surface and deposition in the subsurface layers. The sand and silt content decrease significantly with the increase of soil depth, which may be due to an increase in the relative content of clay (Table 2). Like our results previously studies showed that the clay content tends to increase depending on soil depth (Canbolat & Öztaş, 1997; Gürsoy & Dengiz, 2018; Lan et al., 2019). The moisture content of all soil layers was over the field capacity, the average moisture content of the three soil layers was K_1 (30.57%) > K_2 (27.71%) > K_3 (25.63%). These differences were statistically significant (Table 2). The moisture content of the upper layer of the soil is lower than subsoil because the upper soil layer is more exposed to sunlight. However, soil samples were taken after heavy rainfall, which caused higher moisture content in the upper soil layer in fall.

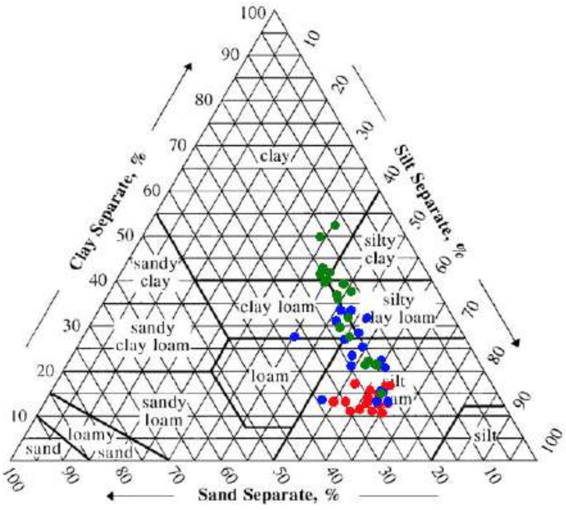

Figure 2. Soil texture classes of the soil samples

The organic matter content differed statistically in the sampling layers. It decreased from the top layer to the bottom layer. Plants are the most important source of soil organic matter (Baldock & Nelson, 2000; Karaman et al., 2007). Especially in pasture soils, this situation is more prominent because of the dense vegetation (Benbi et al., 2015). Similar to our findings the researchers reported that the organic matter content was the highest in the upper soil layer and decreased along with the soil profile (Aydın et al., 1997; Demir et al., 2012; Maillard et al., 2019).

The amount of the aggregates did not change significantly with soil layers. However, the amount of the water stable aggregates in the K_1 (79.07%) was significantly higher than K_2 (72.9%) and K_3 (66.83%). Clay and organic matter content are the most effective properties of aggregate stability (Bronick & Lal, 2005; Duiker et al., 2003). They are positive correlation between clay content-aggregate stability and organic matter content-aggregate stability. The reason for decreasing the aggregate stability along with the soil layers is the low organic matter content. The penetration resistance differed significantly along with soil layers, it was lower on the K_1 (1.16 MPa) than the K_2 (1.37) and K_3 (1.84). The main reason for the higher penetration resistance in the subsurface layer is the soil tillage in the past. Clay activity index was the highest value in K_1 (1.70), decreased to 1.02 in K_2, and 0.75 in K_3. This difference was found to be statistically significant (Table 2).

Sampling layers were different in terms of liquid limit like the other soil properties in the study area. It had the highest value (60.52%) in the K_1 and showed a downward tendency to be 53.28% in the K_2, and 52.63% in the K_3. As a result of the variance analysis, it was determined that the difference along with the sampling layers was statistically significant (Table 2). Similar to our study it was reported that plastic limit and liquid limit had high values in upper soil layers and tended to decrease due to depth increase (Stanchi et al., 2017). Like the liquid limit, the plastic limit was the highest in K_1 (38.85) and decreased to 33.17% in K_2 and 30.95% in K_3, this difference was statistically significant (Table 2). Atterberg limits are a mechanical behavior that is affected by the basic physical and chemical properties of soil such as grain size distribution, soil moisture, aggregation and organic matter content (Scott, 2000). Since these properties varied in the sampling layers, the plastic limit values changed in the soil profile. The difference in the sampling layers in terms of plasticity index was not statistically significant (Table 2). The highest plasticity index was calculated in K_3 (23.22) and the lowest in K_2 (21.49).

Table 2. Variance analysis results comparing layers in terms of soil properties

	Clay content (%)	Silt content (%)	Sand content (%)	Soil moisture (%)	Organic matter (%)	Aggregation rate (%)
K_1 (0-25cm)	12.98C	60.30A	26.73A	30.57A	3.25A	81.57
K_2 (25-50cm)	23.21B	53.26B	23.32B	27.71B	1.59B	81.43
K_3 (50-75cm)	33.98A	44.98C	20.48C	25.63C	0.62C	80.58
F value	36.48**	21.87**	26.22**	17.39**	128.9**	0.22^{ns}
	Aggregate stability (%)	**Penetration resistance (MPa)**	**Clay activity index**	**Liquid limit (%)**	**Plastic limit (%)**	**Plasticity index (%)**
K_1 (0-25cm)	79.07A	1.16B	1.70A	60.52A	38.85A	22
K_2 (25-50cm)	72.9B	1.37B	1.02B	53.28B	33.17B	21
K_3 (50-75cm)	66.83C	1.84A	0.75B	52.63B	30.95B	23
F value	49.19**	22.70**	21.49**	68.33**	14.75**	0.64^{ns}

Soil Properties Affecting Aggregation Rate

The relationships between clay, sand, moisture, organic matter content and aggregation rate are shown in Figure 3. The direct coefficients between the clay content, organic matter content, moisture content, and moisture content, with aggregation rates, were 0.40, 0.28, 0.16, and 0.11, respectively. According to the direct coefficients, the clay content is the most effective property of the aggregation rate.

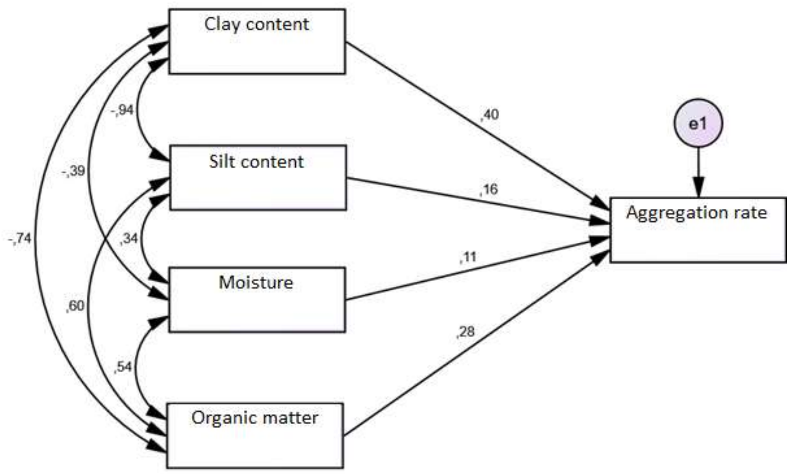

Figure 3. The effects of soil properties on aggregation rate

Soil Properties Affecting the Aggregate Stability

As a result of path analysis, it was determined that the most effective parameter in aggregate stability was organic matter content (0.77). This was followed by clay content (0.26), silt content (0.19), and moisture content (0.12), respectively (Figure 4). While the clay content was effective in the formation of aggregate, the organic matter provided the resistance of the aggregates to the dispersing effect of water.

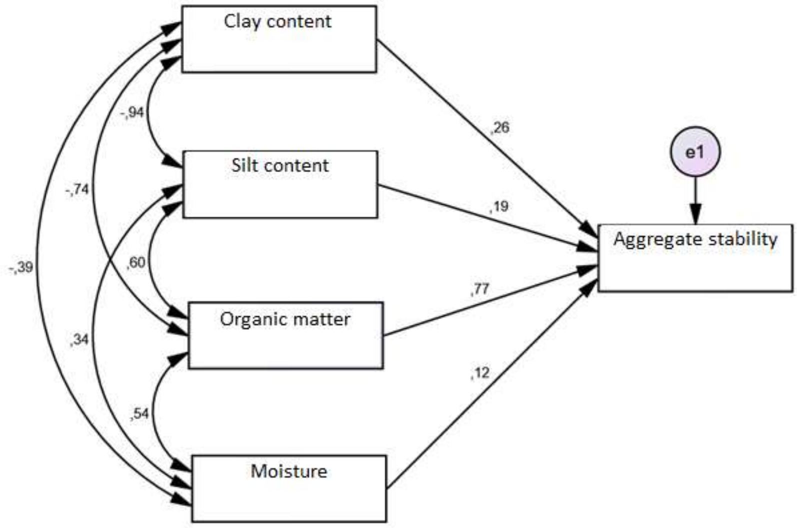

Figure 4. The effects of soil properties on aggregate stability

Soil Properties Affecting the Penetration Resistance

Due to the high correlation between soil moisture and other soil properties, the moisture content was established as the indirect effect in the model. It is known that soil moisture affects many physical, chemical, and biological properties, in this study the penetration resistance was also significantly affected by soil moisture. Dry soils show stronger resistance to compression due to the strong particle-particle bonds. With the increase in moisture content the bonding weakens, internal friction decreases, and the soil shows less resistance to compression. Similar to our results the researchers found negative relationships between soil moisture and penetration resistance (Turgut & Oztas, 2012; Bayat et al., 2017).

The path analysis result (Figure 5) showed that clay content had a positive effect on both moisture content (0.24) and penetration resistance (0.28). The clay content increased the penetration resistance directly because of its structure. However, the positive correlation between clay content and moisture content caused decreasing in the penetration resistance indirectly. In the model, the direct effect of the clay content on the penetration resistance (0.37) was greater than the indirect effect (-0.08). Silt content also had a positive effect on both properties, but different from clay content the effect on moisture content (0.29) was greater than on penetration resistance (0.07). Path analysis showed that the direct effect of the silt content on the penetration resistance (0.17) was more important than the indirect effect (-0.10). Like our findings, researchers reported that penetration resistance values tend to increase due to the increase in clay content of soils (Lipiec et al., 2018).

Organic matter content increased moisture content and decreased penetration resistance, but the effect on moisture content (0.50) was greater than the penetration resistance (-0.16). Soil organic matter, which closely affects many structural properties such as aggregation of soil particles, pore formation and continuity (Bullock, 2005), significantly affected the penetration resistance. Path analysis showed that soil organic matter decreases penetration resistance directly and indirectly with moisture content. However, the indirect effect of organic matter (-0.17) was higher than the direct effect (-0.01). The direct effect of soil organic matter on the penetration resistance was due to its increased porosity in the soil and the continuity of the pores. Like our results, researchers found that there was a negative relationship between penetration resistance and organic matter content (Stock & Downes, 2008; Turgut, 2008; Celik et al., 2010).

The effects of aggregation rate on both moisture content and penetration resistance were low. The direct effect coefficient (-0.11) of AS was greater than the indirect effect coefficient (-0.07). It is expected that the improvement in the structure of the soil can lead to decrease in penetration resistance. The excessive number of aggregates in the unit soil mass prevents the soil particles to be packed and compacted more firmly (Turgut, 2008). Like our findings, the researchers reported that the penetration resistance values decreased due to aggregation of soils (Turgut & Öztaş, 2012; Barik et al., 2014).

The effect of the clay activity index on penetration resistance was negative (-0.06). High clay activity index indicates the presence of swelling clay types (Wagner, 2013). High pore volumes of swelling clays lead to low penetration resistance. Therefore, the adverse effect of the clay activity index on penetration resistance is expected.

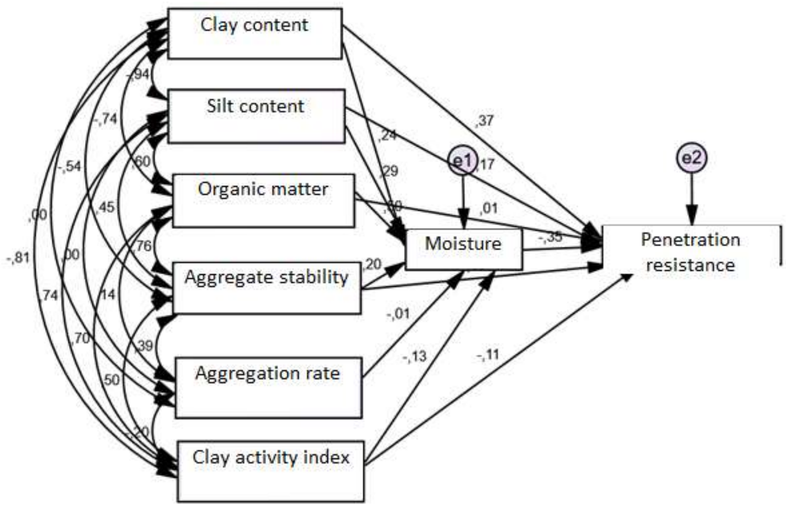

Figure 5. Direct and indirect effects coefficient of soil properties on penetration resistance

Soil Properties Affecting the Plastic Limit

The analysis results (Figure 6) showed that the direct effect of the clay content on the plastic limit (0.17) was higher than the indirect effect (0.08). The silt content showed similar behavior the direct effect (0.09) was higher than the indirect effect (0.06). It is well known that fine-textured soils show plasticity in moist conditions (Hoek & Brown, 1980; Scott, 2000). Like our results, researchers found that high clay content increases the plastic limit (Yakupoğlu & Özdemir, 2006; Stanchi et al., 2017).

The organic matter content has the highest direct effect coefficient on the plastic limit. It is known that soil organic matter affects many physical, chemical, and biological properties (Rowell, 1993; Karaman et al., 2007). It is especially effective in increasing the water holding capacity of soils through aggregation (Scott, 2000). Casagrande (1948) suggested that the more organic matter content in the soil the more plastic and liquid limit. Like our results, researchers reported that the increase in organic matter content positively affected the plastic limit and liquid limit (Yakupoğlu & Özdemir, 2006; Zentar et al., 2009; Stanchi et al., 2017).

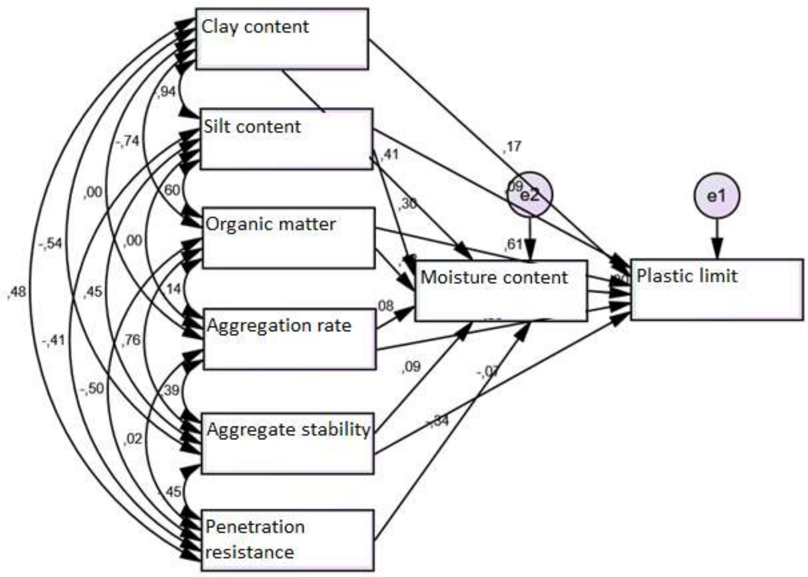

Figure 6. Direct and indirect effects coefficient of soil properties on plastic limit

Soil Properties Affecting the Liquid Limit

According to the results of path analysis (Figure 7), clay content positively affected the liquid limit. The direct effect (0.41) of clay content on the liquid limit was higher than the indirect effect (0.16). Silt content showed similar behavior and had a positive effect on the liquid limit both directly (0.30) and indirectly (0.12). Like our findings, the researchers reported that clay content affects the liquid limit (Ball et al., 2000; Stanchi et al., 2017).

As in the plastic limit model, the soil property having the highest coefficient of effect was the organic matter content. Its direct and indirect effects were positive, but the direct effect (0.72) was higher than the indirect effect (0.16). In previous studies, it was reported that organic matter content affected the liquid limit (Hemmat et al., 2010; Stanchi et al., 2017).

The direct and indirect effects of aggregate stability on the liquid limit were positive, but it was determined by the path analysis that the direct effect coefficient (0.13) was higher than the indirect effect coefficient (0.03). Stanchi et al. (2017) reported that the liquid limit in poorly structured soils has low values.

The penetration resistance, whose indirect effect coefficient (-0.13) was greater than the direct effect (0.06), was more effective at the liquid limit than at the plastic limit. Ball et al. (2000) reported that the liquid limit has a higher correlation with the penetration resistance than the plastic limit.

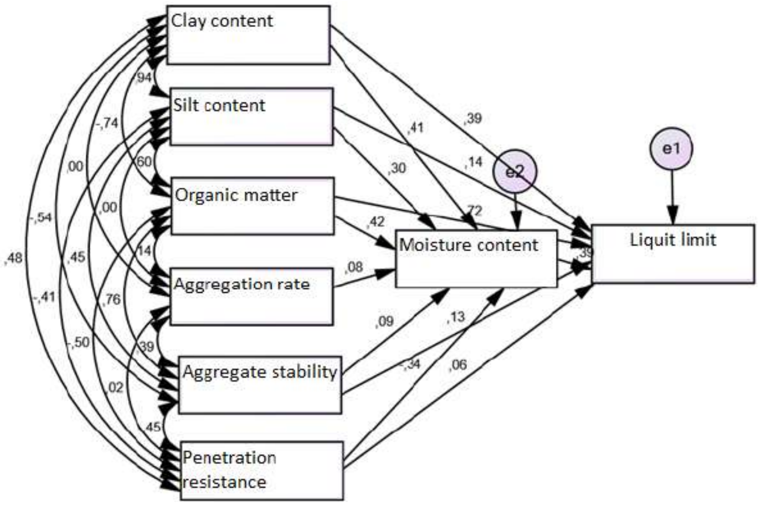

Figure 7. Direct and indirect effects coefficient of soil properties on liquid limit

Soil Properties Affecting the Plasticity Index

As in other consistency limits, moisture content was used as an indirect effect parameter in path analysis modelling (Figure 8). In the examination of the direct and indirect effects of the independent variables affecting the plasticity index, it was found that the clay content had a positive effect on plasticity both directly and indirectly, but the coefficient of direct effect (0.17) was higher than the indirect (0.01). The consistency index, which is least influenced by the silt content, is the plasticity index. As it is known, the increase in the plasticity index of soil means that it shows high plasticity, and this feature is related to clay content (Bleam, 2017). Researchers reported that the plasticity index tends to increase due to the increase in clay content (Winterwerp & van Kesteren, 2004).

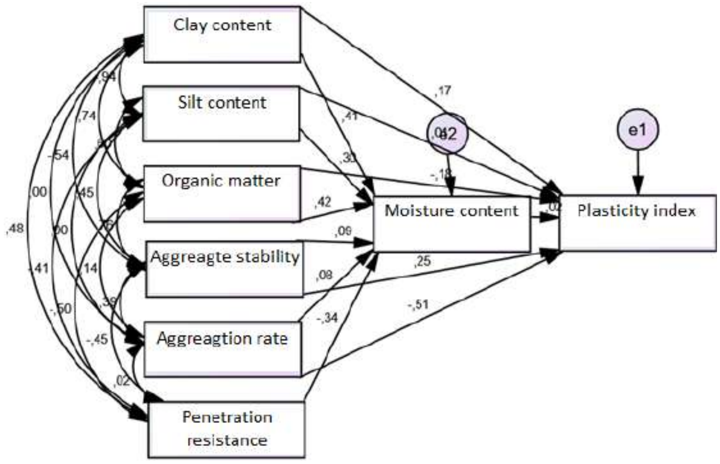

Figure 8. Direct and indirect effects coefficient of soil properties on plasticity index

While the direct effect of organic matter on the plasticity index was negative, the direct effect had a very low coefficient. Due to the colloidal properties of organic matter, it is generally known that the effect on the plasticity index is positive (Zentar et al., 2009; Stanchi et al., 2017), but in this study, it is estimated that the negative effect of organic matter on plasticity index, even if with a low coefficient, may result from clay mineralogy.

The soil properties negatively affected the plasticity index directly with the highest coefficient (-0.51) was the aggregation rate. However, its indirect effect was negligible. No studies are investigating the effects of aggregation rate on the plasticity index, but it is thought that aggregation may decrease the number of free clay minerals and decrease the plasticity index. The aggregate stability had a positive effect on the plasticity index and its direct effect coefficient was calculated as 0.25. The direct and indirect effect of penetration resistance on plasticity index was negative, and the direct effect coefficient was higher. Like our findings, Wagner (2013) report that high plasticity index caused low resistance to soil-applied force.

Conclusion

The effects of soil properties on structural parameters such as aggregate stability, aggregation rate and penetration resistance were different. While the clay content was effective on the aggregation rate, the organic matter content was the most effective property on the aggregate stability. It was determined that the soil properties had direct and indirect effects on the penetration resistance, the clay content had the highest direct effect, and the organic matter content had the highest indirect effect. Organic matter content has the highest direct effect on the plastic limit and liquid limit, while the aggregation rate is on the plasticity index.

Acknowledgment

This manuscript is a part of the Master Thesis of Aktan Hangişi.

Conflict of Interest

The authors declare that they have no conflict of interest.

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http://silvaworld.org
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e-ISSN: 2822-6127
https://prensip.gen.tr

RESEARCH ARTICLE

Contributions of Game Theory to Economic and Political Rationality in Forestry

Hüseyin Çalışkan[1*] • Sezgin Özden[2]

[1]Çankırı Karatekin University, Graduate School of Natural and Applied Sciences, Çankırı/Turkey
[2]Çankırı Karatekin University, Faculty of Forestry, Department of Forest Economics, Çankırı/Turkey

ARTICLE INFO

Article History
Received: 15.09.2022
Accepted: 22.09.2022
First Published: 23.09.2022

Keywords
Decision making
Forest management
Game theory
Rationality
Sustainability

ABSTRACT

Political and economic decision-making processes take into account the rationality criteria of forests such as productivity, profitability, and economy. While these criteria in developed countries in the sense of forestry have positive values, such values of developing countries are fluctuating. In Turkey, only wood-based and non-wood forest products of forests are included in national balance sheets. Therefore, it is thought that the real value of forests could not be calculated. However, calculating the actual values will change all balances. Thus, the discussions on the capacity of forests are moved to a more mathematical ground. The fact that the capacity of the forests is not enough to meet all the needs causes the forest assets to be endangered and therefore requires rationality in using. The concept of rationality is based on rules and obtaining reasonable results, and it has been used frequently in recent studies of game theory modeling initiatives. Effective use of this approach in forest policy and economics will contribute to the development of forests, villagers and the country's economy by obtaining more rational results, and will also be beneficial to eliminate some problems between decision makers and the public. In the last 20 years, the 10-fold increase in forestry-based game theory modeling researches in the world indicates that the game theory approach has begun to be included in decision-making processes aimed at achieving sustainable forestry. As a consequence, the game theory approach seems a new and effective tool that will contribute to the economically and politically rational management of forestry.

Please cite this paper as follows:
Çalışkan, H., & Özden, S. (2022). Contributions of game theory to economic and political rationality in forestry. *SilvaWorld*, *1*(1), 33-38. https://doi.org/10.29329/silva.2022.462.04

Introduction

Forests are communities that need to be managed in order to be transferred to future generations in an efficient and sustainable manner. Political and economic results of management are output of the implementation and management characteristics (Elkin, 1985). According to Akyol and Tolunay (2011), forest resources have been operated with an understanding of sustainability for many years, but since this understanding is understood as the sustainability of wood raw material production, the fact that the forest is a complex ecosystem has always been ignored (Akyol & Tolunay, 2014). However, Political and economic decision-making processes must take into account the rationality criteria of forests such as productivity, profitability, and economy (Alkan, 2009; Türker, 2016). While these criteria in developed countries in forestry have positive values, such values of developing countries are fluctuating.

The problem which forms the basis of this research is that the capacity of the forests is not enough to meet all the needs, and it causes the forest assets to be endangered, therefore requires rationality in using (Çalışkan & Özden, 2021). To explain the concept of rationality, it is defined by some authors as the behavior that brings the most satisfaction to the individual (Bulutay, 1982; Kanlıoğlu, 2019), while according

* Corresponding author
E-mail address: hcaliskanphd@gmail.com

to some authors it is defined as an effort to maximize interests (Doğan, 2012; Can Kamber, 2018). When these definitions are applied to the Sustainable Forest Management Criteria and Indicators (OGM, 2020), the rationality of other items will show negative values when it is aimed to maximize profit from only one item, for example, only wooden raw material production, without considering other criteria. For this reason, instead of seeing forests only as a source of raw material, they should be considered as ecosystems (Akyol & Tolunay, 2014) and the rationality of the entire ecosystem should be considered. This study examines the contribution of the game theory to rationality in order to contribute to the economically and politically efficient management of forests within the framework of the concept of rationality.

Materials and Methods

The concepts of rationality and Game Theory are the two concepts used as method in the basis of this study. Karabacak says that the concept of rationality has a multidimensional development process extending from Greek philosophy to today's modern philosophy and science world, and the concept of rationality has been defined in different disciplines such as economics, political science, sociology, psychology and biology, and has been the subject of some debates, theses, and books (Karabacak, 2017). Accordingly, the definition of rationality at the level of strategic games is similar to rationality used in economic terms. So, rationality means that each player wants to maximize his payoffs.

On the other hand, game theory is a multi-person analysis of a decision problem, founded in 1928, where each player thinks about what the others do (Gibbons, 1992). In game theory, strategies need to be determined after players have been identified. On the basis of game theory, strategy is the path that a player will follow in order to obtain optimum payoff. Players may choose fixed or mixed strategy. In this study, it is predicted that the players will determine a mixed strategy, that is, they will be able to benefit from more than one strategy to a certain extent. Gibbons (1992) defines mixed strategy as the probability distribution of players' strategies. Research shows that game theory and its strategies may be applied to almost every field. The use of this method on forest policy and economy has become widespread recently. This study was carried out by scanning past researches, documents, information and statistics on game theory, forest policy and economy.

Results and Discussion

Forests have many ecological and economic values besides meeting the need for wood raw materials. The concept of rationality discussed in this research is the use of the values attributed to the forest within the framework of rationality and thus its contribution to the sustainability of the forests. The general assumption in determining the value of natural resources is that every asset has a value and this value is not high to be measured (Türker, 2020). According to Türker, the economic values of forests are divided into two parts as active and passive values. Active values include direct and indirect uses, while passive values are specified as existence and inheritance values.

The benefit obtained by the active use of forests means the direct or indirect use of natural resources. The use of timber and firewood, which are wood-based forest products, falls within the definition of direct use in terms of forestry. Some researches in this area (Atmış, 2020; Kömürlü, 2020) show that the use without limiting or by stretching for all kinds of wood production has a negative effect on the dominant species number, species diversity and sustainability, and therefore on rational use.

The thought that the sustainability of forests may be endangered affects not only the direct use but also the indirect use of these assets. People indirectly benefit from the recreational properties of forests. In addition to all kinds of psychological and spiritual benefits, forests have many indirect benefits such as soil protection, prevention of air pollution, water purification and preserving biological diversity that are not noticed by non-experts. Indirect use features are the social services of forests (Akyol & Tolunay, 2011; Gümüş & Kaya, 2021). However, a large part of such benefits provided by forest ecosystems are seen as non-monetary benefits, which causes damage to forests which is caused by misuse of these resources. (Geray & Eker, 2006; Özüpekçe, 2021).

In addition to the active values of forests, there are also passive values such as existence and heritage (Türker, 2017). Türker characterizes these values as values that individuals acquire without expecting any benefit from them. Because future generations have the right to use forests as much as we do. Our decisions should not affect future generations, "because future generations do not vote" our decisions (Brundtland, 1987). For example, a study conducted in Turkey, determined the total economic value of Turkey's forests and it was concluded that 41.99% of these components are wood-based products (Türker et al., 2005).

National balance sheets include only the first two (50.02%) of the values given in Table 1, wood-based products and non-wood forest products (Türker, 2020). Therefore, it is thought that the real values of forest resources are not calculated. It is clear that the balances will change if these values are observed and considered.

The concept of game theory discusses the consequences of a problem. It enables the players to maximize their returns/benefits by predicting different results that may arise with some different perspectives and keeping the decisions made in a rational framework. Assuming that the percentage sum of the values in Table 1 is 1 (one), the integration of this situation into the zero-sum game can be exemplified.

Table 1. Total economic value and components of Turkey's forests (Türker, 2020)

Component	**Type**	**Percent (%)**
Direct Using Value	Wood Based Products	41.99
Direct Using Value	Non-wood Products	8.03
Direct Using Value	Grazing	21.00
Direct Using Value	Hunting	3.35
Direct Using Value	Recreation	0.18
Indirect Using Value	Carbon Sink	14.78
Optional Value	Medical Use	10.5
Existence Value	Conservation of Biodiversity	0.12
Total Percentage (%)		99.95

A zero-sum game is defined as a situation where one player wins and the other loses (Çubukçu, 2016). That is, one player's gain means the other's loss. We can define this situation to a balance of scales or a tug of war game. While there is a contrasting relationship between zero-sum games which is defined as perfect competition and the goals of environmental protection and economic growth, the production process incurs significant social costs (Orhan & Karahan, 2003; Karabacak & Akdeve, 2021). To put it more clearly, environmental resources are rapidly consumed by increasing the process of capitalist production based on natural resources, and the emission that occurs in the same process also destroys the environment or natural life as a whole. Therefore, if it is desired to reduce the social costs or the negative effects in the environment, it is necessary to impose restrictions on the production process. To turn this situation into a game, we set up a matrix by identifying two different players. Assuming that one of the players, *Player A*, intends to produce only wood and non-wood products with the full capitalist approach strategy, it can be assumed that the other player, *Player B*, adopts a more social approach.

During the determination of the game, the rules must be set first, because the concept of rationality is based on rules and obtaining reasonable results, and it has been used frequently in recent studies of game theory modeling initiatives (Held, 1977; Dekel & Gul, 1997). For this game, *Player A* is assumed to be the government. Because, for example, for Turkey, forests are almost entirely owned by the state in terms of ownership. Since the decision-making authority in this matter is entirely with the state, each action creates a net burden on the forests. The extent of this burden is determined by the laws enacted and the policies implemented. Also, in this study, Player B was considered to be the public. Because the public will be adversely affected in terms of recreation and weather in the absence of forests.

In countries where forests are managed by the state, the decision is made by the managers. Therefore, *Player A* mentioned in this game has a dominant role and he plays first. While determining the utilization strategies of the players for a certain forest area, let's assume that player A adopts the "Wood Based Products" and "Non-Wood Based Products" production strategies in Table 1 as the first strategy, S_{1A}. *Player B* wants to focus on more social benefits with his first strategy S_{1B}. This means that *Player B* will want to take advantage of the recreational, carbon sequestration and other benefits in that area. Of course, there are S_{2A} and S_{2B} strategies that express the opposite of the same situation. This is illustrated by the extensive-form game in Figure 1.

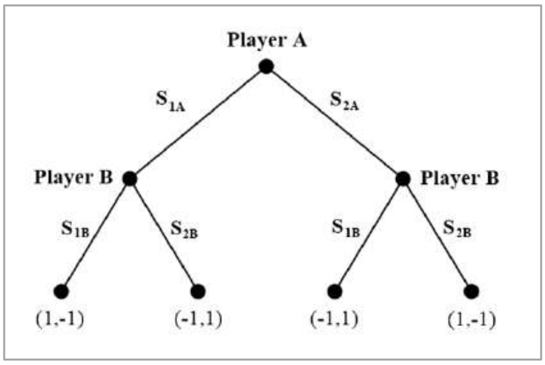

Figure 1. Extensive form of the game

The illustration in Figure 1 shows that each decision of *Player A* affects the behavior and strategy of *Player B*. When this situation is considered in terms of a country, it is clear that the decisions of the country, and the government affect the people. However, when we put these strategies and revenues in the game theory matrix to get a clear picture, a situation like Table 2 emerges.

Table 2. Zero-sum game matrix with a capitalist and social approach

		Player B	
		(S_{1B})	(S_{2B})
Player A	(S_{1A})	(1,-1)	(-1,1)
	(S_{2A})	(-1,1)	(1,-1)

Table 2 shows us that *Player A* focuses on the S_{1A} strategy, namely "Wood Based Product" and "Non-Wood Based Product" production, and *Player B* is negatively affected socially by this strategy. However, this cannot be a rational approach as it is not possible for the country and the government to completely abandon wood production from natural forests. Instead, the mixed strategy approach of game theory comes into play where each player does not pursue only one strategy, but partially adopts both strategies. In this case, each probability will be seen in Table 3.

Table 3. Mixed Strategy Zero-sum game matrix with a capitalist and social approach

		Player B	
		(S_{1B}) (n)	(S_{2B}) (1-n)
Player A	(S_{1A}) (p)	(1,-1)	(-1,1)
	(S_{2A}) (1-p)	(-1,1)	(1,-1)

Table 3 shows that *Player A* will play strategy S_{1A} with probability *p*, and strategy S_{2A} with probability *1-p*. Likewise, *Player B* plays S_{1B} with probability *n*, and plays S_{2B} with probability *1-n*. Here, the game theory approach aims to find a common balance so that both players may get the optimum payoffs. Here the players earn their income by using *Pure* and *Mixed Strategies* in Table 2 and Table 3. Since it is not possible for governments to completely abandon wooden production from natural forests, it is necessary to find out which strategy to adopt and how much, and the expected payoffs by using the mixed strategy. According to Table 3, Expected Payoffs of *Player A* and *Player B*, E_A and E_B, is calculated as follows.

$$E_A = [pn + p(1-n)(-1)] + [(1-p)n(-1) + (1-p)(1-n)] \quad (1)$$

$$E_B = [np(-1) + (1-n)p] + [n(1-p) + (1-n)(1-p)(-1)] \quad (2)$$

These equations are formulated considering the probability distribution whose sum is 1, since the game is zero-sum. Therefore, the sum of A's strategy distribution should be 1 which is calculated as $1 - p + p = 0$. The same is true for Player B, $1 - n + n = 0$. The expected payoffs of the players are calculated by multiplying the strategies they have determined with their probabilities.

In this case, while calculating the expected Payoff of one of the players, the strategy probabilities of the other are also considered. The fact that these strategies and probabilities are in the multiplier position indicates that the more benefit a player using *Mixed Strategy* expects from an area, the less the other player's expectation will be. For this reason, the application of *Mixed Strategy* games to political and economic decisions is useful to see which strategy or which policy is effective or harmful in reality.

Decision making is not easy for policy makers in uncertain situations and it is important for decision makers to make decisions based on scientific principles by using models (Kıral, 2015). As a result of this study, using and spreading of the game theory approach in forest policy and economics will enable decision makers to see the strategies they implement and their results more easily, by eliminating some uncertain situations. Thus, the future of our forests may be further guaranteed by adopting more rational and beneficial decisions and strategies. As a result, there will be a further interaction between the scientific and academic community and decision makers, and the future will be seen more clearly and mathematically, and conflicts will diminish. Thus, policy makers will rarely be criticized, and since the effectiveness of the decisions will be foreseen, the ground will be prepared for the research of more effective and scientific applications.

Game theory isn't just about zero-sum games. There are many types of games that require different strategies in the decision-making stages such as, bargaining or auction. Most of the academic research reviewed in this paper indicates that game theory is widely used in the non-forestry sciences. Adapting the game theory concept to forest policy and economics, as in almost every field, will increase the success of academic research, and will pave the way for the emergence of more well-known, effective and sought-after publications at the global level.

As game theory considers the strategies and choices of other players, it will be possible to restore the benefits that the public did not derive from the recreational use of forests. Therefore, the resulting win-win situation will lead to more rational returns. In cases where scarce resources such as forests are in question, transferring these assets to future generations means making their lives healthier. Therefore, the social benefits obtained today and in the future are also benefits for decision makers.

The effective use of game theory method in forestry, as in other branches of science, will help to find the most effective and reliable choice in solving complex problems that need to be social and objective in the real world. Thus, more rational decisions may be taken, free from political ideology.

Most research on forestry or sustainability (Akyol & Tolunay, 2011; Başkent, 2015; Hakverdi, 2020; Uygur Erdoğan, 2020) generally deals with the individuals who directly or indirectly benefit from forests. For example, forests have been among the most important resources for human beings throughout history (Hakverdi, 2020), and people have used the forest continuously for many of their needs, including firewood and shelter (Başkent, 2015). As a result of this pressure that has been going on throughout history, it has been seen that ecological problems are caused by the damage caused by humans to the ecosystem (Uygur Erdoğan, 2020). The game theory approach may contribute to the establishment of a more rational basis for academic studies with a sustainable development approach while creating development projects. Thus, it can be mathematically predicted where the players, namely the villagers or the people of the region, will reach at the end of that project. Decisions made with these predictions will contribute positively to the country's economy, the regional welfare and the income of individuals. In this way, an effective and realistic war may be waged against inflation either directly or indirectly.

In the last 20 years, the 10-fold increase in forestry-based game theory modeling researches in the world indicates that the game theory approach has begun to be included in decision-making processes aimed at achieving sustainable forestry. As a consequence, the game theory approach is a new and effective tool that will contribute to the economically and politically rational management of forestry.

Acknowledgment

This paper was presented and its abstract was published at 1st International Karatekin Science and Technology Conference held in 1-3 September 2022.

Conflict of Interest

The authors declare that they have no conflict of interest.

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e-ISSN: 2822-6127
https://prensip.gen.tr

RESEARCH ARTICLE

Flora, Life Forms and Chorotypes of Forest Floor Plants in the Asalem Forests, Western Hyrcanian, Iran

Fazel Khodaparast[1] • Hassan Pourbabaei[2*] • Ali Salehi[2]

[1]University of Guilan, Faculty of Natural Resources, PhD Programme in Forestry, Sowme`eh Sara/Iran
[2]University of Guilan, Faculty of Natural Resources, Department of Forestry, Sowme'eh Sara/Iran

ARTICLE INFO

Article History
Received: 16.08.2022
Accepted: 14.09.2022
First Published: 28.09.2022

Keywords
Forest floor plants
Life forms
Chorotypes
Asalem forests

ABSTRACT

The aim of this research was to introduce the forest floor plants species, their life-forms, and describe their geographic distribution in the Asalem Watershed basin (no.7), Western Guilan province (part of Western Hyrcanian) in northern forests of Iran. The Asalem forest is one of the most important and valuable areas of Caspian forest in Iran. The study was conducted on 91 plots of 400 m^2 (20 × 20 m) along 19 transects in the basis of a random- systematic sampling design. Inside each main plot, three quadrates (5 × 5 m) on the diagonal line and internal quadrates (1 × 1 m) were chosen, and all of the floor plants collected. The results revealed that there were 306 species, 181 genera and 54 families. The main family was Poaceae with 36 species and 25 genera (12%). Then, the highest number of species belonged to the Asteraceae with 28 species, Fabaceae with 26 species, Lamiaceae with 20 species, Rosaceae with 14 species, Apiaceae and Cyperaceae each including 13 species, Caryophyllaceae with 12 species, Rubiaceae and Orchidaceae each including 11 species. Regarding to the life forms, Hemicryptophytes with 45% (137 species) were the largest group. The chorological analysis indicated that species belonging to the regions of Euro-Siberian were the most significant ecological groups.

Please cite this paper as follows:
Khodaparast, F., Pourbabaei, H., & Salehi, A. (2022). Flora, life forms and chorotypes of forest floor plants in the Asalem forests, Western Hyrcanian, Iran. *SilvaWorld*, *1*(1), 39-51. https://doi.org/10.29329/silva.2022.462.05

Introduction

Iran is one of the centres of global biodiversity (Farashi & Shariati, 2017). The number of vascular plants in north provinces in Iran and Talesh of Azarbaijan republic is approximately 3234 species, belonging to 856 genera and 148 families (Akhani et al., 2010). Floristic study of an area is one of the most effective methods in managing and protecting the genetic resources of that area (Park et al., 2018). The vegetation of an area results from the environmental conditions, interactions among species, reflects its geographical conditions (Huang et al., 2022). The distribution of vegetation patterns is not accidental, but a plant community includes a collection of species with similar entities and ecological needs which selects a particular site affected by environmental conditions such as soil properties and topographic conditions. Identifying the vegetation of each region and understanding their ecological interactions are necessary for each study and these are the basis of the vegetation map of that area. Floor plants species in a forest area show the potential and the capability of vegetative area, increase the number of species in terms of density, and identify the resistant and invasive species, medicinal plants, and their proper use.

The life form of any plant is fixed to development based on morphological adaptation of plants to environmental conditions (Doležal et al., 2021). According to Raunkiaer's classification system, plant species can be grouped into five main classes:

* Corresponding author
E-mail address: h_pourbabaei@guilan.ac.ir

Phanerophytes, Chamaephytes, Hemicryptophytes, Cryptophytes, and Therophytes. Ecological range of each plant species has a unique variation that will tolerate an environmental gradient and distribution of each plant species may be limited or widespread (Dew et al., 2017).

Iran consists of four important phytogeographical zones, including: Irano-Turanian, Euro-Siberian, Sahara-Saudi Arabian, and Sudan like a bridge (Naqinezhad et al., 2009). Several studies on the flora and their life forms have been carried out in Iran (Asri & Eftekharti, 2003; Atashgahi et al., 2008; Azimi Motem et al., 2011; Basiri et al., 2011; Nadaf et al., 2011; Ghahremaninejad et al., 2012; Khajedin & Yeganeh, 2012; Heydari et al., 2013; Moradi et al., 2013; Pourmoghaddam et al., 2013; Ravanbakhsh et al., 2013; Adel et al., 2014; Mataji et al., 2014; Eslami Farouji & Khodayari, 2015; Gahanbakhsh Ganje & Ebadi, 2015; Soleymanipour & Esmailzadeh, 2015; Akhondnejad et al., 2016; Bakhshandeh Navroud et al., 2017; Negahdarsaber et al., 2016; Dehshiri et al., 2017; Salahi et al., 2018), but few studies have been conducted on the structure and flora of the floor layer in the plant communities in the western part of Caspian forest in Iran. In fact, the western part of Caspian forest in Iran is one of the most important and most valuable parts of Caspian forest and comprises commercial forest with unique vegetation. Vegetation of this area shows a high similarity to vegetation of central European forests (Pourbabaei et al., 2019). Then, it is necessary to do more research to achieve more reliable results concerning flora, geographical distribution, and life forms of this area. The aim of this research was to identify the forest floor plants of Asalem watershed basin where it is one of the largest, the most commercial and unique watersheds in the western part of Caspian forest in north of Iran.

Materials and Methods

Study Area

This study was conducted in the Asalem Watershed basin (no. 7), western Guilan province (part of Western Hyrcanian) in northern forests of Iran. Hyrcanian forests form a unique forested massif that stretches 850 km along the southern coast of the Caspian Sea. The studied area is situated in latitude from 37°36′31″ to 37°44′40″ N and longitude from 48°35′17″ to 48°56′26″ E (Figure 1). The minimum and maximum altitudes were 200 and 1800 m a.s.l., respectively. This region has northern and southern aspects and the slope is from moderate (5%) to high (95%). This area covers approximately 22,000 ha of forests. The average annual precipitation and temperature are about 945 mm and 12.4 °C, respectively. The climate is temperate and humid (Pourbabaei et al., 2020). The common forest soil orders are Alfisols and Inceptisols according to USDA soil classification (Pourbabaei et al., 2019).

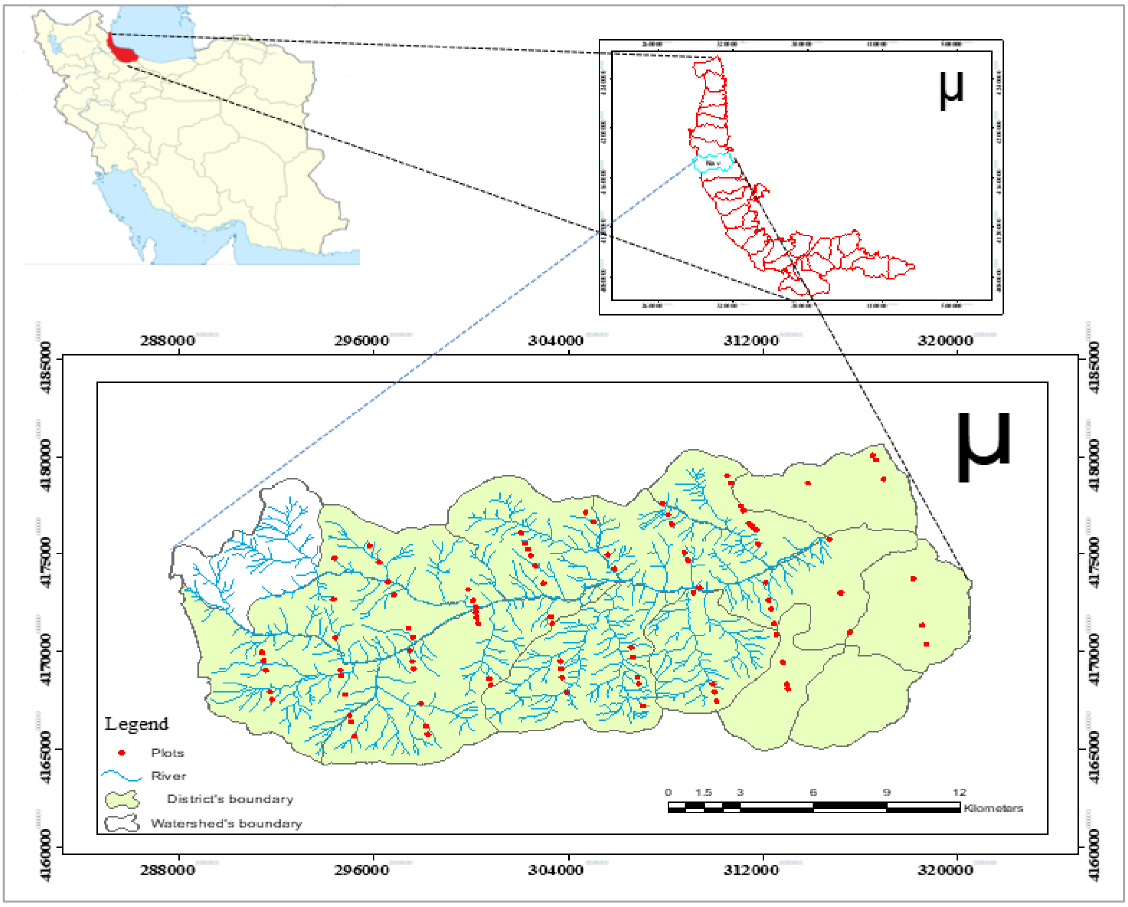

Figure 1. The location of study area, Asalem Watershed basin, north forest of Iran

Field Sampling

The floristic data were collected during the growing season since 2021. Nineteen altitudinal transects were established with 3 km from each other. 46 and 45 sampling plots were located on the southern and northern slopes, respectively between 200 and 1800 m a.s.l. with 200 m intervals. In total, data were collected from 91 plots of 400 m^2 (20 × 20 m) area along transects in the basis of a random-systematic sampling design. To study the floor plants, inside of each sampling plot, three quadrats (5 × 5 m) on the diagonal line and internal (1 × 1 m) quadrates were chosen (Fu et al., 2004).

Identification of Flora

Collected species were dried and pressed, and then they were identified using Flora Iranica (Rechinger, 2015), Flora of Iran (Asadi, 2016), and the Color flora of Iran (Ghahreman, 2006). The life form of plant species was determined using Raunkiaer's method. Chorotype of each species was determined based on Zohary (1973) and Léonard (1992).

Results

In the study area, 306 species belonging to 181 genera and 54 families were found. The highest number of species belonged to the Poaceae family with 36 species and 25 genera (12%). In addition, the other families were Asteraceae with 28 species, Fabaceae with 26 species, Lamiaceae with 20 species, Rosaceae with 14 species, Apiaceae and Cyperaceae each including 13 species, Caryophyllaceae with 12 species, Rubiaceae and Orchidaceae each including 11 species. In total, more than 60% of all species in study area belonged to these 10 families (Figure 2). The list of identified species is presented in Table 1.

Table 1. List of species, family, life form and chorotypes in the study area

Family	Species	Life-form[1]	Chorotype[2]
Amaryllidaceae	*Allium ursinum* L.	Ge	ES, IT, M
	Galanthus caucasicus (Baker) Grossh.	Ge	ES
	Galanthus transcaucasicus Fomin.	Ge	ES
Apiaceae	*Albovia tripartita* (Kalen.) Schischk.	He	ES
	Anthriscus cerefolium (L.) Hoffm.	He	IT, ES
	Bupleurum falcatum L.	He	IT, M
	Bupleurum marschallianum C. A. Mey	Ge	Pl
	Cervaria cervariifolia (C. A. Mey.) Pimenov.	He	IT, ES
	Chaerophyllum meyeri Boiss. & Buhse	He	IT
	Eryngium caeruleum M. Bieb.	He	ES, IT
	Laser trilobum (L.) Borkh.	He	ES, M
	Libanotis transcaucasica Schischk.	He	ES
	Pimpinella affinis Ledeb.	He	Pl
	Sanicula europaea L.	He	Pl
	Torilis arvensis (Huds.) Link	Th	ES, IT, M
	Torilis nodosa (L.) Gaertn.	He	IT, ES
Apocynaceae	*Vincetoxicum funebre* Boiss. & Kotschy.	Ch	IT, ES
	Vincetoxicum scandens Sommier & Levier.	He	ES, IT
Araceae	*Arum maculatum* L.	Ge	ES
Asparagaceae	*Danae racemosa* (L.) Moench	Ge	ES
	Muscari neglectum Guss. ex Ten.	Ge	Pl
	Ornithogalum sintenisii Freyn	Ge	IT
	Polygonatum multiflorum (L.) All.	Ge	ES
	Polygonatum orientale Desf.	Ge	ES, IT, M
	Ruscus hyrcanus Woronow	Ph	IT
	Scilla persica Hausskn.	Ge	IT
	Scilla siberica subsp. *caucasica* (Miscz.)	Ge	ES
Aspidiaceae	*Dryopteris affinis* Fraser- Jenk.	Ge	ES
	Dryopteris radeana (Fomin) Fomin.	Ge	Pl

Table 1. (continued)

Family	Species	Life-form[1]	Chorotype[2]
Aspleniaceae	*Asplenium adiantum-nigrum* L.	Ge	Pl
	Asplenium ceterach L.	Ge	IT, ES
	Asplenium scolopendrium L.	Ge	Pl
	Asplenium trichomanes L.	Ge	Pl
	Asplenium onopteris L.	Ge	Pl
	Athyrium filix-femina (L.) Roth.	Ge	Pl
	Matteuccia struthiopteris (L.) Tod.	Ge	Pl
Asteraceae	*Artemisia annua* L.	Th	ES, IT, M
	Bidens tripartita L.	Th	Pl
	Carpesium abrotanoides L.	He	ES
	Carpesium cernuum L.	Th	ES
	Centaurea hyrcanica Bornm.	He	ES
	Crepis sancta (L.) Bornm.	Th	IT, ES
	Erigeron canadensis L.	He	Pl
	Eupatorium cannabinum L.	He	ES
	Filago vulgaris Lam.	Th	ES
	Hieracium prenanthoides Vill.	He	ES
	Hieracium procerum Fr.	He	IT, ES
	Klasea quinquefolia (Willd.) Greuter & Wagenitz	He	ES
	Klasea radiata (Waldst. & Kit.) Á. Löve & D. Löve	He	ES
	Lactuca garganica Rech. F. & Esfand.	Th	ES
	Lactuca macrophylla (Willd.) A. Gray	Th	ES, M
	Lactuca sativa L.	He	ES
	Lactuca serriola L.	He	ES, IT, M
	Lapsana communis L.	He	ES, IT
	Leontodon asperrimus (Willd.) Endi.	He	ES, IT
	Myriactis wallichii Less.	He	ES, IT
	Petasites albus (L.) Gaertn.	Ge	ES
	Pilosella procera (Fr.) F. W. Schultz & Sch. Bip.	He	ES, IT
	Psephellus zuvandicus Sosn	He	ES, IT
	Sigesbeckia orientalis L.	Th	COSM
	Solidago virgaurea L.	He	ES
	Tanacetum parthenium (L.) Sch. Bip	He	IT, ES, M
	Taraxacum syriacum Boiss.	He	IT
	Willemetia tuberosa Fisch. & C. A. Mey. ex DC	Ge	IT
Berberidaceae	*Epimedium pinnatum* Fisch. ex DC.	Ge	ES
Boraginaceae	*Myosotis anomala* Riedi	Th	ES
	Symphytum asperrimum Donn ex Sims.	He	ES
Brassicaceae	*Alliaria petiolata* (M. Bieb.) Cavara & Grande.	He	ES, IT, M
	Cardamine bulbifera (L.) Crantz.	He	ES
	Cardamine impatiens L.	Th	ES, IT
	Cardamine parviflora L.	Th	ES
	Erophila verna (L.) DC.	Th	Pl
	Hesperis hyrcana Bornm. & Gauba	He	ES
	Thlaspi hastulatum (Stev. Ex) DC.	Th	ES, IT
	Thlaspi perfoliatum L.	Th	IT
Campanulaceae	*Campanula odontosepala* Boiss.	He	ES, IT
	Campanula rapunculoides L.	He	ES
Caprifoliaceae	*Dipsacus strigosus* Willd. ex Roem. & Schult.	Th	ES
	Valeriana alliariifolia Vahl.	He	IT

Table 1. (continued)

Family	**Species**	**Life-form**[1]	**Chorotype**[2]
Caryophyllaceae	*Arenaria serpyllifolia* L.	Th	ES, M, IT
	Cerastium cerastioides (L.) Britton.	He	IT, ES, M
	Cerastium dichotomum L.	Th	IT, ES, M
	Melandrium persicum (Boiss & Buhse) bornm.	He	IT
	Moehringia trinervia (L.) clairv.	Th	ES, IT
	Petrorhagia saxifraga (L.) Link.	He	IT, ES
	Polycarpon tetraphyllum (L.) L.	Th	ES, M
	Scleranthus orientalis Rössler	He	IT
	Silene latifolia Poir.	He	ES, IT
	Silene schafta J. G. Gmel. ex Hohen.	He	ES
	Stellaria holostea L.	Ge	ES, IT
	Stellaria media (L.) Vill.	Th	COSM
Convulvulaceae	*Calystegia sylvestris* (Willd.) Roem. & Schult.	Ge	ES, IT, M
	Convolvulus cantabrica L.	He	ES, IT
Crassulaceae	*Rosularia sempervivum* (M. Bieb.) A. Berger.	He	IT
	*Sedum hispani*cum L.	He	ES, IT, M
	Sedum stoloniferum S. G. Gmel.	He	ES
Cyperaceae	*Carex caucasica* Steven.	Ge	IT, ES
	Carex cuprina (Sándor ex Heuff.) Nendtv. ex A. Kern.	*Ge*	ES, IT
	Carex depressa Link.	Ge	ES
	Carex digitata L.	Ge	ES
	Carex divulsa Stokes.	Ge	COSM
	Carex grioleti (Roem. ex Schkuhr) J. Gay.	He	ES, IT, M
	Carex humilis Leyss.	Ge	ES
	Carex melanostachya M. Bieb. ex. Willd.	Ge	ES, IT, M
	Carex pendula Huds.	Ge	ES, M, IT
	Carex phyllostachys C. A. Mey.	He	ES
	Carex remota L.	He	ES, M
	Carex strigosa Huds.	He	ES
	Carex sylvatica Huds.	Ge	ES
Dennstaedtiaceae	*Pteridium aquilinum* (L.) Kuhn	Ge	Pl
Dioscoreaceae	*Tamus communis* L.	Ge	ES, M
Ericaceae	*Pyrola rotundifolia* L.	Ge	ES
Euphorbiaceae	*Acalypha australis* L.	Th	Pl
	Euphorbia amygdaloides L.	Ch	ES, M
	Euphorbia macroceras Fisch. & C. A. Mey.	Ge	ES
	Euphorbia squamosa Willd.	Ge	ES, IT
	Euphorbia stricta L.	Th	ES, IT
	Mercurialis perennis L.	Ge	ES, M
Fabaceae	*Astragalus glycyphyllos* L.	He	ES, IT
	Astragalus jodostachys Boiss & Buhse.	He	ES
	Lathyrus aphaca L.	Th	ES, IT, M
	Lathyrus laxiflorus (Desf.) Kuntze.	He	ES
	Lathyrus nissolia L.	Th	IT, ES, M
	Lathyrus pratensis L.	He	IT, M
	Lathyrus roseus Steven	He	IT, ES
	Lathyrus vernus (L.) Bernh.	He	ES
	Medicago sativa L.	Th	IT
	Medicago lupulina L.	He	ES, IT
	Medicago orbicularis (L.) Bartal.	Th	ES, IT, M, SS
	Medicago polymorpha L.	Th	IT, SS

Table 1. (continued)

Family	Species	Life-form[1]	Chorotype[2]
Fabaceae	*Securigera orientalis* (Mill.) Lassen	He	ES
	Securigera varia (L.) Lassen	He	IT, ES
	Trifolium arvense L.	Th	ES, M
	Trifolium campestre Schreb.	Th	ES, IT, M
	Trifolium caucasicum Tausch	Th	ES
	Trifolium echinatum M. Bieb.	He	IT, ES
	Trifolium pratense L.	He	Pl
	Trifolium repens L.	He	Pl
	Trifolium tumens Steven ex M. Bieb.	Ge	IT, M
	Trigonella spruneriana Boiss.	Th	IT
	Vavilovia formosa (Steven) Fed.	He	ES
	Vicia abbreviata Fisch. ex Spreng.	He	ES
	Vicia crocea (Desf.) B. Fedtsch.	He	ES
	Vicia tetrasperma (L.) Schreb.	Th	ES, IT, M
Gentianaceae	*Centaurium minus* Moench.	Th	ES, IT, M
Geraniaceae	*Geranium dissectum* L.	He	ES, IT
	Geranium gracile Ledeb. ex Nordm.	He	ES
	Geranium molle L.	He	ES, IT
	Geranium robertianum L.	Th	COSM
	Geranium rotundifolium L.	Th	ES, IT, M
Hypericaceae	*Hypericum androsaemum* L.	Ch	ES
	Hypericum hirsutum L.	He	ES
	Hypericum perforatum L.	He	PL
	Hypericum tetrapterum Fr.	He	ES
Iridaceae	*Crocus caspius* Fisch. & C. A. Mey. ex Hohen.	Ge	ES, IT
	Crocus sativus L.	Ge	Pl
	Gladiolus italicus Mill.	Ge	IT, ES, M
Ixioliriaceae	*Ixiolirion tataricum* (Pall.) Schult. & Schult.f.	Ge	IT, ES
Juncaceae	*Juncus effusus* L.	Ge	COSM
	Luzula forsteri (Smith.) DC.	Ge	ES, M
	Luzula multiflora (Ehrh.) Lej.	He	Pl
Lamiaceae	*Prunella vulgaris* L.	He	ES, IT, M
	Calamintha grandiflora (L.) Moench.	He	ES
	Clinopodium nepeta (L.) Kuntze	He	ES
	Clinopodium umbrosum (M. Bieb.) K. Koch	He	PL
	Clinopodium vulgare L.	He	ES, IT, M
	Lamium album L.	He	ES, IT
	Lamium galeobdolon (L.) L.	He	ES
	Lycopus europaeus L.	Ge	Pl
	Mentha aquatica L.	Ge	ES
	Nepeta racemosa Lam.	He	IT, ES
	Origanum vulgare L.	He	Pl
	Prunella laciniata (L.) L.	He	ES
	Prunella vulgaris L.	Ge	Pl
	Salvia glutinosa L.	He	ES, IT, M
	Scutellaria tournefortii Benth.	Ge	ES
	Stachys byzantina K. Koch.	He	ES
	Stachys iberica M. Bieb.	He	IT
	Teucrium chamaedrys L.	He	ES, M, IT
	Teucrium hyrcanicum L.	He	ES
	Teucrium polium L.	Ch	IT, M

Table 1. (continued)

Family	Species	Life-form[1]	Chorotype[2]
Liliaceae	*Erythronium caucasicum* Woronow.	Ge	ES
Lythraceae	*Lythrum salicaria* L.	He	COSM
Malvaceae	*Alcea hyrcana* Grossh.	He	ES
Onagraceae	*Circaea lutetiana* L.	Ge	ES, IT, M
Ophioglossaceae	*Ophioglossum lusitanicum* L.	Ge	Pl
	Ophioglossum vulgatum L.	Ge	ES, IT
Orchidaceae	*Cephalanthera caucasica* Kraenzi.	Ge	ES
	Cephalanthera longifolia (L.) Fritsch	Ge	ES
	Cephalanthera rubra (L.) Rich.	Ge	ES, M
	Epipactis helleborine (L.) Crantz.	Ge	Pl
	Epipactis microphylla (Ehrh.) Sw.	Ge	ES،IT
	Epipactis persica (Soó) Hausskn. ex Nannf.	Ge	ES،IT
	Listera ovata (L.) R. Br.	Ge	ES
	Neottia nidus-avis (L.) Rich.	Ge	ES, M
	Orchis adenocheila Czerniak.	He	IT
	Platanthera bifolia (L.) Rich.	Ge	M
	Steveniella satyrioides (Spreng.) Schltr.	Ge	ES
Orobanchaceae	*Orobanche cernua* Loefl	He	IT, ES
Oxalidaceae	*Oxalis acetosella* L.	He	Pl
Papaveraceae	*Corydalis cava* subsp. *marschalliana* (willd.) Hayek	He	ES
Phytolaccaceae	*Phytolacca americana* L.	He	Pl
Plantaginaceae	*Plantago lagopus* L.	Th	Pl
	Plantago major L.	He	COSM
	Veronica serpyllifolia L.	He	ES
	Veronica arvensis L.	Th	COSM
	Veronica aucheri Boiss.	He	IT
	Veronica crista-galli Steven	Th	IT
	Veronica officinalis L.	He	ES, M
	Veronica persica Poir.	Th	COSM
Poaceae	*Aegilops cylindrica* Host	Th	IT, SS
	Bothriochloa ischaemum (L.) Keng.	He	Pl
	Brachypodium pinnatum (L.) P. Beauv.	He	ES, M, IT
	Brachypodium sylvaticum (Huds.) P. Beauv.	He	Pl
	Bromus tectorum L.	Th	COSM
	Bromus benekenii (Lange) Trimen.	He	ES, IT, M
	Bromus japonicus Thunb.	Th	IT
	Bromus sericeus Drobow	He	IT
	Bromus sterilis L.	Th	ES, IT, M
	Catapodium rigidum (L.) C. E. Hubb.	Th	ES, IT, M
	Cleistogenes serotina (L.) Keng	He	ES
	Cynodon dactylon (L.) Pers.	He	Pl
	Cynosurus echinatus L.	He	ES, IT
	Dactylis glomerata L.	He	Pl
	Deschampsia caespitosa P. Beauv.	He	ES
	Digitaria sanguinalis (L.) Scop.	Th	Pl
	Festuca drymeia Mert. & Koch	Ge	ES
	Festuca gigantea (L.) Vill	He	ES
	Lolium perenne L.	He	Pl
	Melica uniflora Retz.	Ge	ES, IT
	Microstegium vimineum (Trin.) A. Camus	He	Pl

Table 1. (continued)

Family	Species	Life-form[1]	Chorotype[2]
Poaceae	*Milium vernale* M. Bieb.	Th	ES, IT
	Oplismenus undulatifolius (Ard.) P. Beauv.	Ge	ES
	Paspalum dilatatum Poir.	Ge	Pl
	Phleum phleoides (L.) H. Karst.	He	IT, M, ES
	Poa annua L.	Th	Pl
	Poa longifolia Trin.	Th	IT, ES
	Poa nemoralis L.	Th	ES, IT
	Poa masenderana Freyn & Sint.	Ge	Pl
	Poa trivialis L.	He	ES, M, IT
	Polypogon fugax Nees ex Steud.	Th	Pl
	Rostraria cristata (L.) Tzvelev.	Th	ES, IT, M
	Setaria glauca (L.) P. Beauv.	Th	Pl
	Setaria viridis (L.) P. Beauv.	Th	ES
	Trisetum flavescens (L.) P. Beauv.	Th	IT, M
	Vulpia myuros (L.) C. C. Gmel.	Th	IT, M
Polygonaceae	*Persicaria hydropiper* (L.) Delarbre	Th	Pl
	Persicaria hyrcanica Fisch. Et Mey.	Th	Pl
	Polygonum aviculare L.	Th	COSM
	Polygonum convolvulus L.	Th	Pl
	Rumex conglomeratus Murray	He	ES, IT
Polypodiaceae	*Dryopteris caucasica* (A. Braun) Fraser-Jenk. & Corley.	Ge	ES
	Dryopteris dilatate (Hoffm.) A. Gray	Ge	Pl
	Polypodium interjectum Shivas	Ge	ES, M
	Polypodium vulgare L.	Ge	Pl
	Polystichum aculeatum (L.) Roth	Ge	Pl
	Polystichum braunii (Spenn.) Fée	Ge	ES
	Polystichum setiferum (Forssk.) T. Moore ex Woynar	Ge	ES
	Polystichum woronowii Fomin	Ge	ES
Primulaceae	*Cyclamen coum* Mill.	Ge	ES
	Primula heterochroma Stapf	He	ES, IT
	Primula vulgaris Huds.	He	ES, IT
Pteridaceae	*Pteris cretica* L.	Ge	ES
Ranunculaceae	*Ranunculus constantinopolitanus* (DC.) d'Urv.	Ge	ES
	Ranunculus caucasicus M. Bieb.	Th	IT, ES, M
Rosaceae	*Agrimonia eupatoria* L.	He	ES
	Alchemilla plicatissima S. E. Fröhner	Th	ES
	Fragaria vesca L.	Ge	ES, IT
	Fragaria viridis subsp. *viridis*	Ge	ES
	Geum urbanum L.	He	ES
	Potentilla crantzii (Crantz) Beck ex Fritsch	He	ES, IT
	Potentilla micrantha Ramond ex DC.	He	ES, IT, M
	Potentilla reptans L.	He	ES, IT
	Rubus caesius L.	Ph	ES, IT
	Rubus dolichocarpus Juz.	Ph	ES, IT
	Rubus hyrcanus Juz.	Ph	ES
	Rubus hirsutus Thunb.	Ph	ES, M
	Rubus hirtus Waldst & Kit.	Ph	ES
	Sanguisorba minor Scop.	He	ES, M, IT

Table 1. (continued)

Family	Species	Life-form[1]	Chorotype[2]
Rubiaceae	*Asperula glomerata* (M. Bieb.) Griseb.	Ch	IT
	Asperula odorata L.	Ge	ES, M
	Asperula setosa Jaub. & Spach.	Th	IT
	Asperula taurina L.	Ge	ES
	Cruciata laevipes Opiz	He	IT
	Galium caspicum Steven	He	ES, M
	Galium ghilanicum Stapf	Th	ES, IT, M
	Galium rotundifolium L.	Ge	ES, M
	Galium spurium L.	Th	ES, IT
	Galium tenuissimum M. Bieb.	Th	ES
	Phuopsis stylosa (Trin.) G. Nicholson	He	ES
Scrophulariaceae	*Digitalis nervosa* Steud. & Hochst. ex Benth.	He	ES
	Rhynchocorys elephas (L.) Griseb.	He	ES
	Scrophularia vernalis L.	He	IT
Smilacaceae	*Smilax excelsa* L.	Ph	ES, M
Solanaceae	*Atropa belladonna* L.	Ge	ES
	Solanum kieseritzkii C. A. Mey.	Th	ES
	Solanum nigrum L.	Th	COSM
Urticaceae	*Parietaria officinalis* L.	He	M
	Urtica dioica L.	He	COSM
Viburnaceae	*Sambucus ebulus* L.	He	ES, M, IT
Violaceae	*Viola alba* Besser	He	ES
	Viola hirta. L.	He	ES
	Viola ignobilis Rupr.	He	ES
	Viola odorata L.	He	ES, M
	Viola sieheana W. Becker	Ge	ES
	Viola suavis M. Bieb.	He	M, IT

[1]Life forms in the studied area: Phanerophyte (Ph), Chamaephytes (Ch), Hemicryptophytes (He), Therophytes (Th), Geophytes (Ge). [2]Chorotypes in studied area: Cosmopolitan (COSM), Euro-Siberian (ES), Irano-Turanian (IT), Mediterranean (M), Pluri-regional (Pl), Sahara-Sindian (SS).

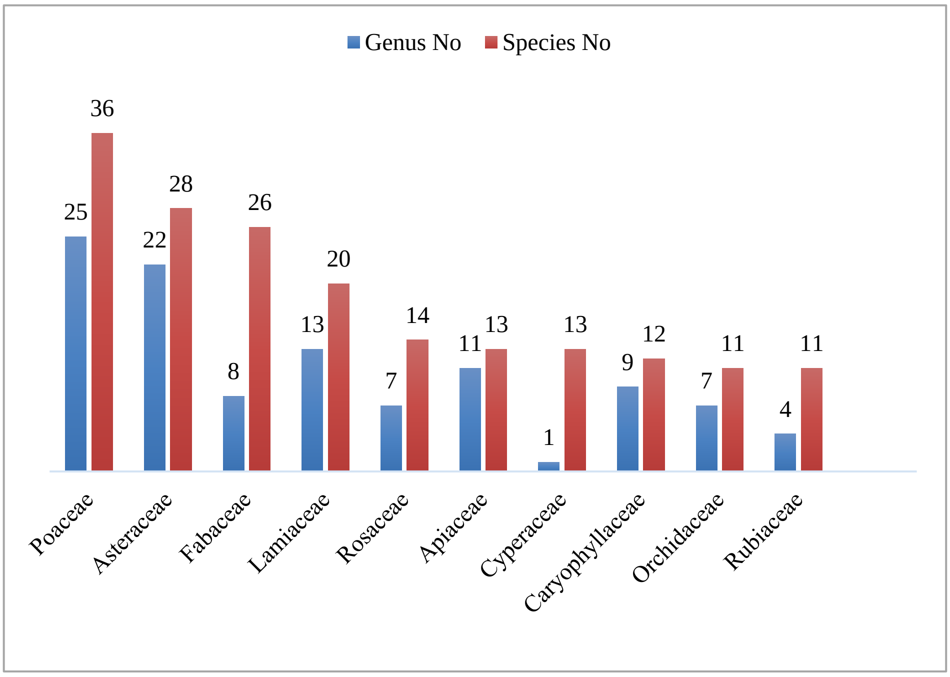

Figure 2. The richest families in terms of number of species and genera

With respect to life forms, hemicryptophytes with 45% (137 species) were the largest group, followed by Geophytes with 29% (89 species), Therophytes with 22% (68 species), Phanerophytes with 2% (7 species), and Chamaephytes with 2% (5 species) (Figure 3).

In terms of geographical distribution, the species with Euro-Siberian elements were the most frequent 32% (97 species). Irano-Turanian/Euro-Siberian 18% (54 species), Pluri-regional 16% (48 species), Irano-Turanian/Euro-Siberian/Mediterranean 13% (39 species), Irano-Turanian 7% (22 species), Euro-Siberian/Mediterranean 7% (20 species), cosmopolitan 4% (13 species), Irano-Turanian/Mediterranean 2% (6 species) were ranked next places in the category ratings. Other chorotypes were in low proportion (1%) (Figure 4).

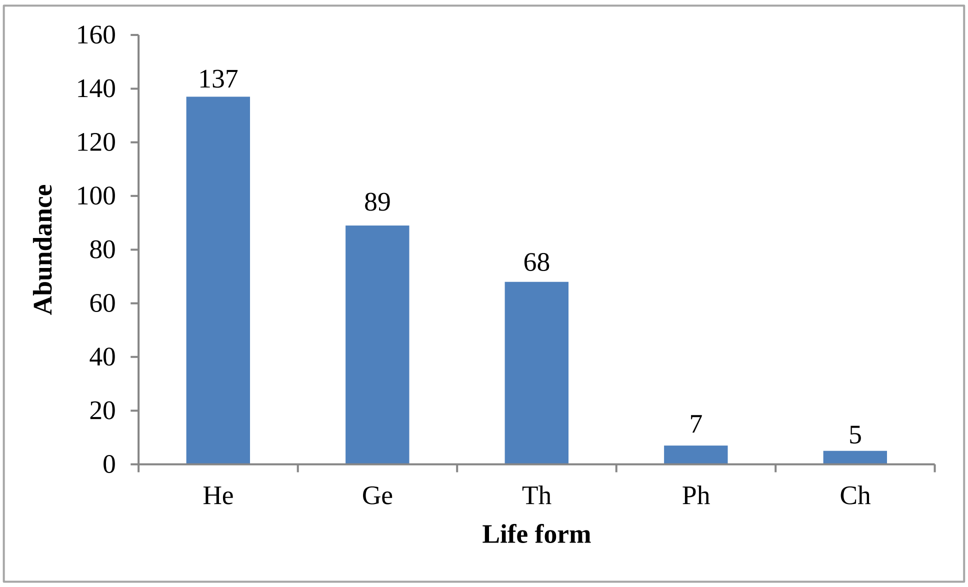

Figure 3. Life forms of floor plants in the study area

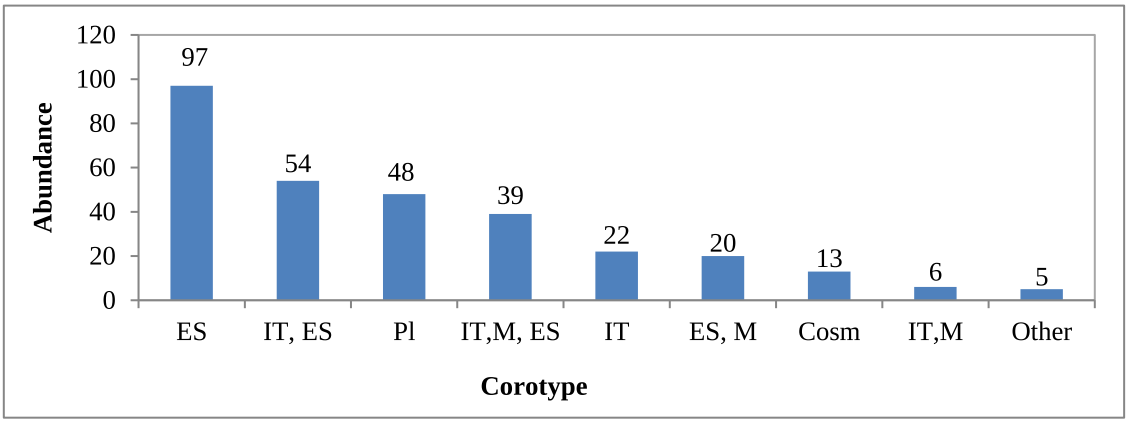

Figure 4. Chorology of floor plants in the study area

Discussion

The study area is in the Asalem Watershed basin (no. 7). This region is in the west of Caspian forests in Iran and it is one of the most important and valuable parts of them. There isn´t much study on the floor plants, life forms and chronology of plant species in the Asalem forest, and this study showed the importance of floor plants in this forest. The results indicated that the mean annual precipitation, temperate and humid climate have caused a high number of species and genera in the study area. This result was supported by the existence of 306 species, 181 genera and 54 families. In the floristic study of herbaceous plants in Hyrcanian beech forests was identified 109 species (Bakhshandeh Navroud et al., 2017). Also, in the Bibi Yanlou's Forest Park, in Astara 92 plant species was identified (Salahi et al., 2018). In another research that conducted in Gisoum forest reserve in Talesh, 76 plant species was determined (Ravanbakhsh et al., 2013). The total of the 10 major families was 60%, the rest families comprising 40%. These families were Poaceae, Asteraceae, Fabaceae, Lamiaceae, Rosaceae, Cyperaceae, Apiaceae, Caryophyllaceae, Rubiaceae, and Orchidaceae. Abundance of species in families namely Poaceae, Lamiaceae, and Orchidaceae were consistent with the result of beech forest, Asalem region, (Bakhshandeh Navroud et al., 2017) and abundance of species in Asteraceae, Caryophyllaceae, Cyperaceae, and Poaceae were like the result of from Bojag National Park (Naginezhad et al., 2006). After Poaceae family the highest number of species were within the Asteraceae and Fabaceae. It is known that Asteraceae members possess the high potential to adapt the harsh conditions and distribute with the seeds. In addition, this family has easy dispersal ability, and some members of the family have spines for protection against potential grazers (Xu et al., 2020).

The other families such as Fabaceae and Poaceae which belong to 10 major families, are important in terms of soil conservation. (Heydari et al., 2013). It is known that the life forms of each area reflect the type of climate, precipitation values, and extent of dry seasons (Khajedin & Yeganeh, 2012). Regarding to the life forms, hemicryptophytes were dominant. It is common in mountainous climate and shows its adaptability with regional ecological conditions (Soft et al., 2022). Hemicryptophytes resist in unfavorable environmental conditions with lying vegetative buds in the soil surface in winter and this feature causes a high resistance to cold temperature conditions. Moreover, Geophytes are 29% of the plants and indicates mountainous area (Tojibaev et al., 2018).

Therophytes display unfavorable environmental conditions, destruction of the region, and anthropogenic pressures (Haq et al., 2019). A high proportion of therophytes (22%, 68 species) revealed that precipitation is decreasing and growth seasons is declining in the study area. The low percentage of chamaephytes and phanerophytes indicated that they were not adapted to existing climate and edaphically conditions. The geographic distribution of plants reflects the climate condition. Considering this fact that 32% (97 species) of herbaceous species were only Euro-Siberian elements and 38% were Euro-Siberian and other chorotypes, we can conclude that the study region belongs to the Euro-Siberian. The present study showing the importance of Asalem watershed basin in terms of plant diversity which also reflects the favorable climate for plant growth and it will be possible to apply these results for management of Asalem forest.

Conclusion

The results of this study indicated that the study area has a high species diversity. Several factors can be involved in the composition and high diversity of the flora of this region. Ecological features, especially topography such as elevation, slopes with different directions and deep valleys were effective factors in the rich flora and the presence of numerous plant communities in the region. The results showed that this region includes 306 plant species that belong to 54 families and 181 genera. The most important families were Poaceae with 36 species, Asteraceae with 28 species, Fabaceae with 26 species, Lamiaceae with 20 species, Rosaceae with 14 species, Apiaceae and Cyperaceae each including 13 species, Caryophyllaceae with 12 species, Rubiaceae and Orchidaceae each including 11 species. The major life form of the region was hemicryptophyte with 45% and in terms of geographical distribution belongs to Euro-Siberian with 97 species. In this study area topographic factors have a higher impact on the distribution of groups, so that the effect of soil properties diminishes. Identifying how this relates and its effects plays a key role in management programs such as vegetation conservation, soil and water protection, and restoring of plant communities.

Conflict of Interest

The authors declare that they have no conflict of interest.

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SilvaWorld
http://silvaworld.org
e-ISSN: 2822-6127
PRENSIP
https://prensip.gen.tr

RESEARCH ARTICLE

Conservation and Sustainable Use of Forest Genetic Resources of English Yew (*Taxus baccata* L.) in Bavaria

Muhidin Šeho* • Barbara Fussi • Bernhard Rau • Darius Kavaliauskas

Bavarian Office for Forest Genetics (AWG), Forstamtsplatz 1, Teisendorf/Germany

ARTICLE INFO

Article History
Received: 09.09.2022
Accepted: 27.09.2022
First Published: 28.09.2022

Keywords
Genetic diversity
FGR
GCU
Conservation strategies
Seed stands
Isoenzyme markers

ABSTRACT

For sustainable forest development a stable, functional, and therefore species-rich ecosystem is required to fulfil the diverse functions of forests. Rare tree species contribute substantially to diversity and provided an important habitat function for other species. Further, they have a vital impact on the stability of forest ecosystems and increase their biodiversity. Under climate change, these tree species become more important and should be planted in the forest to divide upcoming risks among different tree species. In the study altogether 906 trees from 19 populations of English yew were sampled evenly along the Bavarian distribution range. Our study based on 13 isoenzyme markers identified substantial genetic variation between the populations. Based on genetic variation within and between studied populations seed stands and gene conservation units (GCU) were proposed. In addition, following our results provenance recommendations were drawn. Selected forest genetic resources (FGR) will be presented in the Bavarian Forest reproductive material (FRM) information system. In addition to dynamic *in-situ* conservation, an *ex-situ* conservation of the English yew is sought through long-term seed storage and the establishment of a seed orchard. Thus, the first 19 plus trees have been selected. The number of plus trees should be increased by further selection taking into consideration the balance between female and male English yew trees. All efforts will have a strong impact on the conservation of the FGR of English yew in Bavaria.

Please cite this paper as follows:
Šeho, M., Fussi, B., Rau, B., & Kavaliauskas, D. (2022). Conservation and sustainable use of forest genetic resources of English yew (*Taxus baccata* L.) in Bavaria. *SilvaWorld*, *1*(1), 52-67. https://doi.org/10.29329/silva.2022.462.06

Introduction

Forest genetic resources (FGR), defined as the sum of the genetic variation within tree species, represent an intergenerational value of social, economic, and ecological importance. Forest trees are defined as the keystone species of forest ecosystems. For many floral and faunal associations of the ecosystems is the continued existence of forests essential (Rajora & Mosseler, 2001). Increasing severe drought, pests and disease outbreaks, and stochastic events pose a major challenge for European forests and the forest sector under climate change conditions (Aitken et al., 2008; Lindner et al., 2010; Alfaro et al., 2014; Schelhaas et al., 2015). The possibility of long-lived forest trees surviving such changes in a spatio-temporal heterogeneous environment depends on their adaptation capacities and genetic diversity. In the future with rapid environmental changes only high genetic variation will allow a population to respond and survive (Frankham et al., 2002; Willi et al., 2006). Therefore, initiatives to protect and conserve forest trees and their populations must ultimately aim at conserving intraspecific genetic diversity and genetic analyses within species at global and local scales are the basis for sustainable preservation of forest tree resources (Geburek, 1997; Fady et al., 2016). In addition to genetic diversity within populations, the preservation of regional differentiation and site-specific adaptation is an important goal (Donath & Eckstein, 2008).

* Corresponding author
E-mail address: muhidin.seho@awg.bayern.de

In the last few decades genetic conservation activities of FGR are increasing in Germany (Paul et al., 2010). To implement international and national strategies and requirements, Bavarian Office for Forest Genetics (AWG) developed a "Concept for the conservation and the Sustainable Use of Forest Genetic Resources in Bavaria" (Konnert et al., 2015). The concept serves as a basis for the long-term conservation of the genetic diversity and FGR of main, rare, and endangered trees and shrubs. The concept envisages actual conservation measures on a genetic basis. Collected detailed knowledge is an important step for deriving provenance recommendations, the identification of seed stands and for regionally typical conservation of genetic structures.

In contrast to the main tree species, for which numerous studies have already been carried out at AWG (Konnert & Cremer, 2011; Konnert et al., 2014; Neophytou et al., 2017; Fussi & Hübner, 2018; Šeho et al., 2022), there is a lack of knowledge for rare tree species like English yew in Bavaria for successful implementation of gene conservation measures. In Bavaria, 18 tree or woody species (excluding willow species) are currently assigned to the group of rare tree species (Schröder et al., 2013). They cover less than 2% of the Bavarian Forest area. Ten tree species mapped in the federal project account for less than 0.4% of the Bavarian Forest area (Riederer & Fritsch, 2013; Schröder et al., 2013; Huber et al., 2015). Most rare tree species like English yew are often fragmented and have small population sizes (Suppl. Figure 1). Isolation is thought to often disrupt gene flow between populations. In addition, genetic drift and bottleneck effects occur in small populations, which also lead to random gene losses in the short term and can further reduce the adaptability of the populations (Savolainen, 2000; Pardo et al., 2005).

The English yew occurs in Europe from Spain in the west to north Iran on the Caspian Sea. The northern limit of its distribution is in southern Norway and Sweden. In the South, it still occurs in the Atlas Mountains, Apennines, and Greece. Other occurrences are in the British Isles, Corsica, Sardinia, Sicily, and Gotland (Suppl. Figure 1). Mayol et al. (2015) found evidence that yew colonized Europe from the East, and that European populations separated into two groups (Western, Eastern) at the beginning of the Quaternary glaciations. In several European countries, English yew (*Taxus baccata* L.) is an endangered rare tree species (González-Martínez et al., 2010; Klumpp & Dhar, 2011; Linares, 2013; Litkowiec et al., 2018; Komárková et al., 2022). The English yew is one of Bavaria's rare and ecologically valuable tree species.

In Bavaria, there are three main areas of the natural distribution of English yew: on the Franconian Jura and in the Upper Palatinate Jura, in the Bavarian Forest, in the Alps and in the foothills of the Alps (Figure 1). Occurrences outside of these regions are mostly plantations or overgrown garden forms. In the Bavarian Forest, the English yew can grow up to 1,100 meters over sea level and in the Bavarian Alps up to 1,330 meters (Schütt, 1995; Hageneder, 2007). Due to slow growth, it develops an extensive root system, reaches tree heights of over 20 meters, and can cope with various site conditions (Scheeder, 1994). English yew was strongly pushed back in the last 500 years and partly isolated and currently prefers calcareous soils (especially on tuff rock) with a good water supply (Alps, Jura). The fact that today's forest picture in Germany and the whole of Europe is different is mainly because of human activity (Ruprecht et al., 2010). Numerous influencing factors such as isolation, strong population fragmentation, germination inhibition, slow growth and browsing pose an additional threat to English yew populations (Chybicki & Oleksa, 2018). The low and medium forest-type management was reduced in favour of high-forest management on a per-plot basis. After clear-cutting and reforestation with mainly fast-growing tree species such as spruce and shorter rotation times, the English yew could no longer occur and lost more and more of its habitat. Also because of their slow growth and the lack of possible uses of the English yew wood, their forestry importance has almost disappeared (Küster, 1994). In addition to this supposedly low silvicultural importance, the toxicity of the English yew (all parts except for the aril and pollen) posed a great danger to the animals and carters. To avoid deadly poisoning from eating English yew trees, they were immediately removed and replaced by other tree species (Scheeder, 1994). Furthermore, the consequences of climate change are becoming clearer and increasing the risk of dying populations of native tree species like spruce, larch, pine, beech, sycamore, or ash in Germany. The increasing number of forest tree species, e.g., scattered broadleaves and conifers and the establishment of mixed forests can diminish and distribute the risks since different species have differing susceptibility to various stressors and disruptive factors (Rotach, 1999; Spiecker, 2006; Knoke et al., 2008; Bauhus et al., 2017; Wolff et al., 2021; etc.). The focus increase on rare native tree species such as white elm, field maple, service tree and English yew, which can be used as possible alternatives. A major challenge with these tree species is the seed supply with high-quality forest reproductive material. Since these rare tree species are not subject to the FoVG and mostly played a secondary role in silviculture, no suitable seed stands have been selected so far. The aim of the project "Conservation of forest genetic resources and elaboration of provenance-recommendations and improvement of the harvesting possibilities for the rare tree species field maple (*Acer campestre* L.), European white elm (*Ulmus laevis* Pall.), service tree (*Sorbus domestica* L.) and English yew (*Taxus baccata* L.) in Bavaria was to give the first insight of genetic variation". The genetic diversity of conservation units and forest stands plays a crucial role and is the most important scale for the future adaptation and survival of tree species under changing environmental conditions.

Today's natural occurrence of English yew is limited to special and often extreme locations such as steep slopes, rocks, and inaccessible forests where cultivation is not worthwhile. These areas often have a protected status (NSG, NP, NWR, etc.); English yew is an endangered species under special protection (red list species) under the Federal Species Protection Law (BArtSchV). If genetic exchange through pollen or seeds is missing between these areas of occurrence of English yew through steppingstone populations, there is a risk of genetic impoverishment (isolation) of these occurrences, which requires more detailed consideration (Scheeder, 1994; Riederer & Fritsch, 2013). Effects of isolation, in particular for dioecious tree species such as English yew, can include a reduced fructification capacity or a reduced germination capacity of the seeds through increased inbreeding. The sustainable use and importance of rare native tree species like English yew to promote and expand the mixed forest and to improve biodiversity on all three levels (gene, species, and ecosystem) have been widely discussed (UN, 1992; Bollmann & Braunisch, 2013; Laikre et al., 2010).

There are several rare native tree species in Bavaria, such as field maple, white elm, service tree, English yew, or wild service tree, which are not listed in the EU directive 1999/105/EC (EU, 1999) and in the German Forest Reproductive Material Act (FoVG, 2003) and are not included in the EU list which is the basis for the production and marketing of FRM of important native and naturalized tree species. For these tree species, there are no legal requirements regarding the production and trade of FRM, endangering the regional gene pool and the future quality of the stands. At the same time, there are currently initiatives at the EU level to expand the above-mentioned Directive 1999/105/EC to include rare tree species like English yew.

To reach the aims of our study we used isozyme markers to estimate the genetic variability for 19 populations of English yew, and to investigate the partitioning of the genetic variation among studied populations. Overall, isozymes had a long history in plant and forest genetic variability studies, to estimate the genetic diversity and populations structure within natural forest stands (Doligez & Joly, 1997; Ritland et al. 2005; Porth & El-Kassaby, 2014).

Therefore, the aims of our study were: (i) to analyze the genetic structure and diversity of English yew in Bavaria; (ii) to identify and propose new seed stands for English yew in Bavaria; and (iii) to discuss and select GCUs for English yew in Bavaria based on level of genetic variation; (iiii) to generate knowledge for sustainable use of English yew FRM; (iiiii) based on collected knowledge to enable *ex-situ* conservation measures.

Materials and Methods

English Yew Tree Stands Selection and Sampling

Material for this study was collected in the federal State of Bavaria, Germany in 2019. For the genetic characterization, it is intended to sample the Bavarian range of English yew as representatively as possible. The following stand selection criteria were used: minimum number of trees ≥ 20 trees; minimum diameter at breast height (DBH), which was a proxy for evaluation of fructification capacity; good stand health condition and stem quality; stand accessibility and possibility for seed collection; autochthonous stand or the origin of the stand should be known; distance from the nearest poor-quality population of more than 400 meters. In total 906 trees from 19 natural English yew tree populations distributed over Bavaria were sampled for genetic analysis (Table 1 and Figure 1). The sample size per population varied from 35 to 51 mature trees. Buds were sampled from mature male and female trees distanced at least 30-40 meters apart.

Table 1. Sampled English yew populations in Bavaria

No.	Sample size	Location	Stand area (ha)	No. of trees in the stand	m. a. s. l.	District
1	49	Schammendorf	5.9	476	400	Lichtenfels
2	49	Gößweinstein	32.0	2900	440	Forchheim
3	50	Algersdorf	4.0	120	500	Lauf
4	50	Schloß Neidstein	3.6	150	490	Sulzb.-Rosenb.
5	50	Bayer. Wald	200.0	475	680-1000	Freyung-Graf.
6	50	Neutal	12.6	240	410	Neumarkt
7	50	Penk	1.3	210	390	Regensburg
8	50	Zandt	3.2	230	510	Eichstätt
9	50	Kelheim	112.0	630	380	Kelheim
10	39	Landshut	18.5	137	460	Stadt Landshut
11	51	Paterzell	39.2	2320	690	Weil.-Schongau
12	40	Gotzing	1.7	122	700	Miesbach
13	50	Siegsdorf	5.2	81	750	Traunstein
14	50	Au	30.3	1000	660	Miesbach
15	50	Ruhpolding	100.0	400	920	Traunstein
16	44	Bichl	5.2	106	620	Bad Tölz
17	49	Karlstein	3.0	50	620	Bercht. Land
18	35	Tegernsee	1.6	35	1100	Miesbach
19	50	Sigmarszell	8.5	250	650	Lindau

m. a. s. l.: meters above sea level, the codes in Table 1 correspond to the codes in the map in Figure 1 and Table 2.

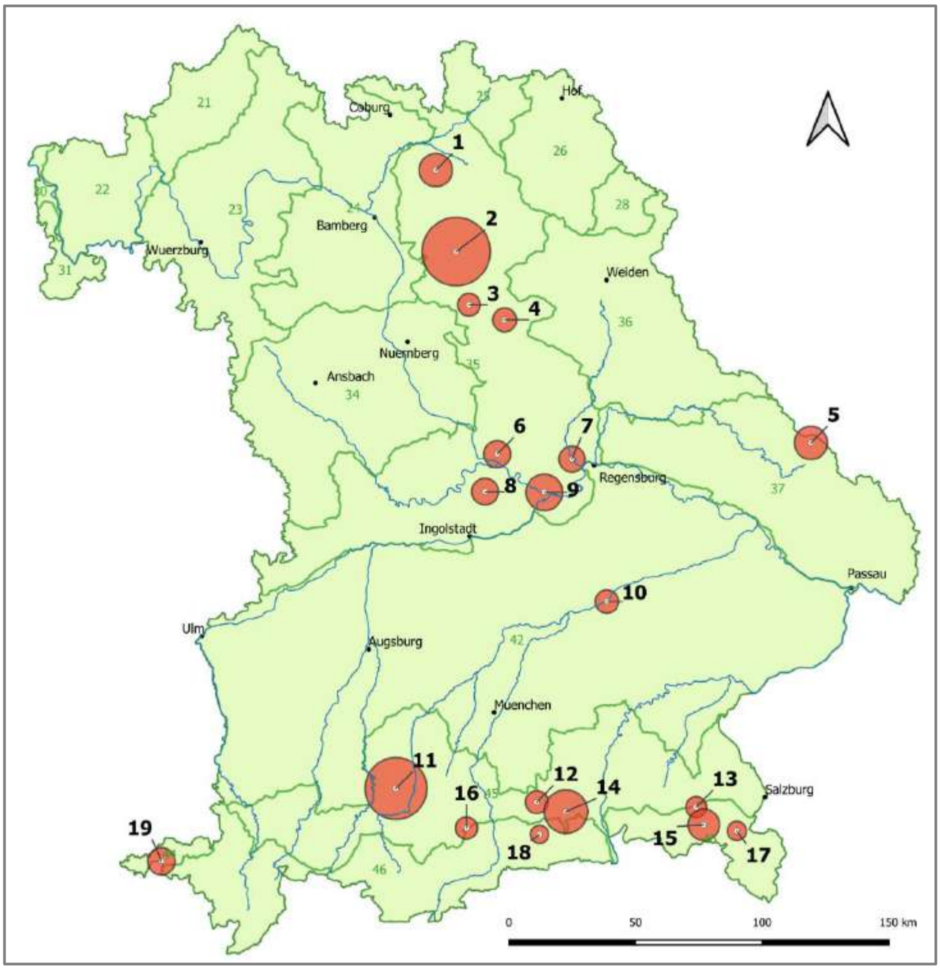

Figure 1. Distribution of sampled populations of English yew in Bavaria (codes on the map correspond to the codes in Table 1). The size of the circle corresponds to actual population size.

Genetic Analysis

For the genetic characterization of the English yew samples, isoenzyme analyzes (biochemical-genetic characterization) of 13 gene loci were applied according to Hertel (1996). The following enzyme systems or controlling gene loci were included in the analyzes: AAT-A, AAT-B (enzyme system: aspartate aminotransferase, E.C. 2.6.1.1), ADH-A (enzyme system: alcohol dehydrogenase, E.C. 1.1.1.1), IDH-A , IDH-B (enzyme system: isocitrate dehydrogenase, E.C. 1.1.1.42), LAP-A, LAP-B (enzyme system: leucine aminopeptidase, E.C. 3.4.11.1), MDH-C (enzyme system: malate dehydrogenase, E.C. 1.1.1.37), MNR-A (Enzyme system: menadione reductase, E.C. 1.6.99.2), 6-PGDH-A (Enzyme system: 6-phosphoglucodehydrogenase, E.C. 1.1.1.44), PGI-B (Enzyme system: phosphoglucoisomerase, E.C. 5.3.1.9), PGM-A (enzyme system: phosphogluco-mutase, E.C. 2.7.5.1), SDH-B (enzyme system: shikimate dehydrogenase, E.C. 1.1.1.25). The isoenzyme analysis was performed using starch gel electrophoresis and procedures used by Hertel (1996).

Data Analysis

Based on the multilocus genotypes determined for the individual trees, the allele frequencies, and the following parameters, which describe the genetic variation within the natural distribution, were first calculated [Software SAS, package MacGen (Stauber & Hertel, 1999)]:

- The allele frequencies at 13 gene loci in the 19 yew occurrences examined.
- Ne: genetic diversity as the mean number of effective alleles per locus (Ne) and as hypothetical gametic multilocus diversity (Vgam).

The genetic differences between the populations were quantified by the genetic distance according to Gregorius (1974). Furthermore, the genetic differentiation between the populations was determined using the differentiation measure Dj according to Gregorius and Roberds (1986). These calculations are also based on the individual collectives' distribution of alleles as allele frequencies (Software SAS, package MacGen). Genetic diversity statistics (e.g., number of different alleles (Na), effective (Ne) alleles (Np), observed (Ho)/expected (He) heterozygosity) were calculated using

GenAlEx 6.5 (Peakall & Smouse, 2006, 2012) per loci and for each population. The Analysis of Molecular Variance (AMOVA) was performed using GenAlEx 6.5 (Peakall & Smouse, 2006, 2012) (for the significance test we used 9999 random permutations). The inbreeding coefficient (F_{IS}) was assessed per locus and sample, as well as a test of whether it is significantly positive or negative (significant deficit or excess of heterozygotes, respectively) with Fstat 2.9.3. software (Goudet, 2001). Allelic richness (Ar) was estimated with Fstat 2.9.3. software (Goudet, 2001), which estimates Ar per locus and sample, and overall samples based on the lowest number of samples (30 samples were used for rarefaction in our study).

Genetic differentiation between English yew populations

The genetic structure and differentiation between English yew populations were estimated using several methods: (a) the Analysis of Molecular Variance (AMOVA) was performed using GenAlEx 6.5 (Peakall & Smouse, 2006, 2012) (for significance test it was used 9999 random permutations); (b) pairwise differentiation based on Nei (Nei, 1972) genetic distances between all pairs of populations (GenAlEx 6.5); (c) the Bayesian clustering approach as the model-based clustering algorithm implemented in STRUCTURE 2.3.3 software (Pritchard et al., 2000). . The online software CLUMPAK was used for identifying clustering modes and packaging population structure inferences across K and visualizing the clustering (Kopelman et al., 2015).

Results

Allele Frequencies

In total 19 English yew populations (Figure 1) were sampled, and 906 trees were genotyped. A total of 41 gene variants (alleles) were detected based on 13 isoenzyme markers (Suppl. Table 1 shows the allele frequencies at 13 gene loci in the 19 English yew populations). Two of the 13 gene loci (AAT-A and MDH-C) were monomorphic.

Genetic Diversity

Genetic variation parameters within populations are given in Table 2. The genetic diversity, i.e., the mean number of gene variants per gene locus, varies in the English yew populations between 2.15 (populations 6-Neutal, 14-Au, 15-Ruhpolding, 18-Tegernsee, 19-Sig-marszell) and 2.46 (populations 1-Schammendorf, 4-Neidstein Castle, 10-Landshut). The genetic diversity (Vgam) varied substantially between 33.01 (in population 8-Zandt) and 773.65 (population 10-Landshut). The effective number of alleles (Ne) varied between 1.36 (in population 8-Zandt) and 1.79 (population 10- Landshut). With a few exceptions, the F_{IS} values were close to zero. Only three populations show slightly higher positive values of inbreeding [F_{IS} = 0.087 (populations 5-Bayerischer Wald, 9-Kelheim) and F_{IS} = 0.112 (in population 10-Landshut)]. Thus, there are fewer heterozygous individuals in these populations than under the Hardy-Weinberg equilibrium would be expected. In contrast, population 3-Algersdorf had F_{IS} = -0.122 which indicates an excess of heterozygous (Table 2 and Suppl. Figure 2).

Table 2. The within-population genetic diversity parameters based on isoenzyme analyzes at 13 gene loci

Population	Location	Na	Ne	Ar	Vgam	Ho	He	F_{IS}
1	Schammendorf	2..46	1.49	2.42	83.76	0.251	0.253	0.003
2	Gößweinstein	2.38	1.61	2.33	138.67	0.259	0.264	0.005
3	Algersdorf	2.23	1.58	2.17	176.00	0.331	0.290	-0.122
4	Schloß Neidstein	2.46	1.62	2.42	202.18	0.289	0.295	0.020
5	Bayerischer Wald	2.23	1.64	2.22	290.30	0.306	0.317	0.087
6	Neutal	2.15	1.61	2.15	212.35	0.283	0.299	0.055
7	Penk	2.31	1.59	2.19	160.87	0.293	0.279	-0.030
8	Zandt	2.23	1.36	2.11	33.01	0.228	0.209	-0.073
9	Kelheim	2.23	1.56	2.21	155.05	0.261	0.285	0.087
10	Landshut	2.46	1.79	2.44	773.65	0.347	0.361	0.112
11	Paterzell	2.38	1.68	2.32	314.57	0.295	0.312	0.051
12	Gotzing	2.23	1.57	2.21	201.11	0.306	0.305	-0.020
13	Siegsdorf	2.38	1.69	2.33	315.56	0.317	0.313	-0.028
14	Au	2.15	1.56	2.14	167.54	0.291	0.292	-0.009
15	Ruhpolding	2.15	1.59	2.11	166.85	0.289	0.284	-0.027
16	Bichl	2.38	1.76	2.37	569.30	0.327	0.342	0.020
17	Karlstein	2.23	1.68	2.23	344.06	0.290	0.317	0.065
18	Tegernsee	2.15	1.59	2.15	145.64	0.277	0.275	-0.001
19	Sigmarszell	2.15	1.58	2.15	212.20	0.294	0.304	0.037
Total mean		2,28	1.61	2.24	245.40	0.291	0.295	0.012

N: Sample number, Na: Mean no. of different alleles, Ne: Mean no. of effective alleles, Ar: Mean allelic richness (based on minimum sample size of 30 diploid individuals.), Vgam: Hypothetical gametic multilocus diversity, Ho: Observed heterozygosity, He: Expected heterozygosity, F_{IS}: Inbreeding coefficient.

Genetic Differentiation and Cluster Analysis

Figure 2 shows the hierarchical distribution of genetic variation at different levels (AMOVA). Most of the total variation is split between populations (9%) and within populations (87%). The value of 9% is relatively high for a wind-pollinated tree species.

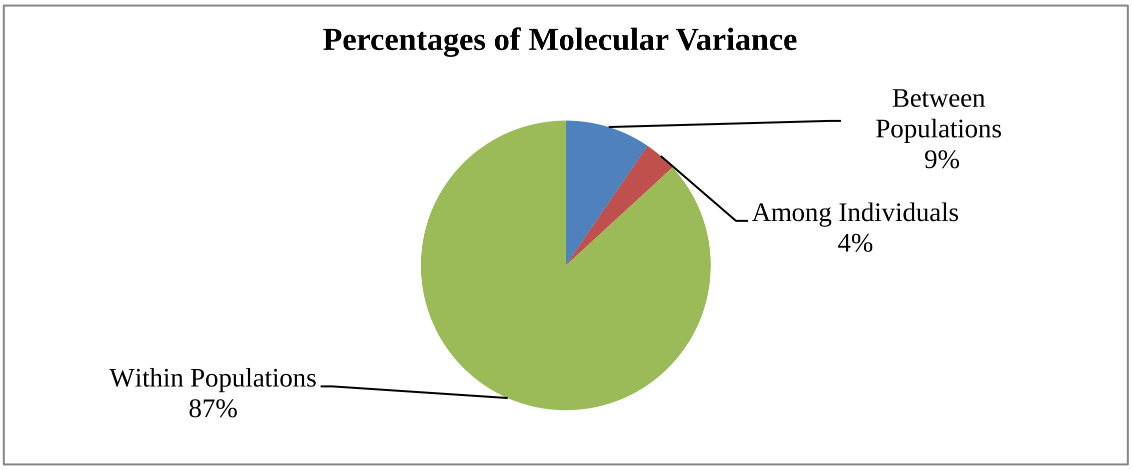

Figure 2. The distribution of genetic variation between and within populations based on the fixation index (F_{ST}) [GeneAlex6.5 Software (Peakall & Smouse, 2006, 2012)].

According to a large number of sampled populations in a relatively small area, the value for the population differentiation based on F_{ST} can be rated as relatively high. Viewed from another perspective, a comparably high value would be expected for a small number of populations across Europe. The values δ of the genetic distances (allelic) are given in Suppl. Table 2. Values δ above 0.10 are to be rated as comparatively high and indicate high genetic differences between the populations. The highest distance was found between populations 1-Schammendorf and 12-Gotzing, and between 8-Zandt and 10-Landshut with 0.35. A distance of 0.34 is found between the populations 8-Zandt and 4-Schloss Neidstein, 7-Penk, 12-Gotzing, 14-Au. In contrast, the distance between the populations 11-Paterzell and 13-Siegsdorf, as well as between 9-Kelheim and 13-Siegsdorf is significantly smaller at only 0.12. The differentiation values of Dj shown in Suppl. Figure 3 quantify the difference in the allelic composition of each population compared to the allelic structure of the entire examined material. The mean differentiation (δ) is given overall nineteen populations. It is an indicator of the genetic heterogeneity of the examined yew populations. The mean differentiation δ is rated as high as 10%, whereby the stand 8-Zandt stands out with the highest differentiation value (Dj = 18.9%). This inventory is by far the least representative of the entire study material. The 11-Paterzell, 13-Siegsdorf and 17-Karlstein populations are the least differentiated and therefore the most representative of the overall gene pool. The combination of low differentiation and quite high diversity in these populations makes them very well suited for the conservation of this tree species together with populations from 10-Landshut and 16-Bichl with extremely high diversity. Pairwise Population Matrix of Nei (1972) genetic distance (Software GeneAlex6.5) is given in Suppl. Table 2.

To determine possible clustering between the examined populations, the Bayesian model-based cluster algorithm was used. The maximum deltaK value (deltaK = 5.39) indicated the existence of 3 separate genetic clusters (Figures 3, 4 and Suppl. Figure 4).

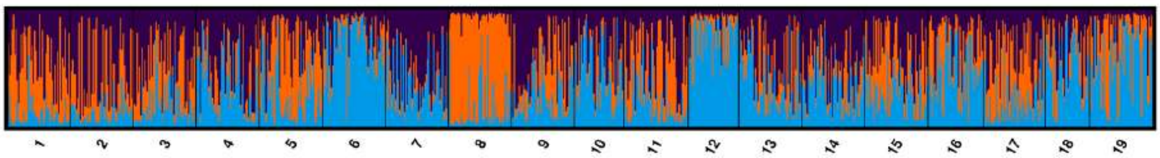

Figure 3. Histogram of the genetic structure of English yew in Bavaria based on Bayesian clustering with STRUCTURE 2.3.3 software (Evanno et al., 2005). The four colors represent different STRUCTURE clusters. Populations are separated by vertical lines and identified on the X-axis by numbers (each individual is a separate color line). The column height of each color in the Y-axis corresponds to the probability of individual assignment to a different cluster separated by the STRUCTURE software. Structuring was performed based on 13 loci for K=3.

Figure 3 shows the result of cluster formation based on the 13 isoenzyme gene loci used and a K value of 3. Three colors represent the different STRUCTURE clusters. Figure 4 below gives a comprehensive overview of the spatial-genetic structures in Bavaria.

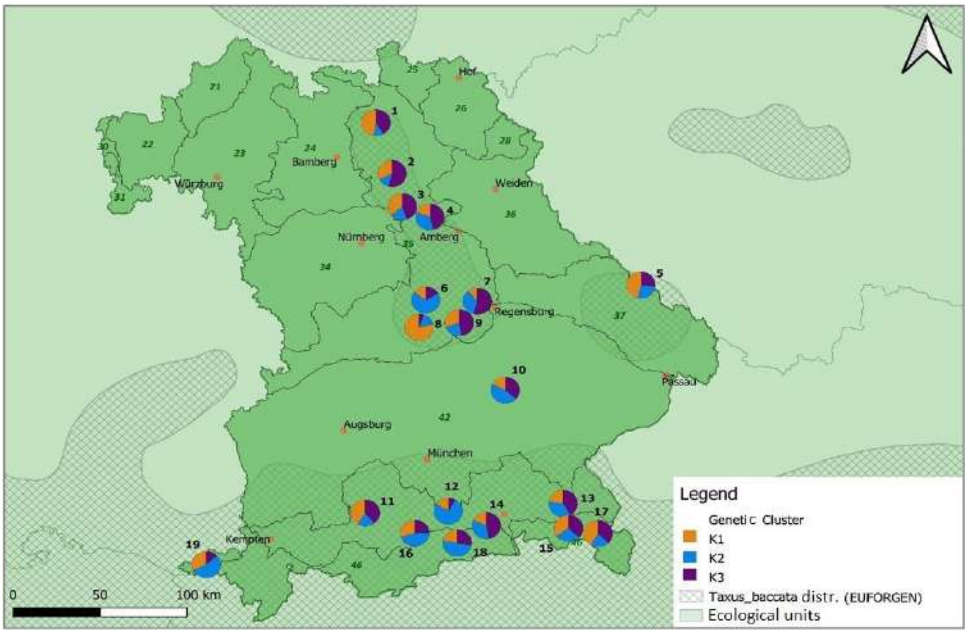

Figure 4. Population genetic structure based on Bayesian clustering (STRUCTURE 2.3.3). The pie charts show the relative proportions of four STRUCTURE clusters.

Discussion and Conclusion

Under climate change conditions the focus increase on rare native tree species such as white elm, field maple, service tree and English yew, which can be used as possible alternatives. However, the major challenge for successful species use is not sufficient the high-quality seed supply. Since these rare tree species are not subject to the German Forest Reproductive Material Act (FoVG, 2003) and mostly played a secondary role in silviculture, no suitable seed stands have been selected so far. Due to the two-stage procedure, important phenotypic characteristics such as quality, vitality, age, sex ratio and the number of trees as well as genetic parameters (structure, variety, and diversity) could be used for the selection and evaluation. Genetic diversity, differentiation and structure of the populations should build the basis for the conservation of FGR and the sustainable use of English yew.

Genetic Diversity, Differentiation and Structure in Taxus baccata Populations

Isozyme analyses have been widely employed in studying the genetic structure and variation of English yew (e.g., Lewandowski et al., 1992; Hertel, 1996; Rajewski et al., 1999; Tröber & Ballian, 2011). Results of the genetic analyses are important to acquire baseline data for the implementation of gene conservation measures and GCU selection (Hattemer, 1995; Petit et al., 1998; Rajora & Mosseler, 2001; Caballero et al., 2010; etc.). In addition, to genetic information, an important is phenotypical assessment, which can supplement existing knowledge on English yew (e.g., Tumpa et al., 2022).

In our study, genetic variation within and between the populations and their genetic structure was analyzed in 19 natural populations of English yew in Bavaria (Germany), using isozyme analyses at 13 gene loci. The study aimed at developing recommendations concerning the future use and genetic conservation strategies for the species, based on species distribution and genetic variation. Our research showed that the differences in the allele frequencies between the examined populations can be rated as very high. English yew populations in Bavaria are characterized by a moderately low level of genetic diversity (i.e., means of Na = 2.28, Ne = 1.61, Ar = 2.24 and He = 0.295), and relatively high differentiation between English yew populations (F_{ST} = 0.09). In comparison with other studies on English yew populations throughout Europe we found moderate values in genetic variability and relatively high genetic differentiation (Zarek, 2009; Tröber & Ballian, 2011; Klumpp & Dhar, 2011). Several studies on the genetic structure of English yew in Europe using different marker systems demonstrated a high level of overall genetic variation and significant differentiation between populations (Lewandowski et al., 1995; Cao et al., 2004; Hilfiker et al., 2004; Myking et al., 2009; Dubreuil et al., 2010; Tröber & Ballian, 2011; Chybicki et al., 2012). Myking et al. (2009) observed that the average observed (Ho) and expected (He) heterozygosities in the northern marginal populations were 0.143 and 0.150, respectively. In that investigation, the fixation index (F_{IS})

across all populations was 0.039, but with consistently higher values (0.119 - 0.226) in the northernmost populations, suggesting inbreeding (Myking et al., 2009). In our study, the average observed and expected heterozygoty was slightly higher Ho = 0.291 and He = 0.295. The inbreeding coefficient (F_{IS}) was lower than 0.012. A similar result (Ne = 1.41, Ho = 0.28, He = 0.29) was found at the national level in the project with the aim of identifying genetic resources of field maple (*Acer campestre* L.) and yew (*Taxus baccata* L.) in Germany (Riederer & Fritsch, 2013). Tröber and Balian (2011) observed higher values for observed and expected heterozygosity of two Bosnian populations in Ozren (Ha = 0.490 and He = 0.334) and Borja (Ha = 0.367 and He = 0.361) in comparison with the results of our study.

Furthermore, the extensive sampling design in our study allowed us to infer the spatial genetic structure of the sampled populations. By applying Bayesian clustering we detected the existence of three genetic clusters (K = 3, deltaK = 5.390) within 19 studied English yew populations in Bavaria (Figures 3 and 4). Part of the spatial genetic pattern can be attributed to the species' ecology (association with covered forest ecosystems) and scattered distribution. However, population 8 have formed a clearly separate genetic cluster (Figures 3 and 4), which can be explained by the artificial introduction of several plants (the founder effect) and/or by isolation and genetic drift. The groups shown in the histogram (see Figure 3) cannot be clearly separated spatially. The pie charts reflect the relative affiliation to the three STRUCTURE clusters and are spatially mixed. It is therefore recommended to designate only one provenance region for *Taxus baccata* L. in Bavaria. Furthermore, knowledge regarding English yew population differentiation and diversity allows us the recommendation of seed stand selection and planning of GCU and conservation measures in Bavaria.

Selection of English yew GCUs in Bavaria

Genetic conservation activities of rare tree species such as English yew need to consist of several main steps: (i) species distribution inventory; (ii) GCU and plus trees (*in situ* protection) selection for conservation; and (iii) *ex situ* genetic resources establishment e.g., seed orchards, collections in a gene bank, etc. (e.g., Hemery et al., 2010; Koskela et al., 2013; Kavaliauskas et al., 2021). Protection of small populations and single trees is vital to ensure gene flow among populations. Known populations of English yew must be preserved through active management, and trees should be introduced into new sites to increase gene flow and reduce spatial isolation.

The information on genetic variation and structure of English yew populations in Bavaria provides a background for the implementation of FGR conservation programmes and seed stand selection. The main criteria for GCU selection should be high genetic diversity which ensures the possibility for populations to evolve and reproduce under changing environmental conditions. Many authors identify allelic richness (Ar) as a key parameter for conservation purposes in genetic conservation programs, especially for rare tree species of subdivided various in size populations (Marshall & Brown, 1975; Petit et al., 1998; Rajora et al., 2000; Rajora & Mosseler, 2001; Caballero et al., 2010; etc.). Therefore, in our study, we used allelic diversity (Ar) between and within populations for populations prioritization for conservation and English yew GCU selection (Petit et al., 1998; Caballero et al., 2010; Kavaliauskas et al., 2021).

The results of our study showed that allelic richness varies slightly across the investigated populations and ranged between 2.11 (8-Zandt) and 2.44 (10- Landshut). Six sampled populations exhibit higher than average allelic richness (Ar ≥ 2.24) based on 13 isoenzyme loci (Table 2). Thus, populations with moderate allelic richness (Ar > 2.20) can be considered as GCUs in Bavaria. However, we proposed to approve 11 populations as GCUs. The selected 11 populations are distributed across Bavaria representing several different ecological zones. Additional criteria for GCU selection were a sufficient number of trees and distribution over the stand, vitality, reproductive age, information about the origin, etc.

Following our experience, we think that further selection of GCUs for rare tree species should be constructed on collective parameters of environmental and genetic diversity data, considering population distribution in certain regions. Marginal populations at the species distribution edge tend to exhibit higher genetic differentiation in comparison to populations from the main distribution, therefore some differentiation indexes such as Nei (1972)'s can be an additional parameter for GCU selection (Petit et al., 1998). However, genetic differentiation results vary depending on the type and the number of genetic markers used. Since Bavaria is at the distribution edge of *Taxus baccata*, the representative selection [three populations (1, 2 and 4) from the north of Bavaria, three (5, 9 and 10) from mid-Bavaria, and five (11, 12, 13, 16 and 17) from the southeast of Bavaria, representing two main STRUCTURE clusters] of putative GCUs in Bavaria was an important step ensuring species conservation measures under changing environmental conditions.

Overall, our research revealed that English yew populations in Bavaria are characterized by moderate genetic diversity (i.e., expected heterozygosity and number of effective alleles). Similar diversity parameters are reported in other studies on *Taxus baccata* (e.g., Zarek, 2009, Tröber & Ballian, 2011, Klumpp & Dhar, 2011, Myking et al., 2009), which can be explained by species ecology and other peculiarities; however, it is important to implement conservation measures and to maintain genetic diversity for the long-term adaptation of populations to changing environmental and climatic conditions. Furthermore, at the European level, 57 GCUs (Gene Conservation Units) of *Taxus baccata* are included in the

European genetic conservation network within the EUFORGEN program. And only five populations, two in Thuringia, one in Saxony and two in Bavaria, in Germany. Thus, considering the results from our analysis, at least a few more populations representing different environmental conditions should be included in the GCU network covering the whole English yew distribution range in Bavaria.

English Yew Seed Stand Selection

Selection of seed stands, and other in-situ conservation measures is an important step under rapid climate change is in preserving and increasing genetic diversity and supporting species adaptability. Because the English yew is not listed in FoVG (2003) or in the EU directive 1999/105/CE (EU, 1999), there are no official requirements and regulations for English yew seed stand selection, FRM collection and trade. Therefore, genetic structure and diversity data deliver important information on English yew genetic status in Bavaria and allow us to perform the selection of seed stands according to collective parameters in a representative manner. In our study, the mean number of effective alleles (Ne) was used as a measure for seed stand selection in Bavaria. Ne value shows the level of genetic diversity within a population and includes the distribution and frequency of the alleles (Kimura & Crow, 1964; Maruyama, 1970). Since the differences in genetic diversity parameters (Na, Ne, Ar, Ho and He) was low among the populations (Table 2), only two populations were not selected as seed stand (pop. 1-Schammendorf, pop. 8 Zandt). Population which was specified by the forest district managers as possibly planted exhibited lower values of genetic diversity (e.g., Ne, Ar, and Vgam) than the overall mean. However, in specific circumstances all studied populations can be considered for seed collection with the recommendation to increase the number of seed trees to collect from. Especially if allelic richness is higher, the lower number of effective alleles can be increased by more intensive and representative sampling/seed tree selection.

Following the results of our study for the rare tree species field maple (*Acer campestre* L.), European white elm (*Ulmus laevis* Pall.), service tree (*Sorbus domestica* L.) and English yew (*Taxus baccata* L.) and based on study by Kavaliauskas et al. (2021) in Bavaria we propose several important preconditions for seed stand selection and seed collection:

- Minimum number of trees: at least 30 seed trees have to be selected for seed collection.
- Seed tree distribution: selected seed trees should be distributed over the whole of the seed stand, to ensure representative seed collection and the highest genetic variation.
- Genetic diversity: selected seed stands have to contain high genetic diversity; thus, genetic markers have to be applied to provide additional information in the process of stand selection.

Seed stand selection involves the consideration of various factors and according to Neel and Cummings (2003), if selection of seed stands and GCUs are made without genetic knowledge, then a larger number and larger populations are required to ensure high genetic diversity and representation of alleles. In our study, a total of 17 stands which fulfilled the genetic diversity and stand quality requirements were proposed as potential seed stands. Furthermore, results on genetic diversity provide us with additional information on the genetic status and variation among stands and form a basis for comparison of potentially new seed stands in further stand selection (Namkoong, 1984). In addition, to improve English yew conservation actions, selected GCUs that are among selected seed stands should be included in the EUFORGEN / EUFGIS (http://portal.eufgis.org/) GCU network to cover and represent different environments at the country level. Finally selected seed stands provide a basis for obtaining seed of higher genetic quality until material from more intensively selected trees in seed orchards will be available.

Overall, successful selection of high-quality forest genetic resources (FGR) is an important part of the Concept for the conservation and the sustainable use of forest genetic resources in Bavaria (Konnert et al., 2015). Therefore, our study of English yew populations in Bavaria is an important contribution to this concept and a further step towards securing FGR of scattered tree species in Germany. Furthermore, increasing interest in rare tree species and mixed forest formation by state and private forest owners is important for conservations of endangered tree species such as English yew. After completion of the project, the selected seed stands, and gene conservation units will be included in the Bavarian Forest reproductive information system (EZR) and thus made available for access by all seed harvesting companies and forest tree nurseries. This ensures long-term use of these valuable survey. The forest reproductive material produced from the seed stands recommended here can be used outside of forestry, as autochthonous (“gebietseigene”) woody plants. The use of native provenances is also demanded by German law: according to § 41 of the Federal Nature (BMU, 2009). In addition, it is planned to establish seed orchards for the four project tree species in the coming years. The first 19 plus trees were already selected and 50-60 trees more to come to establish a clonal seed orchard.

Conflict of Interest

The authors declare that they have no conflict of interest.

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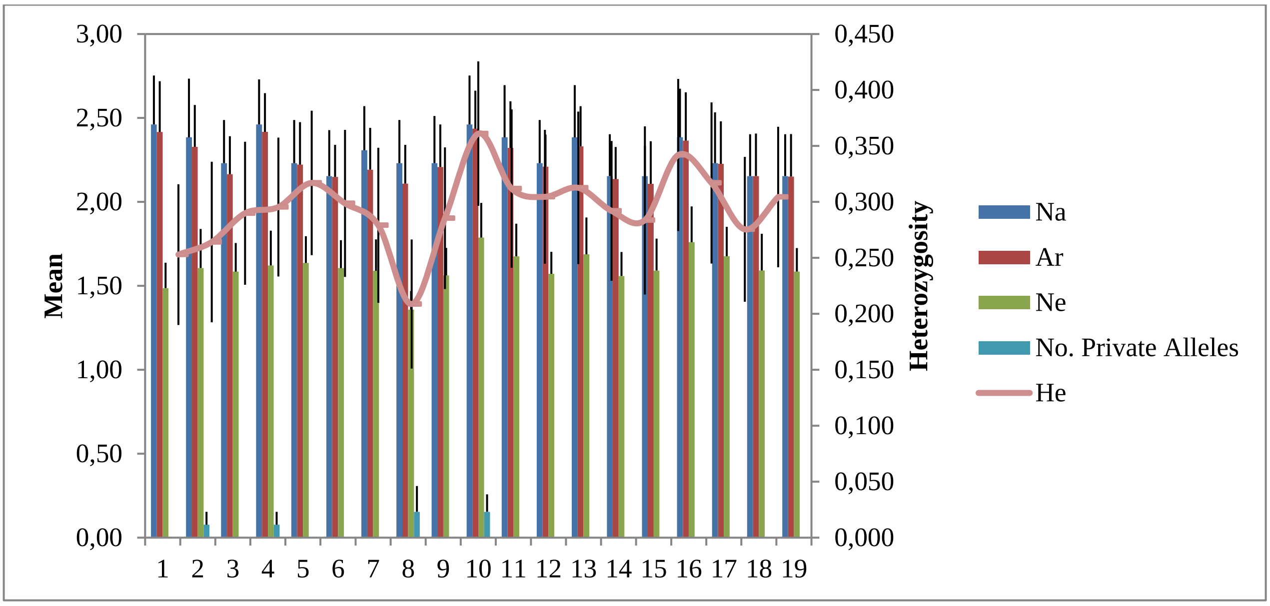
Supplementary Information

Supplementary Figure 1. Natural and introduced distribution area of *Taxus baccata* in Europa after Caudullo et al. (2017); Green: Native range and isolated population, Brown: Introduced and naturalized (synanthropic) area and isolated population.

Supplementary Table 1. Allele frequencies at 13 isoenzyme loci in the 19 English yew populations

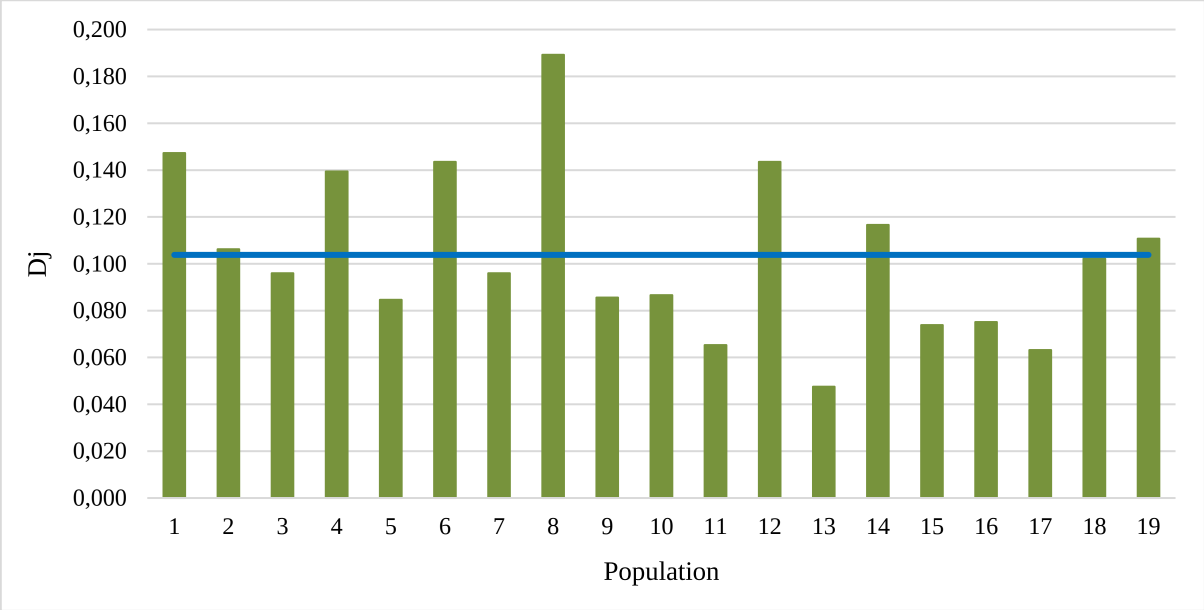
Genort	Population																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
pgib1	0,28	0,29	0,44	0,29	0,49	0,19	0,08	0,89	0,25	0,29	0,31	0,61	0,24	0,02	0,34	0,36	0,31	0,23	0,56
pgib2	0,06	0,21	0,10	0,18	0,08	0,03	0,21	0,02	0,23	0,21	0,08	0,15	0,26	0,21	0,08	0,24	0,03	0,24	0,11
pgib3	0,13	0,26	0,11	0,35	0,19	0,51	0,33	0,09	0,07	0,19	0,28	0,21	0,20	0,24	0,31	0,19	0,21	0,21	0,08
pgib4	0,53	0,24	0,35	0,18	0,24	0,27	0,38	0,00	0,45	0,31	0,32	0,03	0,30	0,53	0,27	0,20	0,45	0,31	0,25
idha1	0,11	0,27	0,31	0,41	0,11	0,24	0,32	0,08	0,23	0,27	0,18	0,26	0,22	0,07	0,21	0,28	0,21	0,14	0,31
idha2	0,82	0,56	0,54	0,51	0,75	0,53	0,59	0,75	0,70	0,63	0,66	0,61	0,66	0,90	0,66	0,55	0,64	0,77	0,65
idha3	0,07	0,16	0,14	0,07	0,14	0,03	0,00	0,16	0,04	0,09	0,15	0,11	0,08	0,00	0,13	0,10	0,16	0,09	0,04
idha4	0,00	0,01	0,01	0,01	0,00	0,20	0,09	0,01	0,03	0,01	0,02	0,01	0,04	0,03	0,00	0,07	0,00	0,00	0,00
idhb1	0,00	0,00	0,00	0,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
idhb2	0,05	0,00	0,09	0,06	0,04	0,27	0,00	0,00	0,01	0,10	0,01	0,23	0,05	0,27	0,12	0,17	0,00	0,04	0,10
idhb3	0,95	1,00	0,91	0,90	0,96	0,73	1,00	0,85	0,99	0,90	0,99	0,78	0,95	0,73	0,88	0,83	1,00	0,96	0,90
idhb4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
idhb5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
pgma1	0,14	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,00	0,01	0,00	0,01	0,02	0,04	0,00	0,00
pgma2	0,19	0,12	0,12	0,09	0,17	0,00	0,01	0,01	0,14	0,29	0,20	0,04	0,21	0,23	0,20	0,36	0,19	0,20	0,16
pgma3	0,06	0,02	0,00	0,12	0,15	0,11	0,01	0,39	0,15	0,03	0,11	0,01	0,06	0,14	0,01	0,07	0,06	0,04	0,18
pgma4	0,60	0,83	0,88	0,79	0,68	0,89	0,98	0,60	0,71	0,68	0,68	0,95	0,72	0,63	0,78	0,55	0,70	0,76	0,66
p6a1	0,34	0,32	0,46	0,21	0,45	0,80	0,38	0,75	0,34	0,45	0,54	0,46	0,48	0,34	0,65	0,69	0,42	0,83	0,78
p6a2	0,66	0,68	0,54	0,79	0,55	0,20	0,62	0,25	0,66	0,55	0,46	0,54	0,52	0,66	0,35	0,31	0,58	0,17	0,22
adha1	0,16	0,11	0,23	0,09	0,15	0,04	0,02	0,21	0,07	0,00	0,24	0,00	0,02	0,02	0,05	0,03	0,18	0,06	0,06
adha2	0,07	0,03	0,01	0,33	0,03	0,35	0,25	0,15	0,09	0,44	0,07	0,51	0,31	0,10	0,08	0,25	0,13	0,39	0,35
adha3	0,77	0,84	0,76	0,58	0,82	0,61	0,73	0,64	0,84	0,56	0,69	0,49	0,67	0,88	0,87	0,72	0,68	0,56	0,59
adha4	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
mnra1	0,69	0,68	0,49	0,17	0,50	0,43	0,49	0,27	0,31	0,53	0,59	0,43	0,37	0,39	0,51	0,38	0,42	0,16	0,23
mnra2	0,11	0,03	0,00	0,01	0,02	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,11	0,00	0,00
mnra3	0,20	0,29	0,51	0,82	0,48	0,57	0,50	0,73	0,69	0,47	0,40	0,58	0,63	0,61	0,49	0,63	0,47	0,84	0,77
aata2	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
aatb1	0,08	0,05	0,11	0,07	0,36	0,38	0,13	0,01	0,15	0,19	0,17	0,83	0,13	0,25	0,13	0,25	0,27	0,19	0,41
aatb2	0,91	0,95	0,89	0,93	0,64	0,62	0,86	0,99	0,85	0,81	0,83	0,18	0,87	0,75	0,87	0,75	0,73	0,81	0,59
aatb3	0,01	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
mdhc2	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
sdhb1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00
sdhb2	1,00	0,97	0,93	0,91	0,88	0,96	0,87	1,00	0,89	0,65	0,95	0,93	0,92	0,97	1,00	0,95	0,97	0,94	0,97
sdhb3	0,00	0,03	0,07	0,09	0,12	0,04	0,13	0,00	0,11	0,33	0,05	0,08	0,07	0,03	0,00	0,05	0,03	0,06	0,03
lapa1	0,03	0,00	0,01	0,07	0,00	0,00	0,01	0,01	0,00	0,00	0,00	0,04	0,00	0,00	0,00	0,01	0,00	0,00	0,00
lapa2	0,97	1,00	0,99	0,93	1,00	1,00	0,99	0,99	1,00	0,97	1,00	0,96	1,00	1,00	1,00	0,99	1,00	1,00	1,00
lapa4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
lapb1	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
lapb2	0,92	0,59	0,30	0,28	0,52	0,90	0,61	0,99	0,56	0,64	0,54	0,69	0,58	0,54	0,53	0,65	0,64	0,54	0,70
lapb3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
lapb4	0,07	0,41	0,70	0,72	0,48	0,10	0,39	0,01	0,44	0,32	0,46	0,31	0,42	0,46	0,47	0,35	0,36	0,46	0,30



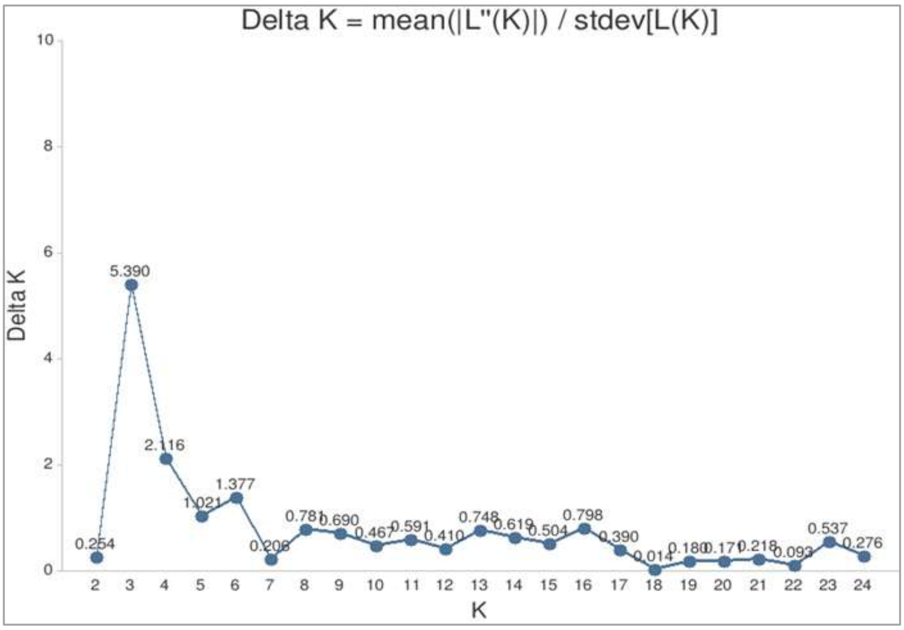
Supplementary Figure 2. The within-population genetic diversity parameters were estimated based on 13 isoenzyme loci [GeneAlex6.5 Software (Peakall & Smouse, 2012)].

Supplementary Table 2. Pairwise population matrix of Nei (1972) genetic distance (Software GeneAlex6.5)

Pop_ID	1	10	11	12	13	14	15	16	17	18	19	2	3	4	5	6	7	8	9
1	0,00	0,26	0,19	0,35	0,22	0,26	0,22	0,27	0,18	0,27	0,27	0,18	0,23	0,29	0,24	0,32	0,25	0,27	0,21
10		0,00	0,19	0,23	0,13	0,25	0,19	0,18	0,20	0,20	0,22	0,22	0,20	0,24	0,21	0,28	0,18	0,35	0,20
11			0,00	0,27	0,12	0,21	0,13	0,17	0,14	0,18	0,21	0,14	0,16	0,23	0,14	0,27	0,17	0,27	0,14
12				0,00	0,23	0,29	0,24	0,24	0,28	0,27	0,23	0,27	0,24	0,28	0,25	0,24	0,23	0,34	0,26
13					0,00	0,18	0,14	0,14	0,16	0,13	0,18	0,16	0,16	0,18	0,18	0,25	0,13	0,29	0,12
14						0,00	0,20	0,18	0,21	0,24	0,24	0,23	0,25	0,29	0,20	0,27	0,24	0,34	0,15
15							0,00	0,17	0,18	0,19	0,21	0,16	0,14	0,25	0,16	0,25	0,19	0,28	0,16
16								0,00	0,19	0,18	0,16	0,24	0,22	0,26	0,20	0,23	0,22	0,27	0,20
17									0,00	0,20	0,18	0,18	0,20	0,26	0,17	0,26	0,20	0,31	0,17
18										0,00	0,14	0,23	0,23	0,19	0,22	0,24	0,22	0,30	0,18
19											0,00	0,26	0,24	0,23	0,20	0,21	0,26	0,26	0,19
2												0,00	0,16	0,21	0,18	0,30	0,16	0,31	0,13
3													0,00	0,20	0,18	0,30	0,18	0,33	0,18
4														0,00	0,27	0,31	0,22	0,34	0,21
5															0,00	0,29	0,21	0,30	0,15
6																0,00	0,25	0,30	0,29
7																	0,00	0,34	0,16
8																		0,00	0,28
9																			0,00



Supplementary Figure 3. Differentiation (Dj) of the 19 populations studied. The blue line indicates the mean differentiation of all populations at the level of 10%.



Supplementary Figure 4. The results of Bayesian clustering [software STRUCTURE 2.3.3 (Pritchard et al., 2000)] on the most likely number of genetic clusters within the studied English yew populations, indicated by the highest delta K value at K = 3 [software CLUMPAK (Kopelman et al., 2015)].

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The studies are sent to the referees according to their content and the expertise of the referees. The field editor examining the study may propose at least two referees from the pool of *SilvaWorld* Advisory Board or referee pool according to their field of expertise or may propose a new referee appropriate to the field of study. The editors evaluate the referee's suggestions coming from the field editor and the studies are submitted to the referees. Referees are obliged to guarantee that they will not share any process or document about the study they are evaluating.

4. Referee Evaluation Process

The period given to the referee for the evaluation process is 15 days. Proposals for corrections from referees or editors must be completed by the authors within 1 month according to the "correction instruction". Referees can decide on the suitability of the study by reviewing the corrections and may also request multiple corrections if necessary.

Referee Reports

Referee evaluations are based in general on the originality of the studies, the method used, and the conformity with the ethical rules, the consistent presentation of the findings and results, and the examination of the literature.

This review is based on the following elements:

1. Introduction and Literature: The evaluation report contains the presentation and purpose of the problem addressed in the study, the importance of the topic, the scope of the relevant literature, the timeliness and the originality of the study.

2. Methodology: The evaluation report includes information on the suitability of the method used, the choice and characteristics of the research group, validity and reliability, as well as on the data collection and analysis process.

3. Findings: The evaluation report includes opinions on the presentation of the findings obtained in the frame of the method, the correctness of the analysis methods, the aims of the research and the consistency of the findings, the presentation of the required tables, figures and images and the conceptual evaluation of the tests used.

4. Evaluation and discussion: The evaluation report includes the opinion on the subject based on findings, relevance to research questions and hypotheses, generalizability and applicability.

5. Conclusion and suggestions: The evaluation report contains the opinion on the contributions to the literature, future studies and recommendations for the applications in the area.

6. Style and narration: The evaluation report includes compatibility of the title with the content, appropriate use of English in the study, refers and references in accordance with the language of the study and APA rules.

7. Overall evaluation: The evaluation report contains opinion on the authenticity of the study as a whole, its contribution to the educational literature and the applications in the area. The journal considers that scientists should avoid research which kills or damages any species of animal which, using IUCN criteria, is regarded as threatened or is listed as such in a Red Data Book appropriate for the geographic area concerned. In accordance with this view, papers based on such research will not be accepted by the Journal, unless the work had clear conservation objectives.

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In agreement with publishing policies of *SilvaWorld*, plagiarism check is required for each study that has undergone the “Review Process”. The Turnitin plagiarism checker software is used for plagiarism detection.

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Beyçelebi mah. Eski Ankara cad. 41/3 No:10,
Merkez/Kastamonu, 37200, TÜRKİYE
info@prensip.gen.tr

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