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Investigating the structure of the mosaics of developmental phases in mixed oriental Beech virgin forests in northern Iran

Untersuchung der Struktur der Bestandesentwicklungsphasen in den Orientbuchenurwäldern im Norden des Iran

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Keywords: development stages, initial phase, optimal phase, decay phase, gaps, forest ecology, virgin forest, close-to-nature forestry

Schlüsselbegriffe: Bestandesentwicklungsphasen, Initialphase, Optimalphase, Zerfallsphase, Lücken, Waldökologie, Urwald, naturnaher Waldbau

Abstract

Close-to-nature forestry is a promising approach for satisfying the criteria of sustainable forestry. This draws attention to natural forests as a comprehensive source of information for forest management. The purpose of this study is to investigating the structure of mosaics of developmental phases and to determine their area based on structural parameters as identification keys in oriental beech virgin forests, which are rarely studied. To this aim, one 10 hectare area in parcel 513, series 5, Eshkateh-Chal forestry project was selected and the location, species type, stem number, gap area, diameter at breast height and tree height of all trees taller than 7.5 centimeters were measured. We also measured standing and lying dead trees (snags and logs). Based on our results, five developmental phases of innovation, regeneration, optimal, aging and degradation were identified in the study area. The results showed that the highest and lowest number of trees were related to the innovation phase (393 trees per

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hectare) and the aging phase (148 ha^{-1}) respectively. In the study area the phases of innovation, regeneration, optimal, aging, and degradation covered 30.5%, 18.8%, 14.0%, 10.8% and 25.9%, respectively. The highest number of dead trees (41 ha^{-1}) was observed in the degradation phase. Except for the optimal phase, where the abundance of snags was higher, in all developmental phases the abundance of logs was higher than that of snags. 2.5% of the study area were covered with canopy gaps and 7.7% with expanded gaps. Our results on tree dimensions and deadwood presence suggest that the studied intact stands were old growth and their structure deviated considerably from managed forests. Silvicultural interventions can be designed to emulate the developmental phases of virgin forests.

Zusammenfassung

Naturnaher Waldbau ist ein vielversprechender Ansatz zur Erfüllung der Kriterien nachhaltiger Forstwirtschaft. Natürliche oder naturnahe Wälder können als Referenz und Informationsquelle für das Waldmanagement dienen. Ziel dieser Studie ist es, die Struktur und Abfolge der Bestandesentwicklungsphasen und deren Anteile in Orientbuchenurwäldern zu untersuchen. Zu diesem Zweck wurde eine 10 Hektar große Probefläche im Parzelle 513, Serie 5 des Forstbezirkes Eshkateh-Chal ausgewählt. Die Lage, Baumart, Anzahl, Lückengröße, Brusthöhendurchmesser und Baumhöhe aller Bäume mit einem Durchmesser größer als 7.5 cm wurden gemessen. Außerdem wurden stehende und liegende tote Bäume gemessen. Basierend auf den Ergebnissen wurden im Studiengebiet fünf Entwicklungsphasen identifiziert: Etablierung, Regeneration, Optimierung, Reife und Degeneration. Unsere Ergebnisse zeigen, dass die höchste und niedrigste Stammzahl in der Etablierungsphase (393 Stämme pro Hektar) und der Reifephase (148 ha^{-1}) auftreten. Von der Gesamtfläche des Studiengebiets machen die Entwicklungsphasen Etablierung, Regeneration, Optimal, Reife und Degeneration 30.5 %, 18.8 %, 14.0 %, 10.8 % bzw. 25.9 % der Fläche aus. Die höchste Anzahl toter Bäume (41 ha^{-1}) wurde in der Degenerationsphase beobachtet. Ausgenommen von den Optimalphase, in der die stehenden toten Bäume häufiger waren als liegende tote Bäume, war in den anderen Entwicklungsphasen die Anzahl liegenden toter Bäume höher als die von stehenden. Von der Gesamtfläche der untersuchten Bestände sind 2.5 % von Baumkronenlücken und 7.7 % von weitläufigen Lücken bedeckt. Unsere Ergebnisse zu Baumdimensionen und Totholz weisen darauf hin, dass die untersuchten intakten Bestände naturnahe Wälder sind und deren Struktur der Bestände sich deutlich von bewirtschafteten Wälder unterscheidet. Waldbauliche Eingriffe können entwickelt werden, um die verschiedenen Evolutionsphasen nachzubilden.

1 Introduction

The old-growth beech forests (*Fagus orientalis* Lipsky) in the north of Iran with trees that are older than 350 years old and usually with a diameter at breast height greater than 110 centimeters (Amini *et al.*, 2009) are a part of temperate deciduous forests, concerning their evolutionary history, are valuable on the international level and considering plant diversity are among the rich forests of the world (Zenner *et al.*, 2019: Moridi *et al.*, 2021: Parhizkar *et al.*, 2021). These forests have expanded at altitudes higher than 750 meters above sea level in the northern parts of the Alborz mountain range on the southern part of the Caspian Sea, whose range extends over 800 kilometers from east to west. The Hyrcanian forests are one of the last remnants of natural deciduous forests (Knapp, 2005; Sagheb-Talebi *et al.*, 2014). There is always a great interest in better understanding the characteristics of these diverse forest communities to manage optimally and multipurpose planning, to preserve diversity in these forests (Fazlollahi *et al.*, 2022).

More than 80% of land ecosystems in the world have been destroyed by human and natural disturbances (Zhu and Liu, 2004). In forest ecosystems, natural disturbances are the source of environmental heterogeneity and vast changes in the temporal and spatial scale of stands and they play an important role in determining the structure, function and dynamics of ecosystems (Oliver, 1981; Paine and Levin, 1981; Pickett and White, 1985). Determining the dynamic of forest stands to expand sustainable forestry and appropriate management strategies is very essential (Oikonomakis & Ganatsas, 2012) and are possible by reviewing the changes in the structure of forest stands over time which consists of behavior and condition of forest stands during and after the occurrence of existing disturbances (Ford-Robertson, 1971).

Oriental beech or eastern beech (*Fagus orientalis* Lipsky) belongs to the family *Fagaceae*. It is a deciduous broad-leaved tree which reaches height of 30-40 meters. In rare instances, trees up to 50 meters in height can be found. In general, oriental beech has a similar appearance to European beech (*Fagus sylvatica*). Both beech species are characterized by their smooth and silver-grey stem. The stem colour of oriental beech is a lighter grey than European beech (Sagheb-Talebi *et al.*, 2014). The spatiotemporal dynamics of the natural European beech (*Fagus sylvatica* L) and oriental beech forests (*Fagus orientalis* Lipsky) have been derived by the scattered and frequent occurrence of gaps on a small scale and by occasional disturbances on the medium and large scale, such as wind disturbances (Korpel, 1995; Sagheb-Talebi and Schütz, 2002; Nagel *et al.*, 2006; Sefidi *et al.*,2011; Zenner *et al.*, 2019). Developmental phases are defined to reflect important environmental processes, such as regeneration, growth, and mortality, which shape the horizontal and vertical structure of a forest during its life cycle (Leibundgut, 1959, 1993; Korpel, 1995). These phases represent multiple structural features of the forest and provide a practical temporal framework to improve our understanding of how structural variation of natural processes evolves (*e.g.*, Huber, 2011; Amiri *et al.*, 2013). Although there is no consensus on the exact definition of developmental phases or even the exact number of them, and no standardized set of criteria are known to distinguish between developmental phases (Leibundgut, 1959; Zukrigl *et al.*, 1963; Mayer, 1984; Emborg *et al.*, 2000; Král *et al.*, 2010; Zenner *et al.*, 2019), but generally, similar to the European natural beech forest, three main developmental stages (initial, optimal and decay stage) are accepted (Leibundgut, 1993; Korpel, 1995), which include several developmental phases (Korpel, 1995).

The identification and explanation of the developmental phases in forest stands are very important because the structural characteristics of the stand in each developmental phase are different (Sagheb-Talebi and Mataji, 2007). Depending on the point of time that the stand is analyzed, or in which developmental phase, it can show different results in terms of density, basal area, and volume between phases and developmental stages (Sefidi *et al.*, 2014; Parhizkar *et al.*, 2021). The developmental cycle occurs in every part of the forest which results in the shifting mosaic of the developmental phase and the total area of each phase is almost directly related to the length of the corresponding period (Emborg *et al.*, 2000). By evaluating developmental phases and the dynamics process of virgin forests, considering the potential of the habitat and benefiting from the knowledge of close to nature silviculture, it is possible to adapt a suitable method to maintain the principle of continuity of production and sustainability of the forest (Mataji, 2002). Thus, evaluating the evolution of forest stands should be conducted separately based on developmental phases (Amini *et al.*, 2018).

The first step in understanding forest ecosystems is investing in their stability and persistence over time. With the knowledge and awareness of this, it is possible to choose appropriate silviculture methods and how to intervene in the forest stands properly. The closer the plans and silviculture interventions are to management applied by nature, the more optimized the protection, productivity, and sustainability of the forest will be. Thus, conserving these valuable sources for the next generations is better conducted and the responsibility and the role of forest ecosystems will be fulfilled to a greater extent. In the Hyrcanian forest, the analysis of developmental phases and stages is emphasized by many studies (Mataji *et al.*, 2014: Moridi *et al.*, 2015; Sefidi *et al.*, 2015; Zenner *et al.*, 2019; Moridi *et al.*, 2021), however, there is still limited knowledge in this domain and none of these researches have focused on the zoning of developmental stages and the identification of developmental phases. Considering the importance of the Hyrcanian forests, this study was conducted with the aim of investigating the structure of the mosaics of developmental phases and determining the area of each of them based on structural characteristics as identification keys in the oriental beech virgin forests in one 10-hectare area.

2 Method and Materials

2.1 Study region

The studied area is located in parcel No. 513, Series 5 of the Eshkatehchal forestry project, in Ramsar 30 watershed, in the northern latitude of 36°49'N to 36°53'N and the eastern longitude of 50°22'E to 50°30'E. Figure 1 shows the location of the studied area.

The average annual rainfall of the region is 1215 mm and the average annual temperature is 15.8 °C. Autumn is the most rainy season with 465 mm of rainfall and spring is the least rainy season with 144 mm. Based on the Ambergris climate curve, the studied area has a cold humid climate. In addition, the vital dry season in the region is short. From the point of view of rock stratigraphy, the studied parts are composed of limestone and marl sediments that belong to the Cretaceous period and the end of the second era. Soil type is rundzin and the forest type is mixed beech.

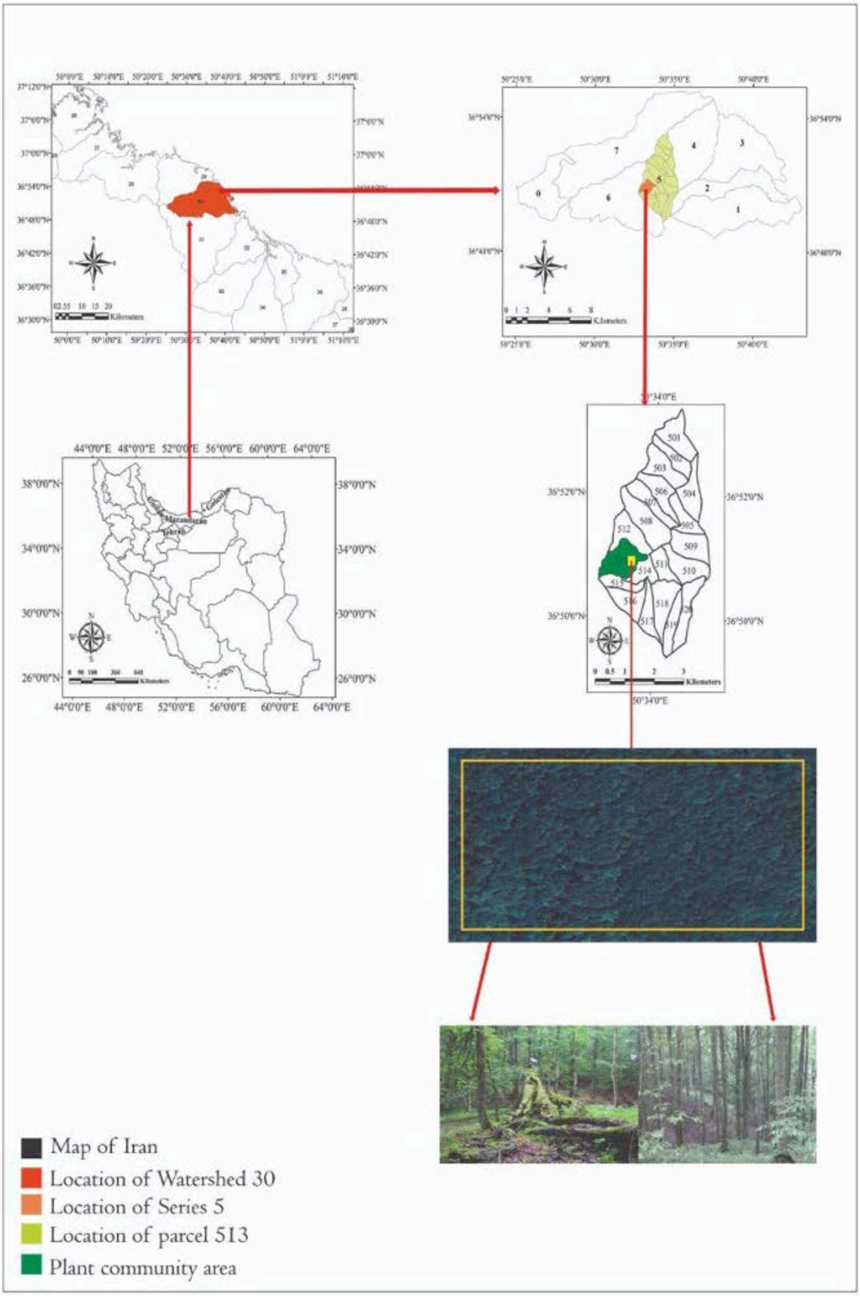

Figure 1: The geographical location of the studied area.

Abbildung 1: Geografische Lage des Studiengebiets.

2.2 Methodology

Considering the purposes of the study, the 10-hectare plot in parcel No. 513 was determined and separated based on the indicators and criteria for determining the developmental stages in nature. To investigate the structure of the stands, a full inventory approach was used. The trees' location was conducted by measuring and recording the distance and the azimuth of the individuals relative to each other. The quantitative characteristics of the live and dead trees, including the species, diameter at breast height (DBH), basal area, the volume for live stems and type, number and volume for dead trees, and also the number and size of gaps were calculated for all stems over 7.5 cm at the breast chest diameter.

Using the azimuth parameter and the distance of trees within each other and taking advantage of the following trigonometry relationships, the location of each tree was determined on the initial map, and then considering the species and the diameter at the breast height trees, the final distribution map of trees was created.

$$X = L \times \sin(\alpha)$$

$$Y = L \times \cos(\alpha)$$

X length difference between two points; Y width difference between two points α: azimuth of trees relative to one another; L the distance of trees within each other

In order to measurement of gaps and determine their area, the trigonometry method was used (Lima, 2005). So first by moving around the canopy gaps, the location of the image of the bumps and depression of the crown around the gaps was determined on the ground, and then by the placement in the approximate center of the gap, azimuth and the sloped distance and the slope of the each of the marked points were determined, measured and recorded. This action was conducted on expanded gaps as well, with the difference that in expanded gaps all the measurements and readings were done up to the stems of the surrounding trees. During the field collection of each gap, the center of each gap was first determined. Next, with placement in the center of each gap by using the trigonometry method, and by measuring distance and azimuth relative to each corner of the gap (the image of the end of canopy gap edge trees on the ground), the area of each canopy gaps among the forest crown was measured and calculated using trigonometry (Lima, 2005).

$$A_i = [p_i\,(p_i - a_i)(p_i - b_i)(p_i - c_i)]^{\,0.5}$$

$$p_i = (a_i + b_i + c_i)/2$$

Where A_i is the area of each triangle and a, b, and c are the sides of each triangle. By summing the obtained levels, the area of each gap (A_{gap}) was calculated:

$A_{gap} = A_1 + A_2 + ... + A_n$

To estimate the volume of trees, the following function was used:

V = F x A x H

Where *A* = basal area at 1.3 m above ground, *H* = tree height *F* = the form factor. According to Moridi *et al.* (2016), the form factor was considered 0.42.

We also identified and recorded dead tree species, total length, form (log, snag, or stump), diameter at both ends, diameter at the midpoint (for stumps, only the diameter at the midpoint was recorded), and decay class. To calculate the volume of dead trees, Newton's formula was used (Harmon and Sexton, 1996) for snag and log volume:

$$V = \frac{L\,(A_b + 4A_m + A_t)}{6}$$

Where, V = volume of dead trees in m³, L = length of dead trees, and A_b, A_m and A_t = the cross-sectional area at the base, middle, and top of dead trees, respectively.

The decay classes in the current study included five classes for snags and logs (Akala, 2010):

- Class 1. Snag or log with intact bark and all wood sound; intact structure and wood's original colour.
- Class 2. Bark broken up into patches and partly fallen off; wood still maintains its structural integrity and original colour; the outer layers started to soften because of rot.
- Class 3. Bark completely absent; all wood structure has started to soften; the soft outer layers disintegrate easily (knife test); the core is still solid and the colour has already started to fade.
- Class 4. Bark totally absent; texture small and soft; shape oval.
- Class 5. Wood structure soft and powdery; wood partially covered with moss and vegetation, mixed with the forest soil.

The separation of the mosaics of the developmental phases was conducted using structural indicators and parameters including the existence of the gap, dead trees, regeneration, height, diameter, basal area, volume, and the spatial distribution of all trees based on the identification keys mentioned in the following studies (Leibundgut, 1993; Korpel, 1995; Emborg *et al.*, 2000; Mataji *et al.*, 2014; Sagheb-Talebi *et al.*, 2003). There are different phases in each stage. During the initial stage, trees are going toward a higher height and diameter class. Their volume increases and trees found in all strata (upper, middle, and lower). The percentage of canopy and density of trees is high per hectare, and small gaps which are usually a result of the breaking of smaller branches, are filled by the canopy cover of other trees (Leibundgut, 1993; Korpel, 1995). In the optimal stage, there are two phases: mature and aging. This stage begins when the dominant trees ultimately reach the upper canopy layer. Compared to the previous stage, the number of trees decreases, but the volume of trees increases. The decay stage comprises building, pioneer, regeneration, and degradation phases (Emborg *et al.*, 2000; Mataji *et al.*, 2014). The decay stage begins when density and stand volume are decreasing and amounts of dead wood are increasing. In a slowly decaying stand, shade-tolerant tree species regenerate and recruit underneath persistent canopy gaps. During this stage, old trees begin to degenerate, and due to various reasons including the breaking of large branches, death of trees, and windfall, many gaps are formed in the canopy (Mataji *et al.*, 2014). The presence of dead trees and regeneration in the openings accentuate vertical irregularity and uneven-agedness. With an increasing proportion of young trees and a decreasing proportion of old and mature trees, the forest transitions to the initial stage (table 1).

Table 1: Criteria for distinguishing among the three main development stages (Akhavan et al., 2012).

Tabelle 1: Unterscheidungskriterien zwischen den drei Hauptentwicklungsphasen.

Criteria	Initial stage	Optimal stage	Decay stage
Number of stand stories	Number of stand stories More than 2	Usually 1 to 2	More than 2
Number of trees/unit area	High	Medium	Low
The proportion of trees in timber size	The highest amount in small and medium sizes	The highest amount in medium and large sizes	The highest amount in large and extra-large sizes
The proportion of trees in canopy strata	The highest in lower and middle stories	The highest in upper story	The highest in middle and upper stories
Stand volume	Medium	High	Low
The proportion of volume in timber size	Usually highest amount in medium and large sizes	Usually highest amount in medium and large sizes	Usually highest amount in large and extra-large sizes
Dead wood volume	Medium	Low	High
Proportion of dead wood volume in timber size	Usually highest amount in large and extra-large sizes	Usually highest amount in small and medium sizes	Usually highest amount in extra-large sizes
Gap	Present	Usually absent	Present
Regeneration	Group-wise and present in gaps	Little and scattered over the whole area	Group-wise and present in gaps

After using the aforementioned identification keys using the model proposed by various researchers (Korpel, 1982; Emborg, 2000; Leibundgut, 1993; Mataji *et al.*, 2014), developmental phases were carefully determined and the area of each phase was determined as a polygon on the map. Then, having the map and determining the exact area of each polygon of different developmental phases, a visual interpretation is undertaken within each of the polygons in the forest and conforming to the generated map. Therefore, the edges and borders of the polygons were carefully closed and ultimately, the final map of the developmental phases of the target area was prepared. Quantitative variables such as DBH, basal area, volume, characteristics of dead trees, number of gaps, species composition, diameter and height of regeneration were calculated in the Excel (version 2013) and SPSS (version 25) software. Excel was used to draw the graphs. In order to determine the size of the gaps and calculate the area, Auto CAD was used to separate and draw the polygons of the maps of the developmental phases.

3 Results

In the present study 2109 trees with diameters greater than 7.5 centimeters were identified and measured over an area of 10 hectare. The average number of trees in each hectare is 210 and the average volume in hectare was 414.8 $m^3\ ha^{-1}$. The mean and median of the diameter were 30.52 and 21.5 cm respectively. *Fagus orientalis* *Acer velutinum*, *Alnus subcordata*, and other species account for 65.3%, 19.3%, 9.0%, and 6.4% of the species respectively. Other species in the present study included *Carpinus betulus*, *Acer cappadocicum*, *Quercus castaneifolia*, *Prunus avium* and *Ulmus glabra*. Also, the amount of standing volume for *Fagus orientalis*, *Acer velutinum*, *Alnus subcordata* and other species was measured as 74.6%, 16.1%, 7.2%, and 2.1%, respectively. The results of drawing the diagram of the number in diameter classes at the scale of 10 hectare showed that the distribution of trees in the diameter classes is decreasing exponentially (Figure 2). At the beginning, the distribution diagram decreases with a sharp slope, that decrease does not follow a specific order in high diameter classes, and it is mainly imbalanced state and sometimes it increases and decreases alternately.

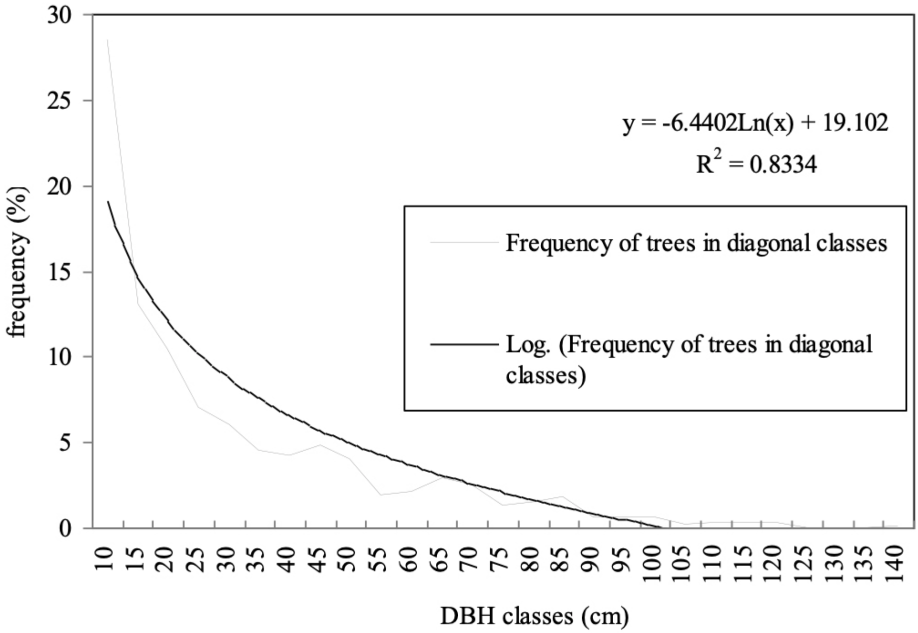

Figure 2: Distribution of trees along the diameter gradient for the 10 hectare orient beech forest.

Abbildung 2: Verteilung der Bäume entlang der Durchmesserklassen im 10 Hektar großen Orientbuchenwald.

After the collection of the data about the stand structure and the location of trees, different groups in terms of similarity, and differences in various statistical parameters were identified, including the mean or median of the diameter or the number of gaps and the amount of canopy opening, the number and the volume of live trees and the number and volume of dead trees. Overall, based on the findings of this study, five developmental phases of innovation, regeneration, optimal, aging and degradation were identified in the study area, which takes the form of 42 irregularly shaped polygons with variable areas, where the developmental phases of regeneration and innovation have the highest distribution with 12 polygons. The aging phase has the lowest distribution with three polygons (Figure 3). The areas of polygons varied in the range of 214 to 10621 m². The smallest and the largest recorded polygon belonged to the developmental phases of regeneration and innovation respectively. The innovation (30480 m²) and aging phases (10767 m²) occupied the highest and lowest area, respectively, in the 10-hectare stand. The average area of the polygons of different developmental phases ranged from 1569 to 3589 m². The regeneration phase has the lowest and the aging phase has the highest of the mentioned characteristic (Table 1).

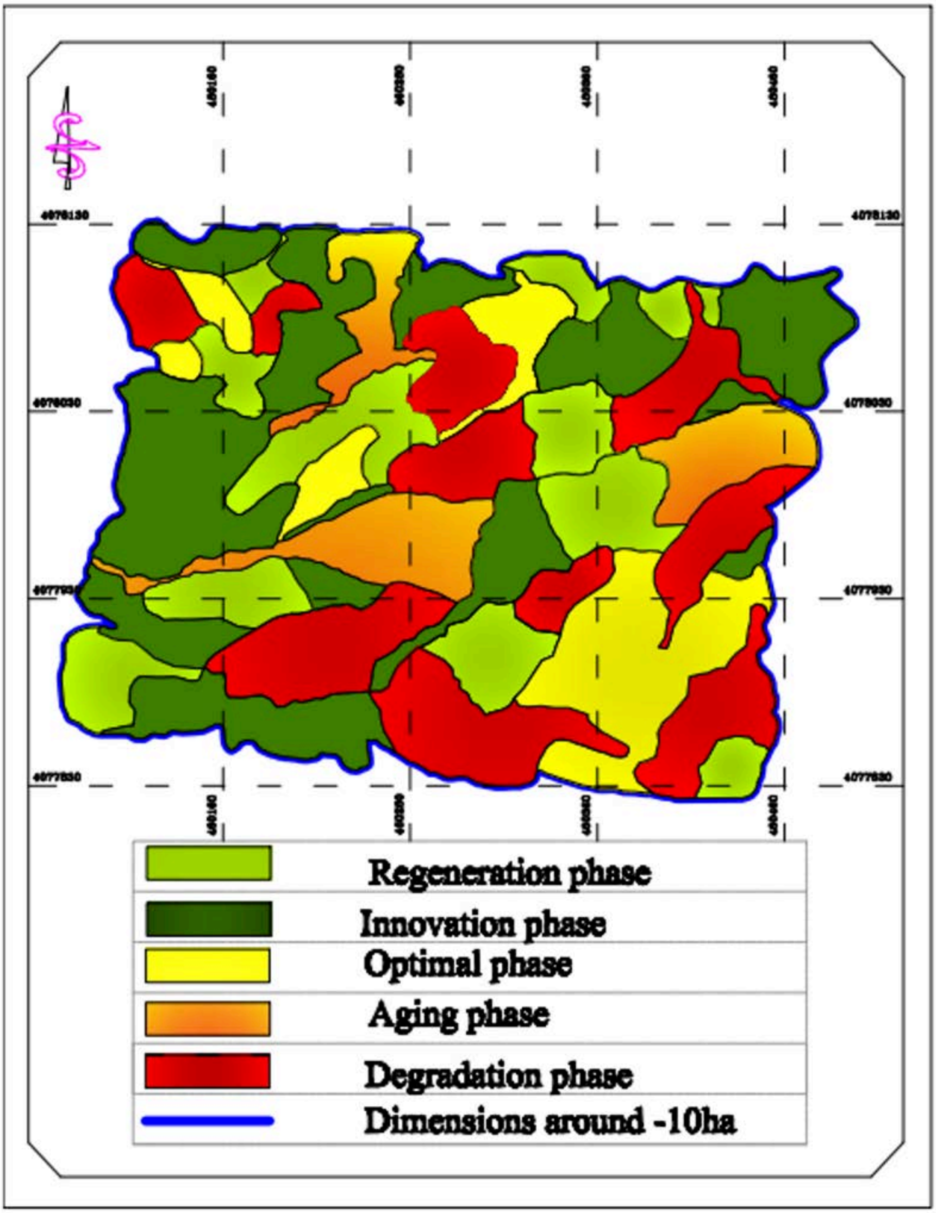

Figure 3: Display of mosaic zoning of the developmental phases in the studied area.

Abbildung 3: Darstellung des Mosaiks der Entwicklungsphasen im Studiengebiet.

The investigation of the quantitative characteristics in the studied area shows that the highest number of trees (393 trees per hectare) are in the innovation phase and the lowest number (148 ha^{-1}) are in the aging phase. The highest and lowest presence of the beech species was measured in the innovation (287 ha^{-1}) and degradation phase (108 ha^{-1}), respectively. Also, the highest basal area of live beech trees was measured (36.4 m^2 ha^{-1}) in the aging phase, and the lowest amount for other species was measured (2.4 m^2 ha^{-1}) in the optimal phase. Additionally, the highest volume of live trees in different developmental phases in the study area in the aging phase was for beech trees (525.4 m^3 ha^{-1}) and the lowest amount of volume of live trees in the study area in the optimal phase was for other species (26.9 m^3 ha^{-1}) (Table 2).

Table 2: The mean of the quantitative characteristics of the trees by developmental phases and based on species in the studied area.

Tabelle 2: Durchschnittliche quantitative Merkmale der Bäume nach Entwicklungsphasen und nach Baumarten im Studiengebiet.

Characteristic	Species	Developmental phases				
		Regeneration	Innovation	Optimal	Aging	Degradation
Stem number (ha^{-1})	Beech	113	287	235	135	108
	other species	174	106	15	14	84
	Total	287	393	250	149	192
Basal area (m^2 ha^{-1})	Beech	10	14.7	24.9	36.4	14.6
	other species	11.4	10.7	2.4	4.8	20.2
	Total	21.4	25.4	27.3	41.2	34.8
Volume (m^3 ha^{-1})	Beech	139.6	170.5	302.2	525.4	203.6
	other species	127.4	117.6	26.9	55.7	241.4
	Total	267	288.1	329.1	581.1	445
Polygon numbers		12	12	5	3	10
Average polygon area (m^2)		1569	2540	2799	3589	2593
Min-max range (m^2)		214- 3412	330- 10621	430- 8350	2655- 4712	744- 4707
Total Area (m^2)		18828	30480	13995	10767	25930
Share (%)		18.8	30.5	14.0	10.8	25.9

The total number of 197 dead trees was identified in the studied stands, of which 66 stems were standing dead trees and 131 of them were fallen dead trees. The highest number of dead trees (106 stems) was observed in the polygons of the degradation phase and the lowest numbers (14 stems) were observed in the optimal phase (Table 3). The volume of dead trees was 31.9 $m^3\ ha^{-1}$, where 33.1% are snags and 66.9% are logs. The highest and lowest volume of dead trees, belongs to the trees which are in the decay classes 2 and 5. The examination of dead trees in different developmental phases shows that the highest and lowest average volume of dead trees was observed in the degradation phase (88.42 $m^3\ ha^{-1}$) and the optimal phase (0.24 $m^3\ ha^{-1}$) respectively. In almost all developmental phases, the highest amount of dead trees has been observed in decay class two (Table 4).

Table 3: Relative abundance of deadwood by type and species in each developmental phase.

Tabelle 3: Relative Häufigkeit des Totholzes nach Art und nach Entwicklungsphasen in jeder Phase.

Type of deadwood	Species	Developmental phases				
		Regeneration	Innovation	Optimal	Aging	Degradation
Snag	Beech	15.6	28.1	53.8	35.8	2.8
	Other species	12.5	6.2	15.4	7.1	26.4
	Total	28.1	34.3	69.2	42.9	29.2
Log	Beech	25	21.9	15.4	0	18.9
	Other species	46.9	43.8	15.4	57.1	51.9
	Total	71.9	65.7	30.8	57.1	70.8

Table 4: The average volume of dead trees by decay classes and divided by the type of dead trees in each developmental phase.

Tabelle 4: Durchschnittliches Volumen der Sträucher nach Zersetzungsgradklasse und nach Totholz in jeder Entwicklungsphase.

Developmental phases	Type deadwood	Mean volume by decay class (m^3 ha^{-1})					
		1	2	3	4	5	Total
Regeneration	Snag	3.684	6.651	1.588	0.052	0.000	11.975
	Log	3.177	6.370	11.010	1.666	0.028	22.251
	Total	6.861	13.021	12.598	1.719	0.028	34.227
Innovation	Snag	0.129	0.036	0.036	0.000	0.000	0.202
	Log	0.052	0.011	0.000	1.787	0.275	2.125
	Total	0.181	0.048	0.036	1.787	0.275	2.327
Optimal	Snag	0.150	0.084	0.007	0.000	0.000	0.241
	Log	0.042	0.013	0.000	0.000	0.000	0.052
	Total	0.150	0.084	0.007	0.000	0.000	0.293
Aging	Snag	0.136	0.104	0.008	0.000	0.000	0.248
	Log	0.000	0.000	0.000	0.000	11.677	11.677
	Total	0.136	0.104	0.008	0.000	11.677	11.925
Degradation	Snag	6.385	2.215	9.379	11.745	1.207	30.929
	Log	4.747	24.598	13.413	12.089	2.650	57.497
	Total	11.131	26.813	22.792	23.833	3.857	88.426

Overall, 62 gaps were identified in the study stands. The total area of the canopy and expanded gaps were calculated as 2520 and 7740 m² respectively. In general, 2.5% of the analyzed stands are composed of expanded gaps and 7.7% were comprised of canopy gaps (Table 5). The investigation of gap characteristics in the polygons of different developmental phases indicated that the number and the ratio of the canopy and expanded gaps in the degradation phase are more than those of other developmental phases.

Table 5: Characteristics of the canopy and expanded gaps in each developmental phase.

Tabelle 5: Eigenschaften von Kronenlichtungen und weitläufigen Lichtungen in jeder Entwicklungsphase.

Developmental phase	Count	Gap relative abundance (%)		Average area (m^2)		Total area (m^2)	
		expanded gap	canopy gap	expanded gap	canopy gap	expanded gap	canopy gap
Regeneration	11	8.0	1.8	141	32	1556	349
Innovation	6	1.8	0.4	90	18	541	109
Optimal	3	2.3	0.3	102	13	306	38
Aging	3	1.7	0.3	60	10	179	29
Degradation	39	19.6	7.6	132	51	5158	1994
Total	62	7.7	2.5	129	41	7740	2520

4 Discussion

4.1 The mosaics of developmental phases

The identification of developmental phases in beech forests is necessary to choose appropriate forestry methods. Each of the polygons in the developmental phases is a coherent spatiotemporal unit and is here assumed to have constant location as they evolve through time. In total, five development phases were identified in the present study. Similar developmental phases were identified in the European beech forests by Leibundgut (1959), Oliver and Larson (1996), Mayer *et al.* (1987), and Emborg *et al.* (2000), and in the beech forests of Iran by Mataji *et al.* (2014). Based on the results of the present study, the measured quantitative characteristics were dissimilar between different phases, so the smallest and largest identified polygons were measured from

214 and 10621 m² respectively. There have been many studies regarding the developmental stages and phases in Hyrcanian forests (Nobahar *et al.*, 2018; Moridi *et al.*, 2021a; Moridi *et al.*, 2022, Kakavand *et al.*, 2020, Sefidi *et al.*, 2014), which all of them have been studied in one-hectare sample plots, that due to the uneven-aged and irregularity of the Hyrcanian forests, the zoning of stages or developmental phases cannot have a regular geometric shape and regular one-hectare plots should not be considered for their study. Alibabaei *et al.*, (2023), in the study of spatial patterns and structural characteristics of the oriental beech forests in the optimal stage, identified 11 polygons that have the features of the optimal stage in the entire parcel 327 of Kheiroud forest where the largest and smallest area of polygons were measured as 3745 and 1679 respectively. This study identified five developmental phases of regeneration, innovation, optimal, aging, and degradation in the studied stands. Sefidi *et al.* (2014), in the study of the late successional stage dynamics in natural Oriental beech (*Fagus orientalis* Lipsky) stands in northern Iran, concluded that beech stands be placed in three development stages of volume growing up, volume accumulations and volume transition. The volume growing stage embraces gap forming, understory initiation and regeneration phases, the volume accumulation stage includes volume stability, lightning and stem exclusion phases, and the volume transition stage includes gap making, old growth and volume degradation phases. Emborg *et al.* (2000) in the investigation the structural dynamics of Suserup Skov, a near-natural temperate deciduous forest in Denmark, reported the area of innovation, aggradation, optimal, aging, and degradation phases to be 5%, 20%, 34%, 38% and 4%, respectively. Kral *et al.* (2014) in a study entitled patch mosaic of developmental stages in central European natural forests along vegetation gradient, concluded that the mean patch size of the mosaic of four developmental stages showed a relatively narrow range of 570-800 m² in all study sites and censuses. The Growth stage was usually the most abundant (covering 25-50% of the stand), and had the highest mean patch size, ranging between 590 and 2800 m². The Growth stage patches also had the most complex shapes. On the contrary, the Breakdown stage usually had the opposite values, forming constantly small (250-720 m²), simple and scattered patches in the mosaic. Sefidi (2012) report reverse J-shape curve to the mixed beech stands. The same results reported in the oriental beech stands in the north of Iran (Nedyalkov and Asli, 1971; Sagheb-Talebi *et al.*, 2004; Marvie Mohadjer *et al.*, 2009) and in European beech forest (Leibundgut, 1993; Meyer *et al.*, 2003; Cancino and Gadow, 2002).

4.2 Stand characteristics description

The number of trees per hectare in the innovation phase was higher than those of other phases, and the lowest value of this characteristic was for the aging phase, which is in line with the results of forest structure assessment in Neka region (Sagheb-Talebi *et al.*, 2020) and Kheiroud forest (Moridi *et al.*, 2021). Therefore, it can be concluded that the high density of trees in the innovation phase, and consequently, the high competitive pressure for light and nutrition, culminates in trees removing in the subsequent phases. The mean number of removed trees from the stand in the regeneration, optimal, degradation, and aging phases compared to the innovation phase were 106, 143, 201, and 245 trees per hectare respectively. Moreover, based on the findings of this study, with the reduction of the number of trees as they move on from the regeneration phase to the aging phase, the average basal area of trees increases. Different researchers have used the mean of the basal area of trees in order to determine the development stages of the forest and also to examine and compare virgin and managed stands, and express that as the stand's age increases and it passes through development phases and stages, the mean of development area increases (Spies and Franklin, 1991; Ziegler, 2000). Franklin *et al.* (1981) in the study of the characteristics of old forests, concluded that young and old stands had the same average basal area and only the old stands had a greater and twice as high diameter change coefficient than the young stands.

4.3 Dead trees

Understanding the quantitative and qualitative characteristics and the role of dead trees in the forest leads to the increasing of knowledge and awareness of forest specialists in order to apply the most appropriate management of natural stands. With the knowledge and awareness of these features, interventions made in line with the natural process of stand evolution will be with the least deviation from nature (Moridi *et al.*, 2017). Based on the findings of the present study, most dead trees in the phases of regeneration, innovation, degradation, and aging were fallen dead trees. Moridi *et al.* (2015) reported that average deadwoods volume was 24 m^3 ha^{-1}. This value was 23 m^3 ha^{-1} in beech forests, Turkey (Atici, 2008), and was 30-85 m^3 ha^{-1} in mixed beech forests, Albania (Mayer *et al.*, 2003). Factors affecting the accumulation of deadwoods in a forest are the age and management history of a stand as well as the rotting speed (Mayer *et al.*, 2003; Christensen *et al.*, 2005). Difference in tree species in various places can also have a significant impact on the deadwood volume in forests (Tinker and Knight, 2001). Kakavand *et al.* (2017) examined the quality and quantity of dead trees in the intermediate stage of the beech forests in the Grozban section of the Kheiroud forest reported the amount of standing and fallen dead trees as 31% and 69%, respectively. Also, analyzing the amount and volume of dead trees in unmanaged forests of Shafarud, the amount of standing and fallen dead trees are reported as 22% and 78%, respectively (Amanzadeh *et al.*, 2013). Rahanjam *et al.* (2018) in a qualitative and quantitative analysis of dead trees in Hyrcanian natural stands in Kheiroud forests, reported the volume of standing and fallen dead trees as 22% and 78% respectively, which are consistent with the results of the present research. Only in the optimal phase were the amount of standing dead trees more than logs, this issue can be due to the closed canopy and the loss of trees due to lack of light, especially the weaker trees in the lower layer. The highest and lowest volume of dead trees per hectare were observed in the degradation and optimal phases respectively, where in the degradation phase, most of this volume was located in the fallen dead trees. In the late successional stages in beech stands this issue can be due to internal disturbance and also the presence of thick trees left from the previous development phase and subsequently falling them, that in the volume of dead trees increases a lot in this phase. In fact, when trees reach the end of their physiological life, they are severely affected by natural disturbances, such as wind and fall, and due to their large dimensions, they take up a lot of volume. In the optimal phase, dead trees had the lowest volume of deadwood compared to other phases, which is due to the small diameter of dead trees that have been eliminated as a result of competition for light. Sefidi and Mohadjer (2010) reported similar findings and this is consistent with the findings of the study of Parhizkar et al. (2011) in the natural beech forests of Kelardasht. The variety of tree diversity in different areas can also considerably affect the volume of dead trees in forests (Tinker and Knight, 2001).

4.4 Canopy gaps

The canopy gaps are the result of different types of natural or unnatural disturbances and biological processes, such as intra- and interspecies competition or mortality (Vahedi, 2021). The considerable difference between the area of the canopy and expanded gap shows that in most gaps, the distance from the last point of the branch extended towards the center of the gap to the point of the tree's establishment was long and the advancement of the canopy is substantial, especially the lateral branches. In fact, with the passage of time, due to the closing of the large gaps from their periphery to the center, they turn into smaller gaps (Mataji *et al.*, 2019). In other words, there is a balance between the advancement of decay in deadwood, as the gap makers, the closing of gaps, longevity of gaps and the growth of the canopy of the surrounding tree as gap fillers. However, it should be mentioned that numerous factors, including environmental conditions and ecological factors such as light, humidity, nutrient elements, etc., can fluctuate the aforementioned balance in different seasons and periods. In the study area the most and biggest gaps are in the degradation and regeneration phases respectively. The ratio of the area of the gaps to the total area of the area was 7.7%. Parhizkar *et al.* (2019) in the unmanaged forest, the proportion of the area of the gaps to the total area of the plot was reported as 10.7% and in the managed forest as 6.3%. Other researchers have reported the range of the gap area to the stand area from 3 to 41.4% (Mataji *et al.*, 2008; Nagel and Svoboda, 2008; Kenderes *et al.*, 2009; Kucbel *et al.*, 2010; Bottero *et al.*, 2011; Sefidi *et al.*, 2011; Rugani *et al.*, 2013; Kian *et al.*, 2017). The results of the present research are in this range. The creation of gaps and their size depends on various factors, including wind, snow, drought, soil features, and the characteristics of tree species (Scharenbroch and Bockheim, 2007; Nagel and Svoboda, 2008). Therefore, the observed difference in the ratio of the gap area to the area of the studied area is not unexpected to be seen. Depending on the ratio of the closing of gaps and the events that cause the creation of new gaps or the enlargement of a gap, the ratio of the area of the gaps to area surface of the entire forest varies by approximately 10 percent (Splechtna and Gratzer, 2005; Feldman *et al.*, 2018).

5 Conclusions

Considering that it is the first time in Iran that developmental phases with variable area and irregular geometric shape have been investigated, as a result, it can be said that the results obtained from this research regarding the structure of the forest can provide the least amount of information for developmental phases to date in Iran's beech forests, which managers can use as a reference point to expand management plans and implement close-to-nature silviculture guidelines in order to protect and restore this forest ecosystem. Because up to now, all the researches about developmental phases have been done in one-hectare sample plots, which is flawed, because the zoning of developmental stages or phases, do not have a regular geometric shape, and regular one-hectare plots.

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