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Research Article

Monitoring of the oak decline phenomenon and its impact on biomass and leaf area in the forest stand, Yasouj

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Abstract
Monitoring forest stands can provide valuable information to forest managers. This study shows the phenomenon of Persian oak decline in a 1-hectare plot. The study was performed over four years, and it was used to see the changes in leaf dieback, with all of the trees, a total of a hundred trees, were analyzed. Trees were classified into four dieback categories: healthy trees, trees with crown dieback, trees with less than 50% crown dieback, and trees and trees that had more than 50% crown dieback. Trees that had the dieback. Also, leaf area was monitored. In the first year of the study, 65% of trees experienced crown dieback. There was a change in dieback, and after a year, 10 to 25% more trees had crown dieback. Over time, it reached about 80%. According to the research, the leaf area decreases from the healthy category to the completely dead one. It turns out the average leaf area in high forest trees was higher than in coppice trees. The study of leaf area also showed a strong correlation between the crown dieback and leaf size. The study also found that the trees with a crown dieback of over 50%, had consistently smaller leaves than healthy trees.
Keywords: Crown dieback, Healthy, Leaf area, Tree

Introduction
Climate change is widely acknowledged as one of the most significant challenges confronting the world today. Its impacts pose substantial threats to the environment, influencing ecosystems, biodiversity, and natural resources. This phenomenon also affects nearly all aspects of human life, including health, food security, water supply, and economic stability. As temperatures rise and weather patterns become increasingly erratic, communities are experiencing more frequent and severe weather events, such as floods, droughts, and wildfires. Additionally, climate change exacerbates existing social inequalities and puts vulnerable (Abbas et al., 2022). The phenomenon

of decline and mortality in various oak species has been reported in vast areas of the world's forests since the early 19th century (Tomiczek, 1993). The prevalence of this phenomenon, referred to by various names such as decline, dieback, or mortality, is due to a complex interaction that plant pests exhibit in response to environmental stresses (Philip et al., 1983). There is a lack of precise information regarding the process of oak tree dieback, from the emergence of initial factors such as branch and crown dieback or premature leaf fall to complete tree dieback, and the impact of important site factors such as geographic direction on the speed or cessation of this process. Oak decline is a multidimensional phenomenon that is not specific to one region or one oak species, but according to existing reports, this phenomenon has occurred in a significant range of oak forests around the world (Brasier et al., 1993; Jung et al., 2000).

Tree decline is a complex process, poorly understood, involving a combination of abiotic (environmental) and biotic (biological) factors. These factors contribute to reduced tree growth and vigor, damage to foliage and root systems, and ultimately, tree death. Variations in the intensity, duration, and frequency of dry periods are expected to impact forest ecosystems significantly. These changes may increase forests' vulnerability to attacks from biotic agents, such as pests and pathogens, while also influencing the forests' resilience to such threats. As trees experience stress from prolonged dry conditions, their defenses may weaken, making them more susceptible to infestations and diseases. Conversely, understanding these dynamics can help in developing strategies for enhancing forest health and resilience in the face of changing climates (Jactel et al., 2012). The Zagros oak forests also faced this phenomenon in the 2000s, with the first symptoms of this phenomenon observed in 2006 in the forests of Ilam, followed by reports in other provinces such as Kermanshah, Fars, Kohgiluyeh and Boyer-Ahmad, and Chaharmahal and Bakhtiari (Arefipour, 2009). Currently, more than one million hectares of Zagros forests are affected by this phenomenon (Pourhashemi et al., 2016). The symptoms of this phenomenon in oak trees appear as dieback in twigs, branches, and trunk, which ultimately leads to complete dieback and tree death with the onset of disease and pest attacks (Mirabolfathy et al., 2011). Oak dieback in the southern Zagros forests, particularly in the forests of Kohgiluyeh and Boyer-Ahmad province, has been reported intermittently over the past decade, raising concerns (Taghavipour et al., 2016). Several factors (sudden temperature changes, wildfires, pests and diseases, water scarcity, climate change**,** air and soil pollution, land use change, and uncontrolled deforestation) are involved in the occurrence of dieback. Some of these factors gradually prepare the conditions for this phenomenon to occur over many years, weakening the ecosystem and the oak trees.

After the trees are weakened, other factors trigger and initiate the phenomenon (Brasier, 1996; Thomas et al., 2002; Henareh et al., 2024). Overall, what causes tree death is a combination of factors, including abiotic factors such as drought, air temperature, soil, and biotic factors such as pests, diseases (Kim et al., 2017), and also human activities such as traditional harvesting of various parts of oak trees, livestock grazing, excessive consumption of water resources, land conversion, and understory plowing. The dieback phenomenon has affected almost all of the Zagros forest habitats with varying intensities. Forest dieback due to stress caused by climate change, in addition to physiological disorders, causes an increase in the occurrence of secondary complications, including pests, diseases, and fires (Ghanbary et al., 2017). Najafi Harsini et al. (2018) investigated the two-way relationship between the xylem vessels of Iranian oak trees and dieback disease. Their results showed that oaks with smaller vessels are more susceptible to dieback, and after being infected, reduced radial growth and continuous shrinking of the earlywood vessels create the necessary conditions for tree decline. Delfan et al. (2021), to understand the morphological adaptation of Iranian oak to oak decline, compared the leaves and fruits of healthy and declining Iranian oak from six populations in the Zagros forest of Iran. Fruits and leaves were sampled from five healthy trees and five declining trees from each population. Healthy Iranian oaks from five out of six populations had larger leaves with more lamina area compared to declining stands. Moreover, the trend was the same in all six populations. The leaves of declining oaks also had degenerated trichomes. Additionally, declining Iranian oaks had smaller fruit. The effect of oak dieback on the morphology of Iranian oak varied greatly among the six populations and limited leaf and fruit size. Leaves and fruits in declining Iranian oak were smaller and had degenerated trichomes. Tulik and Bijak (2016) examined the radial growth and anatomical characteristics of the wood of oak trees (*Quercus robur*) with different health statuses, as well as their response to climatic conditions in Poland. According to the results, radial increase and anatomical parameters for healthy oaks were significantly higher than those for weak and declining trees.

The width of tree rings had less dependence on climatic factors compared to anatomical features. No clear pattern of relationship between oak radial growth and climatic factors was found regarding the health status of the tree. The results showed that drought has a weak effect on the process of oak decline in the habitats studied in Poland. Haidari et al. (2023a) Investigating the oak trees' dieback in the northern and southern aspects of Baneh forests, Iran. The results showed that the number of healthy trees in the Saraki and Belveh sites decreased by 25 and 28 trees, respectively, from 2019 to 2022; in contrast, the number of dieback trees increased by 14 and 19 trees, respectively, and the intensity of oak decline was greater in the Belveh site (southern dieback stands) than in Saraki (northern dieback stands). In general, the decline rate in the southern stands was higher than that in the northern stands, and the highest oak decline was observed in the southern slope.

This research aims to investigate and monitor the four-year changes in the oak decline phenomenon, leaf biomass, and leaf area, categorized into four different dieback classes, within the Dehbar Aftab.

Material and methods

The Dehbar Aftab area is located 15 kilometers northwest of Yasouj (Iran country), the capital of Kohgiluyeh and Boyer-Ahmad Province. It is situated at a geographical position of 51 degrees and 31 minutes longitude and 30 degrees and 45 minutes latitude. The average elevation above sea level is 2030 meters, the total annual precipitation is 653 millimeters, and the average monthly temperature is 14.8 degrees Celsius. In one hectare with dimensions (100 × 100 meters), 100 trees or groups of shoots were numbered in a floating manner (Haidari et al., 2023; Askari et al., 2024), and their geographical location, growth site, and quantitative and qualitative characteristics were recorded. 100 trees were selectively numbered to categorize them into 4 classes of dieback. The quantitative characteristics of high forest trees form growth of *Quercus brantii* (Persian oak) included diameter at breast height, height, and two perpendicular diameters of the crown, while for the coppice bases, it included the number of shoots in the group, the diameter of the thickest shoot, and the total height of the shoot group (the height of the tallest shoot), which were noted at the beginning of the project (fig 1).

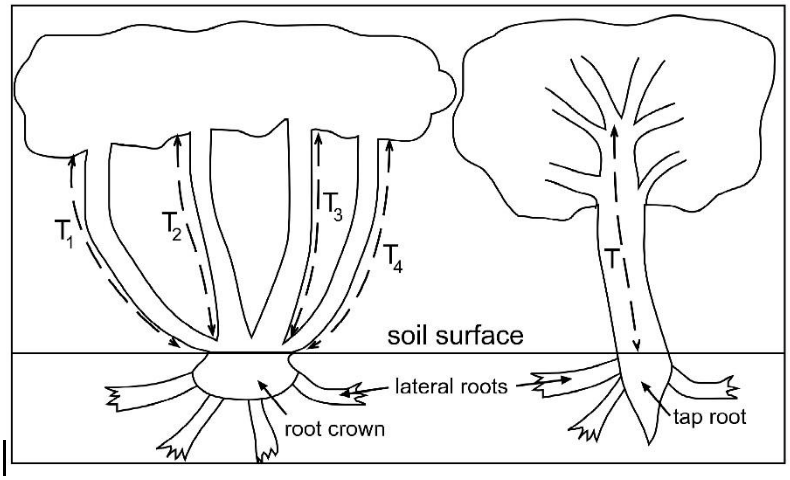

Figure 1. Differences between the two growth forms of Persian oak. Having several shoots or trunks (T1–T4 in this case) and existence of a major root crown are the characteristic features of a coppice tree (left), and standing on a single trunk (T) as well as a prominent tap root are associated with a high-forest tree

The qualitative characteristics included the condition of drying and decline of the trees at four levels (Fig 2): 1- Healthy and vigorous trees (without any signs of drying), 2- Trees with crown dieback, 3- Trees with crown drying (less than 50%), and 4- Trees with crown drying (more than 50%) (Henareh et al., 2024). This was recorded annually from the start of the project until its completion, and at the end of each growing season (October), the presence or absence of the numbered trees, their qualitative condition, and their classification in the decline categories were documented in the relevant forms. Considering the change in leaf size in the stages of decline, each year, 20 leaves (5 leaves from each direction of the crown) were selected from five fixed and numbered trees in each decline category; healthy, with crown dieback, with less than 50% crown drying, and with more than 50% crown drying (Henareh et al., 2024). The leaf area was measured and recorded separately in the laboratory. The leaves were taken from the middle branch of each direction of the crown and included the fourth to eighth leaves of the selected branch. Additionally, from the same bases, 25 seeds were collected from each direction of the crown, and the dimensions of the seeds, seed cups, seed weights, and the weight of 100 seeds were determined. These measurements were repeated and monitored throughout the project duration.

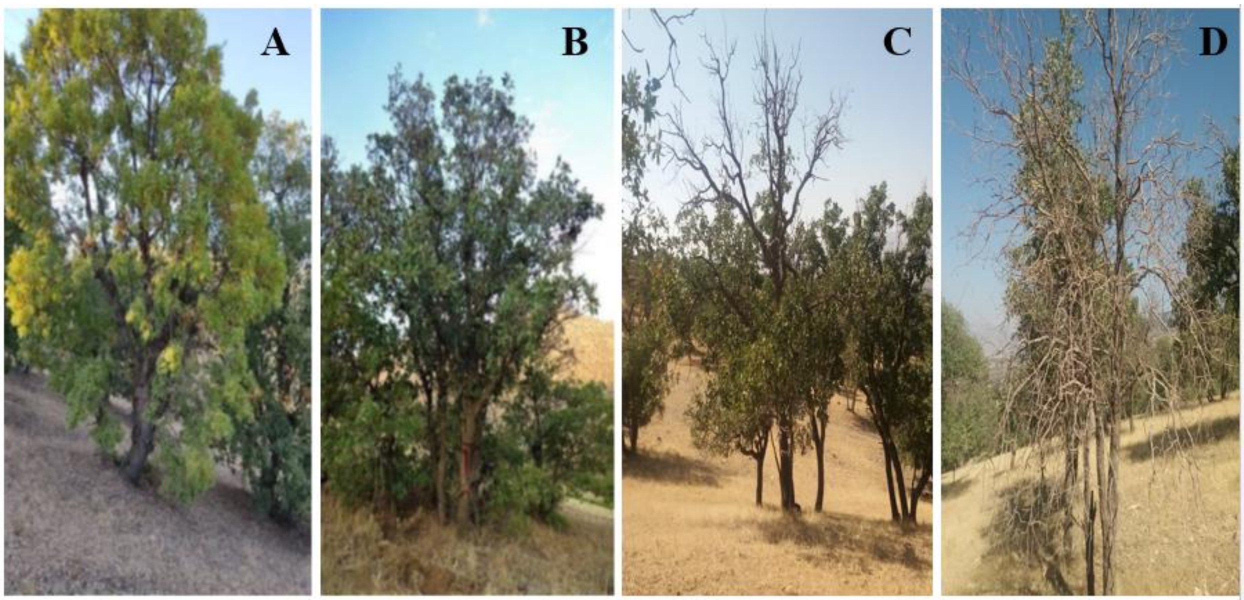

Figure 2. Sample of the healthy tree (A), the tree with crown dieback (B), the tree with crown drying less than 50% (C), and a tree with crown drying more than 50% (D) of the Persian oak species

All collected data were organized in Excel software, and the relevant charts were also prepared in this software. If statistical analysis was needed, ANOVA tests were used while adhering to the assumptions, and mean comparisons were conducted using Duncan's multiple range test.

Results

The quantitative parameters measured for oak trees in each sample plot are presented in Table 1. Generally, in each sample plot, the majority of trees were in a coppice form, while the number of High-forest or single-stem bases was always lower. According to the results from 100 studied trees, about 38% of the trees had a coppice form, and 62% were high forest or single-stem. On average, the multi-stem Iranian oaks in this area had 2 to 6 shoots in each shoot group. The highest number of shoots in each shoot group was observed in the control sample plots (Table 1).

Table 1: Results of some measured parameters in a forest stand

Descriptive statistics	**Dehbar Aftab**
Number of Coppice	38
Number of High forest	62
Mean of DBH (cm)	37.6±16.2
Mean Height (m)	9.73±2.9
Mean of sprouts diameter (cm)	22.3±6.1
Mean of Crown area (m^2)	68.4±44.0

Condition of Drying

In the first year, about 65% of the trees exhibited crown dieback classes. In contrast, only 4% of the trees were healthy and free from signs of decline. Additionally, 20% of the trees had less than 50% drying, and 8% had more than 50% drying and were completely dead. An examination of the trees by growth origin showed that a significant portion of the coppice trees experienced crown drying with less than 50% severity, while the highest frequency of drying in the shoots was observed in the coppice form (Fig 3). Specifically, 71% of the coppice bases had crown dieback compared to 60% of the high forest. In the first year, in the sample plot, only one case of a completely dead high forest tree was observed, and no cases were noted in the coppice form.

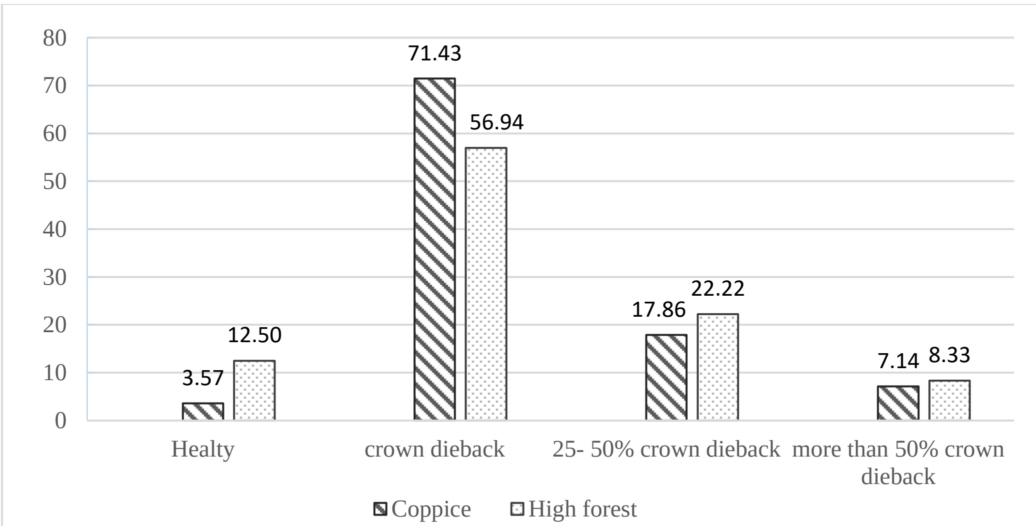

Figure 3. Percentage frequency of drying severity in the plot, categorized by coppice and high forest bases in the first year (2019)

This report describes the results of a second-year monitoring effort in 2020 (1399) focused on tree decline (Fig. 4):

- **Overall Decline:** Similar to the first year, approximately 65% of trees showed crown dieback. Less than 4% were healthy. 23% showed less than 50% dieback, and 7% showed more than 50% dieback or were completely dried.
- **Origin Differences:** Branched trees showed a higher percentage of crown dieback (75%) compared to high forest form (54%). The most frequent type of dieback in coppice trees affected the tips of branches (terminal branches).
- **Southern Slope:** Only one completely dried single-stem tree was observed on the southern slope in the second year, and none were observed in branched trees.

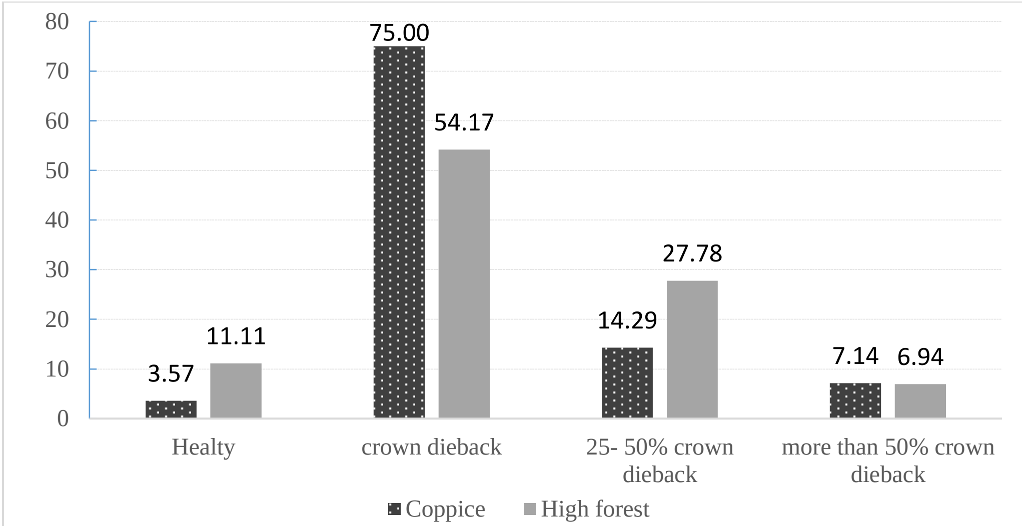

Figure 4. Percentage frequency of drying severity in the plot, categorized by coppice and high forest bases in the second year (2020)

In the third year of monitoring, changes were observed in the tree decline trend compared to the previous two years. Similar to the first two years, approximately 63% showed crown dieback. Conversely, more than 7% of the trees were healthy and free from signs of decline. Also, 14% of the trees had less than 50% dieback. However, unlike the monitoring of the previous two years, in the third year, the percentage of trees with more than 50% dieback and completely dried was zero. This suggests that, despite predictions and expectations, the vitality of the trees improved in 1400 or 2021 (presumably the year). Examination of trees based on their origin showed that a large portion of trees grown from branches experienced crown dieback with less than 50% severity, while, unlike the previous two years, dieback in the branches was most frequent in seedling trees (Fig 5). Specifically, 75% of seedling trees versus 73% of trees grown from branches showed crown dieback. In the first and second years, no trees were cut down in the study area, but in the third year, the cutting of an oak tree in the sample plot was recorded.

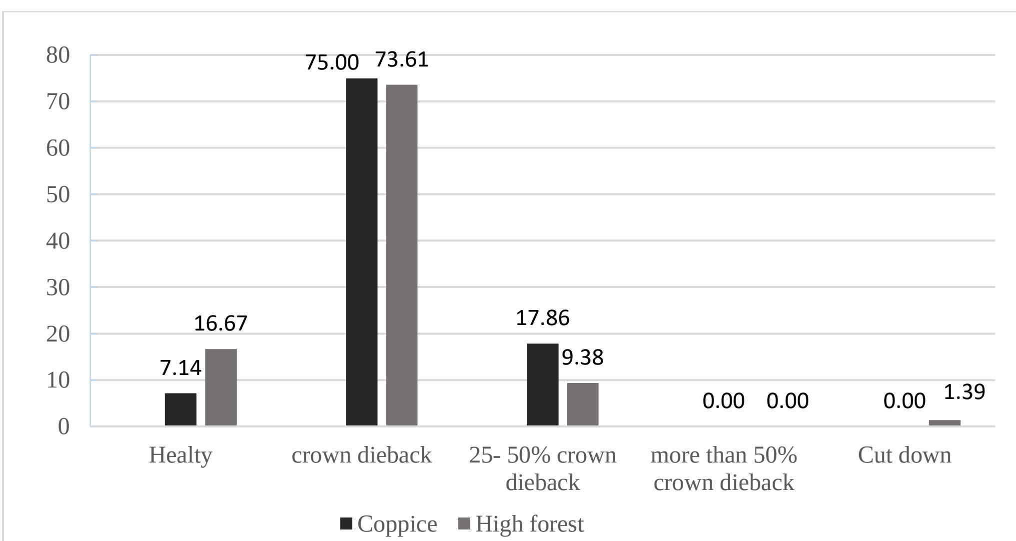

Figure 5. Percentage frequency of drying severity in the plot, categorized by coppice and high forest bases in the third year (2021)

The fourth year's (1401 or 2022) monitoring showed changes in the tree dieback trend compared to the previous three years. Unlike previous years, approximately 82% exhibited crown dieback. Conversely, more than 7% of the trees were healthy and free from signs of decline. Also, 11% of the trees showed less than 50% dieback. However, unlike the first two years, and similar to the third year's monitoring, the percentage of trees with more than 50% dieback and completely dried trees was zero. This suggests that the vitality of trees in this category is improving. In fact, trees from this category have been added to the crown dieback category. Examination of trees based on their origin showed that a large proportion of trees grown from branches experienced crown dieback with less than 50% severity, while unlike the previous three years, dieback in the branches was equal between seedling and branch-grown trees (Fig 6). In such a way that the share of each growth form in the crown dieback category was approximately 82%.

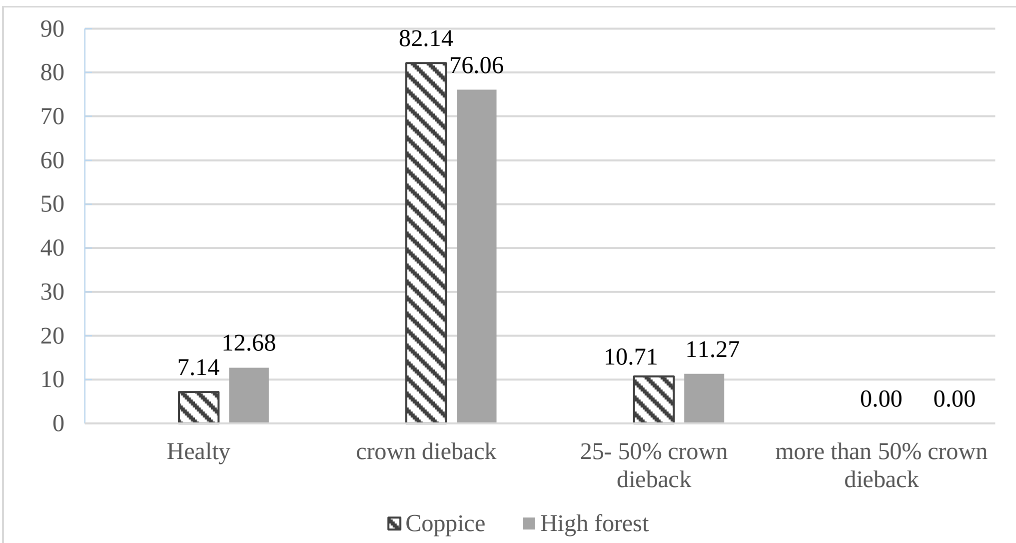

Figure 6. Percentage frequency of drying severity in the plot, categorized by coppice and high forest bases in the fourth year (2022)

Overall, among all the high forest trees evaluated, the dieback trend in the first and second years (2019-2020) showed an upward pattern, with a decrease in the healthy and crown-dieback classes and an increase in the higher classes, namely less than 50% dieback and more than 50% dieback (Fig 7). However, for the years 1400 and 1401 (2021-2022), the dieback trend in the higher classes has taken a downward turn.

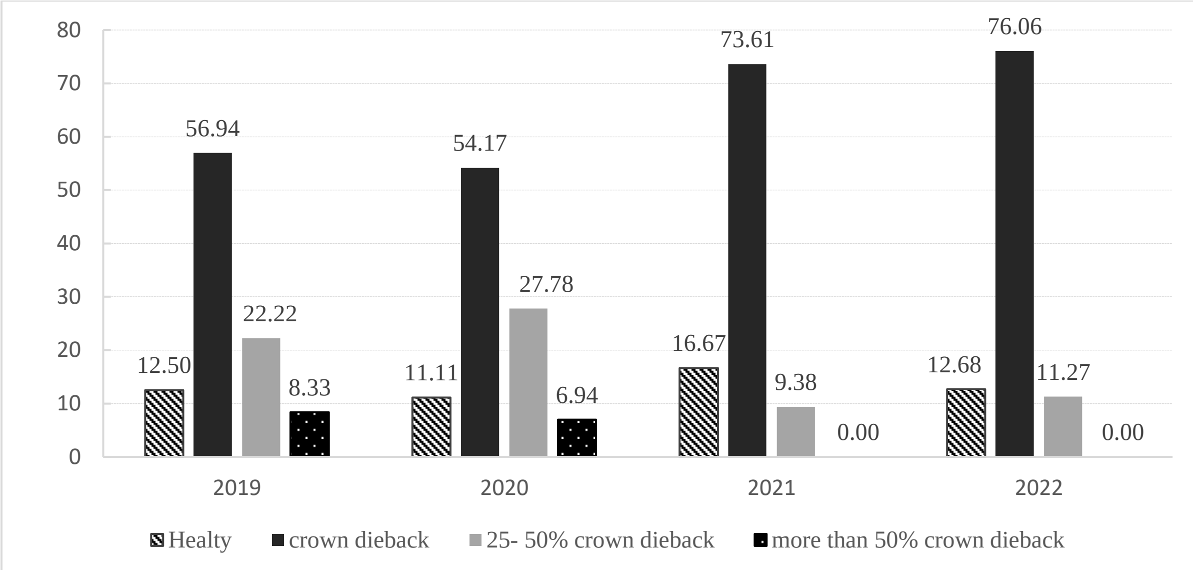

Figure 7. The percentage of drying classes of high-forest trees in the sample plot during the fourth year of monitoring

For the coppice form, a similar trend occurred with minor variations. Overall, the dieback trend in the first two years (1398-1399) showed an upward pattern, with a decrease in the healthy and crown-dieback classes and an increase in the higher classes, namely less than 50% dieback and more than 50% dieback (Fig. 8). However, for the years 2021 and 2022, the dieback trend in the higher classes has taken a downward turn.

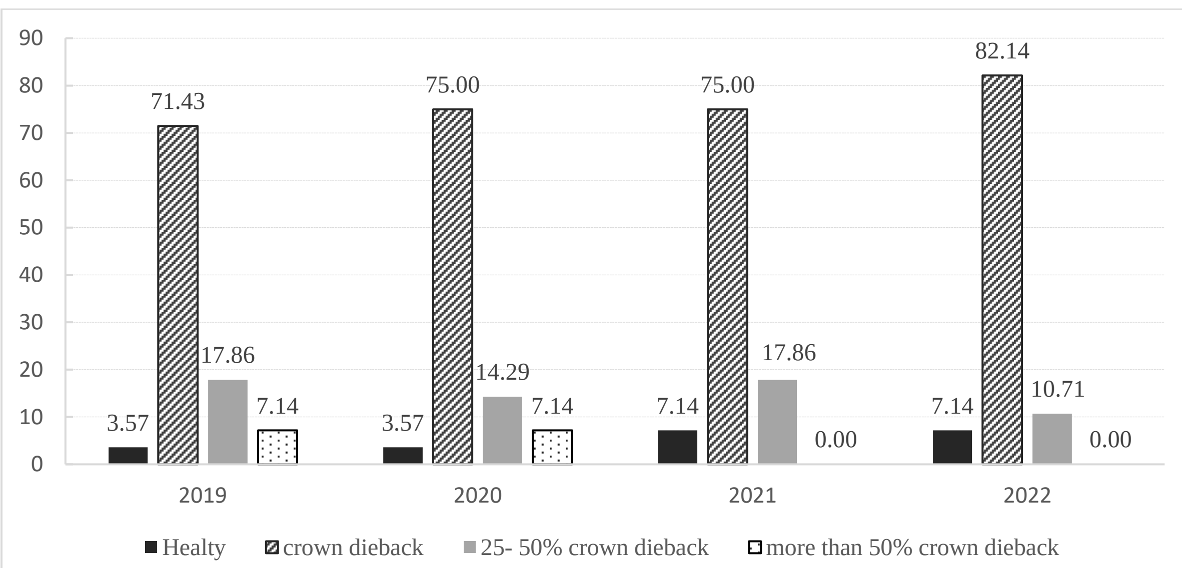

Figure 8. The percentage of drying classes of coppice trees in the sample plot during the fourth year of monitoring

Leaf Biomass

The average biomass of 20 leaves in different dryness classes was recorded and calculated over four years of sampling in this sample plot (southern slope degradation) (Table 2). According to the results obtained, there was a statistically significant difference between the biomass of different dryness classes. In the vast majority of sampling years, healthy trees (without signs of dryness) had the highest amount of biomass, while trees in the >50% dryness class had the lowest. There was no statistically significant difference in leaf biomass between different sampling years. The average biomass of 20 leaves in different years across different dryness classes ranged from 12 to 13 grams.

Table 2. The average biomass of 20 leaves according to the drying classes during four years of statistics

	1398 (2019)	1399 (2020)	1400 (2021)	1401 (2022)
Healthy	13.35±1.63	13.52±1.74	14.95±1.94	14.70±2.41
Crown dieback	13.71±1.45	13.25±1.25	13.63±1.04	13.24±1.76
25- 50% crown dieback	11.92±1.07	13.85±1.44	12.74±1.11	12.85±1.22
More than 50% crown dieback	9.55±1.12	9.81±0.85	10.22±1.27	9.74±0.78

Leaf Area

Among the different dryness classes, trees with crown dryness of less than 50% and greater than 50% had the lowest leaf area. In the first year, a statistically significant difference was observed between different classes of trees. Also, the leaf area of healthy and top-dried trees was greater compared to the rest of the trees (Table 3). In the second year, the average leaf area in different dryness classes was not significant. However, the results from the second year were significantly different from the first year. Trees with crown dryness of less than 50% had a greater leaf area compared to other classes (Table 3). In the third year, the differences in leaf area across different dryness classes became significant, such that the average leaf area decreased from the healthy class to the >50% dryness class. In other words, the healthy class had the highest leaf area, and the class with crown dryness greater than 50% had the lowest. In the fourth year, similar to the third year, the differences in leaf area across different dryness classes became significant, such that the average leaf area decreased from the healthy class to the >50% dryness class. In other words, the healthy class had the highest leaf area, and the class with crown dryness greater than 50% had the lowest.

Table3. The average leaf area of oak trees in different sample plots according to the drying classes during four years

	First year	**Second year**	**Third year**	**Fourth year**
Healthy	21.65 ± 1.24^{b}	22.44 ± 2.07^{a}	26.14 ± 2.91^{ab}	24.53 ± 2.27^{ab}
Crown dieback	22.36 ± 1.38^{ab}	22.01 ± 2.53^{a}	24.71 ± 2.83^{bc}	23.66 ± 2.13^{b}
25- 50% crown dieback	20.84 ± 1.63^{b}	24.55 ± 3.01^{a}	22.11 ± 2.34^{cd}	22.44 ± 1.94^{b}
More than 50% crown dieback	17.22 ± 1.06^{c}	20.13 ± 2.11^{a}	20.74 ± 1.96^{d}	18.55 ± 1.23^{c}

By examining the overall average leaf area without considering different degrees of dryness, in the vegetative forms of coppice and high forest and in different directions of the tree, it was observed that the average leaf area in trees with high forest growth form was greater than the coppice form, although no significant difference was observed between the two growth forms. However, in both growth forms, the leaf area was greater in the north direction of the tree compared to the other geographical directions of the tree (Fig 9).

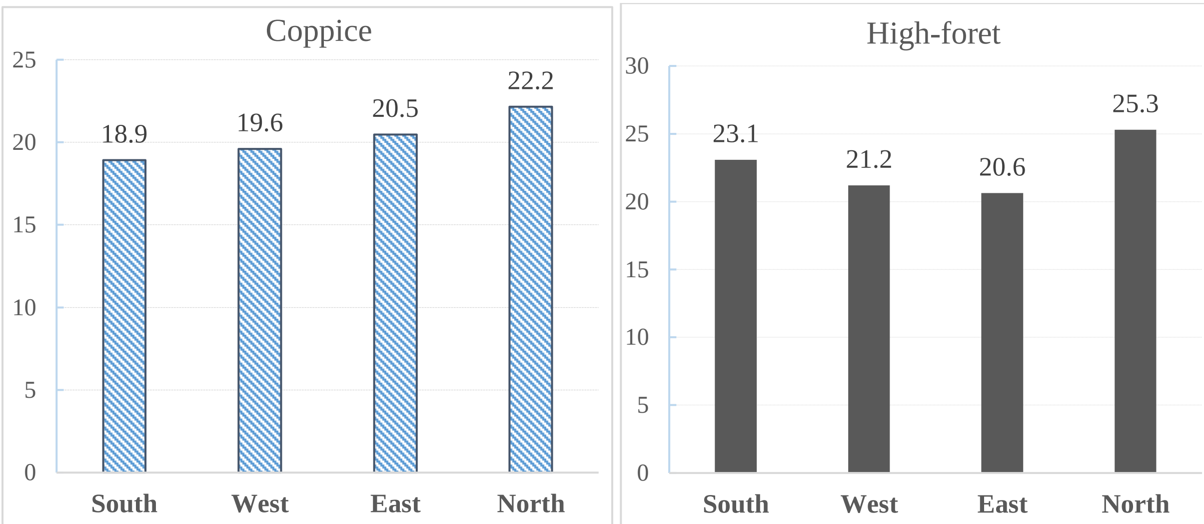

Figure 9. Changes in average leaf area in different aspects for the two vegetative forms

Discussion

This study examined oak tree dieback and decline in the Deh-e Bar Aftab forest, Kohgiluyeh and Boyer-Ahmad province, over four years (2019-2022). In the first year, 65% of trees showed crown dieback, while only 4% were healthy. Over 75% of saplings remained healthy, but 20% of trees had less than 50% dieback, and 8% had over 50% crown dieback or were completely dry. Analysis by tree origin revealed that sprout-origin trees were more affected, with 71% showing crown dieback (mostly under 50% severity) compared to 60% of high forest trees. Twig dieback was also more frequent in coppice trees (Figure 3). These findings highlight the vulnerability of coppice trees and the need for targeted management strategies. In this study, the percentage of dieback greater than 50% was significant on the southern slope. Previous studies have shown higher dieback severity on southern slopes compared to northern slopes due to lower moisture content (Suarez et al., 2004; Golmohammadi et al., 2017). As mentioned, examining trees by their origin showed that a large proportion of coppice trees had crown dieback with less than 50% severity, while dieback in the twigs was most frequent in coppice trees (Figure 4). Specifically, 71% of coppice trees had crown dieback compared to 60% of high forest trees. This may indicate a higher resistance potential in high forest or single-stem trees against environmental stresses. Consistent with the results of this research, higher percentages of dieback in coppice trees have been reported in several studies (Hamzehpour et al., 2011; Hosseini et al., 2014; Golmohammadi et al., 2017).

The average diameter of coppice trees was 22.3 cm, and for high forest trees, it was 37.6 cm, due to the dominance of high forest trees in the study area. The severity of dieback varied among different diameter classes. However, the percentage of dieback was higher in the larger diameter classes, which is consistent with the results of other researchers. Various studies have observed that the percentage of dieback increases in the higher diameter classes (Worrall et al., 2008; Mahdavi et al., 2015; Golmohammadi et al., 2017). Trees with dieback in the degraded sample plots had lower leaf area and leaf biomass compared to trees in the control sample plots. The lower rate of leaf area and biomass in plants under biotic and abiotic stresses is a common mechanism aimed at conserving more moisture and reducing energy expenditure (Corcobado et al., 2014; Ghanbary et al., 2017). By examining the overall average leaf area without considering different degrees of dieback in coppice and high forest vegetative forms, and in different directions of the tree, it was found that the average leaf area in trees with high forest form was greater than the coppice form, although no significant difference was observed between the two forms. However, in both growth forms, the leaf area was greater on the north side of the tree compared to other geographical directions. Examination of oak seed morphology showed that sample plots with decline had lower average weight, length, and diameter of seeds than control sample plots, and in fact, the seeds of trees with decline were smaller. Consistent with the results of this research, Delfan et al. (2021) reported that the size of oak seeds in declining trees was smaller than in healthy trees. In fact, it can be said that trees under stress conditions allocate their food reserves to maintenance, preservation, and defense functions, and survival and adaptability to stress are more important than reproduction (Breda et al., 2006). Therefore, oak trees with decline likely allocate more of their reserves to defense and adaptability functions, resulting in a smaller leaf area and the production of smaller seeds.

The study revealed that approximately 75% of all the studied trees showed effects of dieback, which indicates a worrying situation for the forests of this region. If this trend continues, it appears that we will witness the destruction of these forests in the near future. As expected, the amount of crown dieback greater than 50% was significant on the southern slope, and the degree of dieback was higher in thicker trees. It was also observed that trees with decline produce smaller fruits and have a smaller leaf area. In general the increase in dieback severity over time suggests a potential underlying stressor, which could be environmental factors such as prolonged drought, leading to water stress and increased vulnerability. Alternatively, biotic factors like insect infestations (e.g., defoliators) or fungal pathogens could be expanding, weakening the trees' defenses and accelerating dieback. Leaf area decreased with increasing dieback severity (healthy to dead). Seed-origin trees showed a higher average leaf area than sprout-origin trees, which might indicate that seed-origin trees are more resilient to the stressors affecting the stand, possibly due to deeper root systems or genetic advantages. A strong correlation was found between crown dieback and leaf size; trees with over 50% crown dieback had smaller leaves. This relationship suggests that reduced leaf area is a direct consequence of the dieback process, limiting the tree's ability to photosynthesize and further exacerbating its decline. The specific environmental and biotic factors involved in the decline should be further investigated to identify possible causes and develop targeted management strategies.

Conclusion

This study highlights a severe oak tree dieback (approximately 75%) in the Dehbar Aftab forest, posing a significant threat to the ecosystem's health and survival. Dieback is more pronounced on southern slopes due to lower moisture availability and is more prevalent in larger, mature trees. While high forest trees showed slightly larger leaf areas and seed sizes compared to coppice trees, these differences were not statistically significant. Leaf area was consistently larger on the northern side of trees, likely due to sun exposure and moisture gradients. Dieback-affected trees exhibited reduced leaf area and biomass, suggesting an adaptive response to water stress, with smaller seed sizes indicating a trade-off between reproduction and survival. Coppice trees experienced higher dieback rates than high forest trees, warranting further investigation into their resilience or micro-site conditions. The findings emphasize the need for urgent management strategies to address dieback, including identifying contributing factors (e.g., water stress, pests, disease), understanding physiological decline mechanisms, and developing targeted interventions. Spatial distribution patterns of dieback should guide management plans, with early interventions focusing on southern slopes and larger trees to prevent further losses. It is suggested that factors exacerbating dieback be managed, and human-caused disturbances and destruction in nature be controlled. By maintaining the current situation, there is hope for the restoration and regeneration of dieback-affected stands. On the other hand, seeds from healthy stands on the northern slope can be used for the restoration and expansion of the forest.

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