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A research note on developing a novel method for the estimation of annual volume increment in standing trees

Ein Vorschlag für eine neue Methode zur Schätzung von Jahresvolumenzuwachs an stehenden Bäumen

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Keywords: forest ecosystems, silviculture, forest measurement, tree growth

Schlüsselbegriffe: Waldökosysteme, Waldbau, Waldmesslehre, Baumwachstum

Abstract

Measuring tree growth rates is an important requirement in many scientific disciplines and forest production sector. The assessment of annual volume growth rates in standing living trees, under ambient field conditions without destroying the tree has so far only been conducted with model approaches or by repeated measurements of tree dimensions in the field. This research note proposes a novel simple non-destructive method for the estimation of annual volume increment in standing trees, based on tree ring analysis of sampling of the two increment cores for each targeted tree and simple trigonometry rules. The extracted data by the method application can be widely used in many forest disciplines, such as forest ecology, silviculture, and forest management.

Zusammenfassung

Die Messung der Baumwachstums ist in vielen wissenschaftlichen Disziplinen und im forstwirtschaftlichen Sektor eine wichtige Aufgabe. Die Bewertung der jährlichen Volumenwachstumsraten stehender lebender Bäume unter Feldbedingungen ohne

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Zerstörung des Baumes wurde bisher nur mit Modellansätzen oder durch wiederholte Messungen der Baumabmessungen im Feld durchgeführt. Hier zeigen wir eine neuartige, einfache, zerstörungsfreie Methode zur Schätzung des jährlichen Volumenzuwachses an stehenden Bäumen, die auf der Jahrringanalyse von zwei Zuwachskernen pro Baum und einfachen Trigonometrieregeln basiert. Die mittels dieser Methoden gesammelten Daten könnten in vielen Forstdisziplinen wie Waldökologie, Waldbau und Waldbewirtschaftung verfügbare Datenquellen ergänzen.

1 Introduction

Forest tree growth is a complicated biological process depending on the species, as well as on the environmental and ecological conditions (Bowman et al. 2013), tree individual competition, stand tending, *etc.*, and varies annually with climate fluctuations (Duchesne *et al.* 2012). Knowledge on tree growth rates over time is a key basic parameter for population dynamics, species interactions and forest science *e.g.* forest ecology, silviculture, forest management, (Pacala *et al.* 1993; Foster *et al.* 2016; Toochi 2018; Woo *et al.* 2020). Stem volume estimation is commonly based on the measurements of tree diameter and height, two variables that can be easily measured in the field. On the contrary, the assessment of annual volume increment of standing trees is extremely difficult to acquire in the field. Even though diameter annual increment can be accurately measured with the core sampling procedure, and annual ring-analysis, the annual tree height increment is challenging or even impossible (Ganatsas *et al.* 2023). Some efforts to correlate the tree annual height increment with the rate of diameter increment (*e.g.*, Meixner 1978) are generally not widely accepted, since it is no consistent relationship between tree diameter increment and height increment (Hasenauer 2006). For tree volume increment under ambient conditions two basic methods exist:

i) analytical tree measurements after tree felling, and,
ii) repeated diameter and height measurements on standing trees in the field (Hasenauer and Monserud 1997).

The first method concerns the known stem analysis method of the felled trees, which is the most accurate method, but it is a destructive method for the trees, and very time-consuming and expensive method (Dyer and Bailey 1987; Fabbio *et al.* 1994; Hasenauer and Monserud 1997; Kariuki 2002), and thus, it cannot be widely applied. Other methods that have been suggested for the estimation of annual tree volume growth, based on model approaches (Hasenauer 2006; Clark *et al.* 2007), even though they are commonly used, generally contain great uncertainties. This study develops and suggests a new simple and non-destructive method for a reliable estimation of stem volume annual increment in standing trees, in the field. The method is based on the tree annual ring-analysis from two increment cores taken for each targeted tree, and basic rules of trigonometry.

2 Material and methods

The execution of the method requires few common forestry scientific equipment, which is usually available in a forestry scientific laboratory: Tree hypsometer, common tape, Pressler's increment borer or similar equipment, Stereomicroscope or an Image analysis system (*e.g.*, WinDENDRO). The estimation of the annual volume increment of a standing tree is performed in five steps, that are described below. However, it can be noted that the method, in fact, consists of an expansion and integration of the method developed by Ganatsas *et al.* (2023) for the estimation of tree height annual increment, and is based on the classical geometry approach that the tree trunk shape (in surface projection) is a triangle (Domke *et al.* 2013). At the first step, a sampling of two increment cores is performed according to Ganatsas *et al.* (2023) (Figure 1). The second step includes the measurements of the two sampling increment cores in the lab.

Then, at the third stage, the tree rings for both cores are dated, and pair the two radiuses corresponding to the same year (*e.g.*, last year, the year before, *etc.*) at the two sampling height points. The differences between the tree radiuses at the two sampling heights (0.5 and 2.0 m) are computed for each year, *e.g.*, AB for the last year *t*, A1B1 for the year before t_{-1}, etc. (Figure 1) (values in meters). By considering the triangle created by the distance between the two sampling points of the tree trunk (1.5 m) as one vertical side (distance BC in Figure 1) of the orthogonal triangle ABC and the difference between the paired tree radiuses (corresponding to the same year) as the second horizontal side of the triangle (distance AB (in m) for the current tree height), we compute the angle ($\boldsymbol{\alpha}$) of the triangle, using the typical formula, $\boldsymbol{\alpha}$ equals to opposite side of a triangle divided by the adjacent side, which in our case, for a year *t* corresponds to:

$$\boldsymbol{\alpha} = 1.5/(RAD - RCE) \qquad (1)$$

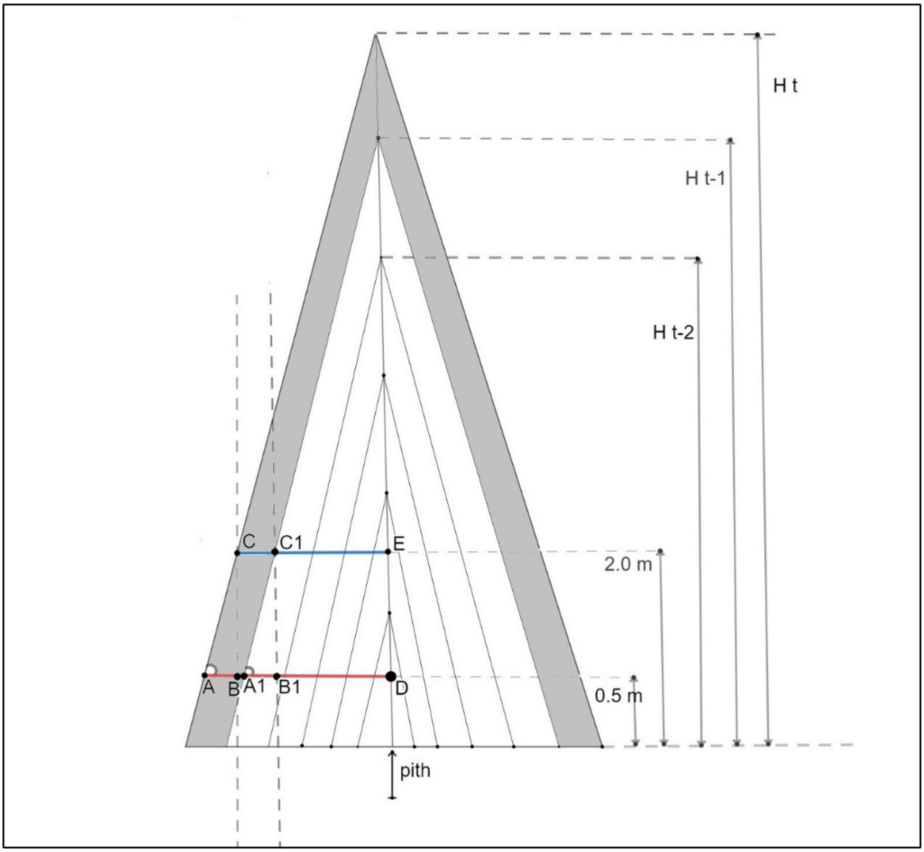

Figure 1: Tree stem simulation showing the procedure of sampling the two increment cores at two different tree trunk heights (0.5 and 2.0 m). Red line AD shows the tree radius at 0.5 m (RAD), Blue line CE shows the tree radius at 2.0 m (RCE). H_t = current tree height, H_{t-1} = tree height at one year before, etc. Shaded area indicates the stem volume increment (in two dimensions) for the current year.

Abbildung 1: Schematische Darstellung eines Baumes mit zwei Zuwachsbohrkerne entnommen an zwei Positionen (0.5 und 2.0 m). Rote Linie AD zeigt den Baumradius in 0.5 m Höhe (RAD), blaue Line den Radius in 2.0 m Höhe (RCE). H_t = aktuelle Baumhöhe, H_{t-1} = Baumhöhe ein Jahr zuvor. Schraffierte Fläche zeigt den Volumenzuwachs (in zwei Dimensionen) für das aktuelle Jahr.

Based on the equation (1), the size of ***α*** is computed. Then, based on the size of ***α***, we compute the total tree height, as the opposite side of the triangle formed by the total dimensions of the tree, named total height for the year *t* (in m), as vertical side (H_t in the Figure 2), and total tree radius at 0.5 m (RAD, in m), as horizontal side. Thus, the total tree height in *t* time (H_t in m) equals to total tree radius (in m) at the point 0.5m multiplied by ***α***, plus 0.5:

$H_t = (RAD \times \alpha) + 0.5$ (2)

For avoiding any decline in the estimation of total tree height, we simultaneously measure the total tree height by a common tree hypsometer, and we check if any correction (- or +) is required in the current method, in relation to the real total tree height.

Current volume calculation is performed at the fourth stage. Generally, tree trunk treated as paraboloid, cylinder or conoid (Cruz de León 2010; Kushwaha *et al.* 2021). Thus, based on the radius *RAD* and the estimated H_t form the equation (2), we compute the current tree volume at year *t* using the general equation for the cone volume (in m^3) (both parameters' values in the equation are in m):

Current tree volume $V_t = 1/3 \times H_t \times \pi \times RAD^2$ (3)

The same procedure is followed for the next inner annual ring pairs, corresponding to the previous years, towards the interior (pith) of the two increment cores, computing the angles at years t_{-1}, t_{-2} … t_{-n}. Tree height estimation at each year is estimated with the same way as the equation (2) as tree height of the year t_{-1} (H_{t-1}) equals to tree radius at the year t_{-1} multiplied by $\alpha 1$ (at the year t_{-1}) plus 0.5:

$H_{t-1} = (RA1D \times \alpha 1) + 0.5$ (4)

Thus, similarly to equation (3), tree volume one year before is:

$V_{t-1} = 1/3 \times H_{t-1} \times \pi \times RA1D^2$ (5)

At the fifth stage, the Annual Tree Volume Increment (ATVI) for the last year is computed as follows (in m^3):

$ATVI_t = V_t - V_{t-1}$ (6)

which is indicating by the shaded area (in two dimensions) in Figure 1.

Similarly, the annual tree volume increment for the year before (ATVI t-1) is (in m^3):

$ATVI_{t-1} = V_{t-1} - V_{t-2}$ (7)

Following the same procedure for each paired of annual rings (last year, the previous year *etc*.), we reconstruct the whole tree development during its life, similarly to the results extracted by the complete stem analysis method, without destroying the tree. The two sampling points at tree trunk heights of 0.5 m and 2.0 m are suggested because at these two heights the core sampling is feasible for a human from the ground. If there are opportunities and appropriate facilities, this distance (1.5 m) can be modified as suggested by Ganatsas *et al.* (2023). In that case, the equation that gives the value for $\boldsymbol{\alpha}$ takes the form:

$$\alpha = X / (R_{t-1} - R_{t-2}) \qquad (8)$$

where X is the distance (in m) between the two sampling points at year t_{-1} and t_{-2}, and R_{t-1}, R_{t-2} are tree radiuses (in m) from the two sampling points respectively.

3 Limitations of the method

This method assumes that:

i) the tree volume of standing trees can be estimated using the cone basic equation, and

ii) the tree diameter's reduction rate with height is relatively uniform throughout the tree life span.

Field testing for the method validation for different tree species would help to provide additional evidence of the accuracy and reliability of the method.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Importance of tree species composition and forest structure on recreational use – a case study for mountain forests in Upper Styria

Die Bedeutung von Baumartenzusammensetzung und der Waldstruktur für die Erholungsnutzung – eine Fallstudie für Bergwälder in der Obersteiermark

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Keywords: tree species composition, forest condition, silviculture, recreational function, climate change

Schlüsselbegriffe: Baumartenzusammensetzung, Waldzustand, Waldbau, Erholungsfunktion, Klimawandel

Abstract

The development of rural tourism is closely linked to the recreational function of the forest and the provision of forest services for recreational purposes. Due to the high share of forest cover (about 50 %), Austria features a large number of such "natural" recreational areas. In rural and urban regions forests are regularly utilized for tourist activities such as hiking or mountain biking. Recreational and landscape-based tourism in forests has become more attractive in Austria, as in many other parts of Europe. Aesthetically pleasing, adaptable and functional forests and landscapes are increasingly attracting tourism. An example of a region rich in forests with different tree species is the district of Murau in Styria, Austria. In this area, there was an ongoing project to promote more Larch (*Larix decidua*) more strongly in mixed stand in order to investigate

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i) how the forest in its diversity could be placed increasingly at the centre of tourism considerations,
ii) what recreation seekers think about the "tourism product" forest in general and
iii) which silvicultural strategies and measures are necessary for this.

Therefore, a quantitative survey was carried out in various hiking areas of the region using a standardized questionnaire. The survey took both tourism and forestry aspects into account. Of particular interest was the question 'What influence does the tree species composition and forest condition have on the recreational function?' The results confirm that open mixed stands are very attractive for recreationists. Respondents use the forest for low-intensity recreational activities such as hiking and recreation. The forest is characterised as quiet, slowly relaxing and can be used for fun, play and exercise.

Zusammenfassung

Die Entwicklung des ländlichen Tourismus ist eng mit der Erholungsfunktion des Waldes und der Bereitstellung von forstlichen Leistungen für Erholungszwecke verbunden. Aufgrund des hohen Waldanteils (ca. 50 %) gibt es in Österreich eine große Anzahl solcher "natürlichen" Erholungsgebiete. In ländlichen und städtischen Regionen werden die Wälder regelmäßig für touristische Aktivitäten wie Wandern oder Mountainbiking genutzt. Der Erholungs- und Landschaftstourismus im Wald hat in Österreich, wie auch in vielen anderen Teilen Europas, an Attraktivität gewonnen. Ästhetisch ansprechende, anpassungsfähige und funktionale Wälder und Landschaften ziehen zunehmend den Tourismus an. Ein Beispiel für eine Region, die reich an Wäldern mit verschiedenen Baumarten ist, ist der Bezirk Murau in der Steiermark, Österreich. In diesem Gebiet gab es ein laufendes Projekt zur stärkeren Förderung der Lärche (*Larix decidua*) in Mischbeständen, um zu untersuchen,

i) wie der Wald in seiner Vielfalt verstärkt in den Mittelpunkt touristischer Überlegungen gerückt werden kann,
ii) was Erholungssuchende über das "Tourismusprodukt" Wald im Allgemeinen denken und
iii) welche waldbaulichen Strategien und Maßnahmen dafür notwendig sind.

Dazu wurde eine quantitative Befragung in verschiedenen Wandergebieten der Region mittels eines standardisierten Fragebogens durchgeführt. Die Befragung berücksichtigte sowohl touristische als auch forstwirtschaftliche Aspekte. Von besonderem Interesse war die Frage 'Welchen Einfluss hat die Baumartenzusammensetzung und der Waldzustand auf die Erholungsfunktion?' Die Ergebnisse bestätigen, dass offene Mischbeständen für Erholungssuchende sehr attraktiv sind. Die Befragten nutzen den Wald für Freizeitaktivitäten mit geringer Intensität wie z. B. Wandern und Erholung. Der Wald wird als ruhig, langsam entspannend charakterisiert und kann für Spaß, Spiel und Bewegung genutzt werden.

1 Introduction

Forests in all their variations have always been used and valued by people in many ways. On the one hand, they provide important resources (timber), fulfil a protective function and are a source of income (Stoltenberg, 2009). On the other hand, Austrian forests are considered as 'open access attractions' by law (everyone is allowed to enter private and public forests for recreational purposes (§ 33 ff ForstG). As a consequence, the range of activities undertaken in forests is broad (Elands & van Marwijk, 2012), which is a challenge for the management of the forests (Oliveira *et al.*, 2015). The forest as an ecosystem can be described as an essential basis of life for humans ("At the Human-Forest Interface", 2018; Endreny *et al.*, 2017). The forest has many different functions and services to fulfil, and sustainable management is of great importance for the sustainable development of rural regions. In addition to the ecological and economic benefits of sustainable forest management, the social and cultural benefits are increasingly gaining value for people (Johann, 2004). From the perspective of social science forest research there is a two-way interaction with forest ecosystems conditions and people activities. Firstly, the direct effects of human activities that cause disturbance and maintenance and affect forest ecosystem processes and functions, and secondly, the ecosystem services that the forest provides for human well-being. These have the reverse effect, linking people's socio-economic conditions to forest ecosystem processes and functions (Ali, 2023).

About 48% of Austria's federal territory is covered by forests, which includes numerous natural and recreational areas (Russ, 2019). Forests in general offer ideal space for recreation and relaxation and therefore contribute to human health (Ezebilo *et al.*, 2015; Grieshofer *et al.*, 2011). According to Kulczyk *et al.* (2014), recreation is an important contributor to human well-being and an increasing number of people are spending their recreational time in forests (Burgin & Hardiman, 2012; Elands & van Marwijk, 2012). Forests are not only preferred areas for recreational purposes and related outdoor activities (Oliveira *et al.*, 2015) they are of significant importance for numerous tourist offers (Breman *et al.*, 2010) and human well-being (Füger *et al.*, 2021).

The range of possible recreational activities in forests is broad. These activities have changed from predominantly non-intensive ones, such as walking, relaxation or enjoying nature, to more intensive ones such as skiing or mountain biking (Burgin & Hardiman, 2012; Wilkes-Allemann *et al.*, 2017). The recreational function of forests not only benefits the local population but is also strongly demanded by tourists. Both winter and summer visitors appreciate Austria especially due to its numerous and varied natural areas (Arnberger *et al.*, 2016). Recreational and landscape-based tourism in forests has become more attractive not only in Austria but in many parts of Europe (Bell *et al.*, 2009; Mann *et al.*, 2010).

Another important aspect to be considered in this discussion is the high aesthetical value of forests for recreational purposes. The aesthetics of a landscape are important from a tourism point of view because it influences the visitor experience and whether and how often people come back (Sheppard & Picard, 2006). Many studies deal with the aesthetics of mountain and agricultural regions and how they are beneficial for tourism purposes (Grunewald & Bastian, 2015; Liu *et al.*, 2023; Othman *et al.*, 2015; Schirpke *et al.*, 2013, 2016). At the same time, there are studies with a focus on forest aesthetics and their importance for the tourism sector (Kohsaka & Flitner, 2004; Ribe, 1989). Some studies are concerned with the forest scenery itself and its effect on visitors (Jensen, 1999; Oku & Fukamachi, 2006; Petucco *et al.*, 2018; Shelby *et al.*, 2005). Some studies have analysed the influence of the structure of the forest on the aesthetics and attractiveness of the forest and whether these differences are important for recreational purposes (Carvalho-Ribeiro & Lovett, 2011; Füger *et al.*, 2021; Gundersen & Frivold, 2008).

In contrast to this, the intensive usage of forests for recreational purposes can quickly become a burden due to various conflicting interests. The forest itself and wildlife are subject to ecological pressure by an increasing number of visitors. Locals and tourists who use the forests for recreational purposes are being confronted with an increasing number of people and might not find the recreational value they are looking for. According to Breman´s *et al.* (2010) an increase in conflicts among different user groups, such as hikers, cyclists, horse-riders or hunters can be observed. In addition, the owners of the forests are often faced with a lack of economic benefits from tourists and other forest visitors (Górriz-Mifsud *et al.*, 2017).

As a consequence, the increasing exploitation of forests in general and the use of forests for recreational purposes in particular, must be brought into a sustainable balance (Pröbstl & Wirth, 2011). To avoid, or at least decrease the amount of possible conflicts, it is important to acknowledge recreational functions in forest management (Ezebilo *et al.*, 2015). Especially in hunting areas and forests that are used intensively for wood production, forest recreation infrastructure should be managed properly (Wilkes-Allemann *et al.*, 2017). Conflicts arise when recreation seekers leave marked footpaths and roads (Breman *et al.*, 2010). Although forests and forest roads are used for recreational purposes, forest owners are only responsible for the conservation of forests and not for the maintenance or provision of such recreational infrastructure (Wilkes-Allemann & Ludvig, 2019).

Other variables such as the degree of "naturalness" of a forest or the environmental quality of a forest are important factors for people to enjoy spending time in the forest, but it also increases the biodiversity of the forest (Bernasconi & Schrott, 2008; Lapin *et al.*, 2021). The percentage of old trees and the presence of natural parks or protected areas in a forest are positively linked to the willingness to pay of tourists and visitors (Bartczak *et al.*, 2008; Scarpa *et al.*, 2000).

At the same time, in recent years many forest owners have decided to move from intensive forest use to multifunctional forest management, which supports the above-mentioned increasing demand among visitors and tourists for 'naturalness'. The backgrounds for these changes in management are different. On the one hand, climate change will alter the tree species composition in the forest in the coming decades and this will result in new forest patterns (Allgaier Leuch *et al.*, 2017; Reif *et al.*, 2010; Wissenschaftlicher Beirat für Waldpolitik, 2021). A possibility to counteract this with foresight is to rely on site-appropriate tree species composition, natural regeneration and different forest structures. (Allgaier Leuch *et al.*, 2017; Wissenschaftlicher Beirat für Waldpolitik, 2021). And furthermore on the other hand increasing number of forest owners are realizing that the shift from pure stocks to mixed forests has many advantages (Grilli *et al.*, 2016). Mixed forests have a lower financial risk than pure stocks (Knoke *et al.*, 2008).

The advantages of mixed forests are both higher growth rates (Piotto, 2008) and more valuable forests in terms of habitats and biodiversity (Grilli *et al.*, 2016; Liang *et al.*, 2016). Liang *et al.*, (2016) show in their study that mixed stands have higher timber growth and are more productive than pure stocks. Mixed forests represent a higher recreational value for tourists (Grilli, 2014), although the forest itself, for example certain tree species, is often not of primary interest for visitors. It serves rather as background scenery for recreational activities such as hiking, mountain biking or other sports (Petucco *et al.*, 2018). Furthermore, forest visitors appreciate the peace and quiet, the good air and the calming environment of the forest (Bernasconi & Schrott, 2008). In other words, the forest becomes a framework for tourist activities, but it is important to note that tourists are primarily interested in the forest as a place of recreation and do not view the forest from a forestry perspective.

In forest management, based on site-ecological conditions, economic aspects are in the foreground. Economic considerations are often of higher importance than the aesthetic value of forests, which is, however, often decisive for a visit to the forest (Stölb, 2012). According to a study by Othman *et al.* (2015), an aesthetically attractive, flexible and functional landscape motivates people to visit it. A wide range of aesthetic landscape elements define an area as "relaxing" (Othman *et al.*, 2015). As an example, larch meadows are an important aesthetic element of forest-landscapes. Due to their high aesthetic quality, larch meadows are of great importance for recreation and tourism (Norz, 2014; Sailer *et al.*, 2017). One example are the Larch-forests in Vinschgau, which characterise the region in terms of landscape aesthetics and cultural history (Delvai, 2015).

Another example of a densely wooded region is the Holzwelt Murau with a forest coverage of about 70%. The dominating tree species are spruce (*Picea abies*), larch (*Larix decidua*), and swiss stone pine (*Pinus cembra*), with larch accounting for about 19% of the area. The current silvicultural management recommendations forecast an increase of larch proportion in mixed stands up to 30% (Langmaier *et al.*, 2019). This can be considered a significant change regarding the share of larch and subsequently constitutes a change of tree and structural diversity. Consequently, it is of particular interest how this change on stand and landscape level will be evaluated by tourists.

The existing and current literature shows that the state of knowledge on the relationship between forest structures and tree species composition and the interests of recreationists is still unsatisfactory, especially for spruce-larch mixed forests in the Inner Alpine Forests. This work was designed to improve the state of knowledge.The objectives of this paper are to investigate

i) how the forest in its diversity could be placed increasingly at the centre of tourism considerations and
ii) what guests think about the "tourism product" forest in general and
iii) which silvicultural strategies and measures are necessary for this.

These considerations led to the following research question: What influence does the tree species composition and forest condition have on the recreational function?

And derived from this, the following hypothesis can be made: The tree species composition is not relevant for the recreational function. Society perceives the forest only as part of nature.

2 Research and conceptual framework

This study was conducted as part of a research project in the Holzwelt Region Murau. The research project itself dealt with various aspects of forest management in this region. After the windthrow calamities of 2007/2008 (hurricane Kyrill and storms Emma and Paula), a higher proportion of larch was planted with the aim of mitigating the risks in mixed larch stands for the next decades. For this purpose, it was discussed what influence the increasing larch proportion in the stands and in the regions will have on the restoration targets. t aimed at how the share of the mixed tree species larch can be promoted. Furthermore, different aspects of biodiversity, seed production and recreation aspects in the forest were surveyed. The research project focused on a variety of objectives. These included the preservation and promotion of mixed stands of spruce, larch and swiss stone pine, the adaptability of forest ecosystems to climate change, the protection as a habitat for plants and animals, and the protection as a recreational area for the population and tourism.

For the present study, the focus was on recreation aspects:

1) forest function (in particular productive and recreational function),
2) forest composition (in particular the mixture of tree species and the structure of the stand) and
3) forest visitors and tourists an which significance (for example only work or also recreation) and characterisation (for example the forest is loud or calm) the forest should fulfil in order to support the recreational effect (figure 1).

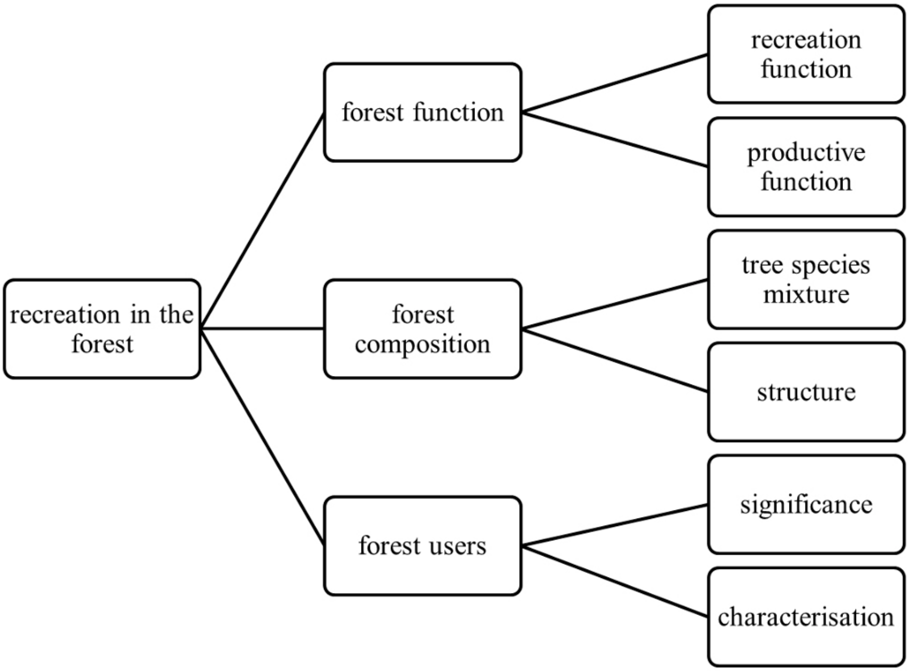

Figure 1: Conceptual framework of the study.

Abbildung 1: Konzeptioneller Rahmen der Studie.

In addition, the study focused on the fact that forests in Austria are mostly private forests and how forest owners can manage the forest under aspects of climate change and the recreational effect in order to maintain structured and tree species-rich stands. The productive function of these stands should not be disregarded. The forest has not only an important value regarding the productive function but also the recreational function and is therefore visited by different people. Therefore, questions were asked to find out what value the forest has and what attributes (significance and characterisation of the forest) people associate with the forest.

3 Material and method

3.1 Study area

The study was carried out in Austria in various hiking areas of the district of Murau in Styria (figure 2). The region is located in the eastern part of the European Alps and is characterized by its mountainous topography. The district covers an area of 1,384 km^2 with a forest coverage of about 70%. The dominant tree species are *Picea abies (L.)H.Karst.* (spruce), *Larix decidua Mill.* (larch), *Pinus cembra L.* (swiss stone pine), *Betula pendula ROTH* (silver birch) and *Acer pseudoplatanus L.* (mountain maple). Typical for the forests of the region is the high proportion of *Larix decidua*, which makes the district one of the *Larix decidua* richest regions in Central Europe (Langmaier *et al.*, 2019). According to the Austrian Forest Inventory, *Larix decidua* represents 18.9% of the total stock in Murau compared to an average of 6.6% in Austria (Bundesforschungszentrum für Wald, 2009). The two main economic pillars of the region are the raw material wood (including wood processing) and tourism.

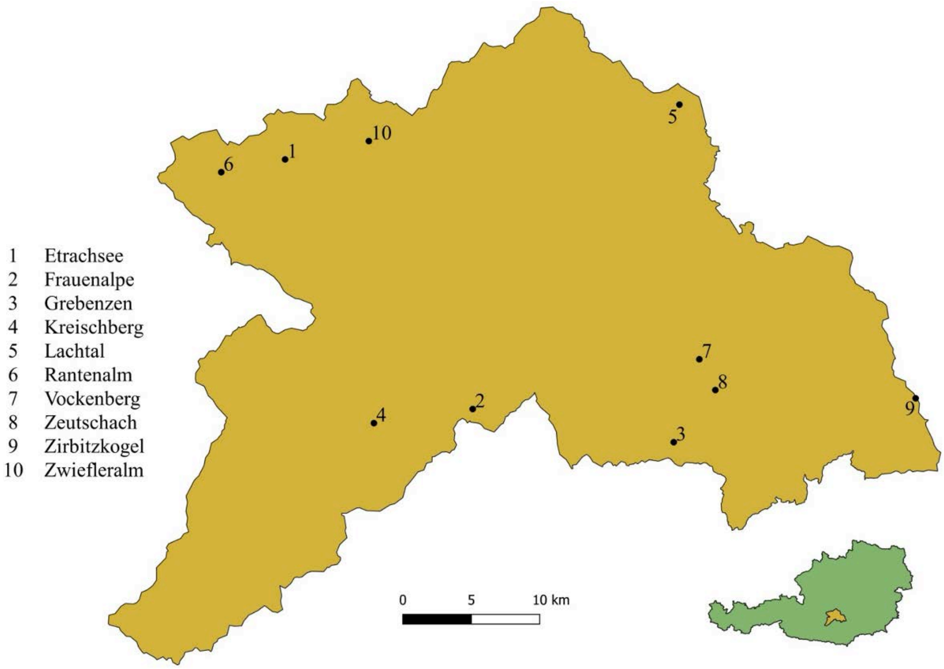

Figure 2: Overview of the study area, district Murau- Styria, and the location of the survey points. The numbers represent the individual areas oft he survey.

Abbildung 2: Übersicht über das Untersuchungsgebiet, Bezirk Murau-Steiermark, und die Lage der Befragungspunkte. Die Zahlen stellen die einzelnen Gebiete dar.

3.2 Design of the survey

3.2.1 Structure of the questionnaire

A quantitative survey was carried out using a standardised questionnaire. The questionnaire was a mix of open, closed and semi-open questions (Döring & Bortz, 2016).

The questionnaire was divided into four sections, including:

(1) a short introduction with general questions about the stay in the region,
(2) questions about the use of forests for recreational purposes with special attention to the role of different types of forests and the tree species *Larix decidua*
(3) selection and evaluation of pictures
(4) questions about the respondents' socio-demographic characteristics.

1) At the beginning of the questionnaire, the project was briefly introduced and what the survey was concerned with. Furthermore, it was pointed out that the evaluation and survey would be anonymous. After this introduction, the respondents were asked about their stay in the Murau region. The questions covered the following aspects: with who they are on holiday (multiple response answer scale), for how long they are on holiday (the number of overnight stays) and in which accommodation they are staying (single response answer scale). This part of the questionnaire filtered out whether the respondent was a local or a tourist.

2) In the second part of the questionnaire different questions about recreational purposes in the forests were queried. The questions were dealing for what recreational purposes people go to the forest (multiple response answer scale), if they know the tree species *Larix decidua* (dichotomous response scale) and what they associate with this tree species (single response answer scale). The last question of this part was that people must value the forest with different attributes. This question was presented as a semantic differential. Respondents could fill in their answers using a scale.

3) In the third part, participants were asked to rank four woodscape images which illustrate different types of forests (cf. figure 3). The four images all had the same format when surveyed. Two were in portrait format and two in landscape format with the size 17 cm x 11 cm. The pictures were selected with the aim of covering various single-species and mixed stands and to find out, which type is preferred by recreation seekers for what reason. The single-species stands were stands with *Larix decidua* and the mixed stands were stands with the three tree species *Picea abies*, *Larix decidua* and *Pinus cembra*. The pictures either represented a dense or open and a single-species or mixed stand. The pictures had to be ranked from the most preferred to the least preferred. In addition, participants had to give a reason for their preferences. The pictures were real, non-manipulated images, taken in the study area under the same weather and light conditions during the summer. In general, the use of pictures for landscape research is an accepted analytical tool (Daniel, 2001; Zoderer *et al.*, 2016b).

4) The last part of the questionnaire queried socio-demographic aspects. Gender, age, place of residence, level of education and net household income were asked (single response answer scale; place of residence was to enter).

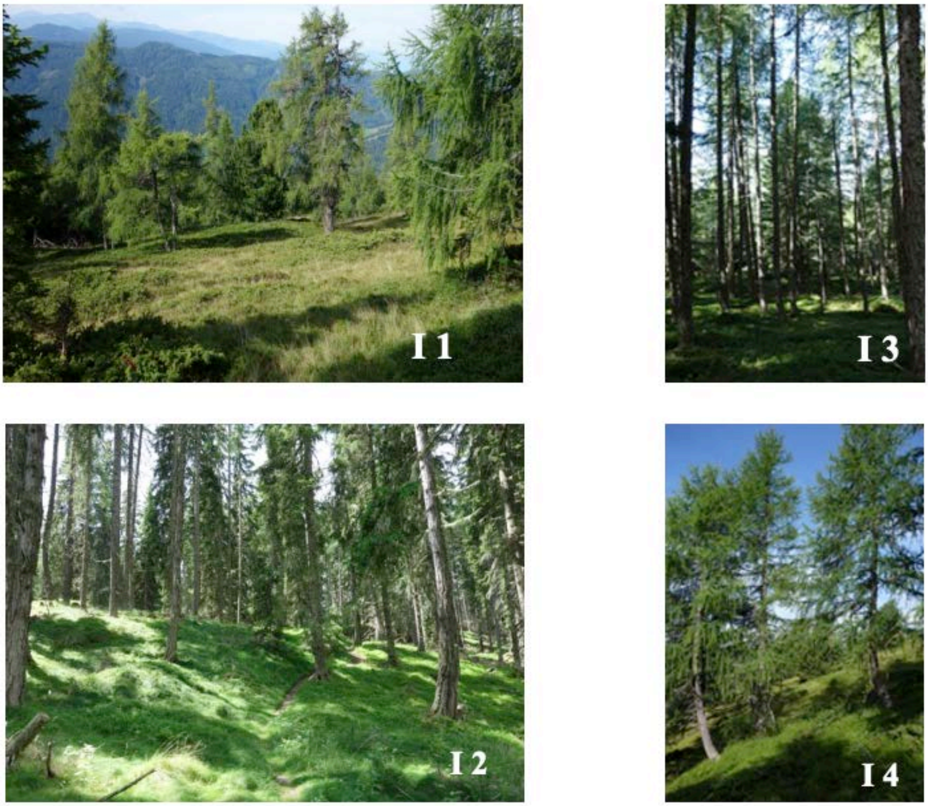

Figure 3: Visualization of the different forest types and the attributes; I1) Image 1 – Mixed stand and open crown cover, I2) Image 2 – Mixed stand and closed crown crown cover, I3) Image 3 – Single-species stand and closed crown cover, I4) Image 4 – Mixed stand and closed crown cover.

Abbildung 3: Darstellung der verschiedenen Waldtypen und ihrer Eigenschaften; I1) Bild 1 – Mischbestand und offenes Kronendach, I2) Bild 2 – Mischbestand und geschlossenes Kronendach, I3) Bild 3 – Reinbestand und geschlossenes Kronendach, I4) Bild 4 – Reinbestand und geschlossenes Kronendach.

3.2.2 Implementation of the survey

The survey was conducted in 10 popular hiking areas in the region of Murau. The selected forest types in these hiking areas represent a typical picture of the region (figure 2). It was important to interview people directly in the forest under the assumption that they are recreation seekers in the forest. The participants were selected randomly and asked to complete the questionnaire ("Paper Pencil" survey). No questionnaires were given to children (Age from 0 to 13 years). Everyone who was encountered at one of the survey locations during the survey period was asked to fill out a questionnaire. The participants completed the questionnaire on their own and approached the interviewers only in case of questions and uncertainties.

Data sampling took place between July 24^{th} and August 13^{th} 2017. Of these 21 days, interviews could be made on 17 days. On the four days where no survey took place, the weather was rainy or thundery and not suitable or too dangerous for surveys in a mountain and hiking region. The minimum requirement set was to conduct questionnaires on at least 14 days and to interview at least 100 women and 100 men. The weather in the study area was on these 17 days stable and sunny. This time was chosen for several reasons. Firstly, all trees are fully developed at this time. Especially in a region with a high proportion of *Larix decidua*, it is important to take care not to influence the respondents subjectively. In autumn, the needles of the larch turn a bright yellow-orange colour. This natural spectacle is beautiful to observe, but it influences the respondents because they pay special attention to the larch and disregard other tree species. After discolouration, the larch loses its needles and is needleless from winter into spring. This again represents an influence for the respondents to believe that the forests are diseased or not intact. At the interview time *Larix decidua* was fully developed and juicy green. Therefore, a time was chosen when all tree species were fully developed from the tree physiology. The survey took place during daytime from 7 am to 5 pm.

3.3 Data processing and analyses

Data were analysed with IBM SPSS Statistics version 24 and Microsoft Excel 2016 software. Descriptive statistics, cross tables, Chi-square tests, Mann-Whitney-U-tests and t-tests were used and calculated.

The differences in recreational purposes between women and men as well as between local and tourists are calculated using the Pearson Chi-square test. To get an idea of which characteristics the respondents attribute to the forest, a semantic differential was created. Apart from the graphical processing, which was done in Excel, an independent t-test was calculated for the statistical evaluation. An explorative factor analysis was done to make the large number of items collected in the semantic differential, which were necessary to fully capture the construct, tangible via a corresponding dimensional reduction and subsequent index formation (Backhaus *et al.*, 2021). After this we did a reliability analysis to determine the Cronbach's Alpha. And in a last step we calculated the index (mean value) to be able to derive the ranking of importance for recreationists.

The Bradley-Terry-Luce model (hereinafter BTL-model) was used to evaluate the order of the images. The participants had to rank four images illustrating different forest stands. The aim was to get an idea of the preferred type of forest for leisure purposes. Based on the ranking of the images, the BTL-model was used to calculate which type of forest is preferred by locals and tourists. The ranking of the images was tested by using Kendall's concordance analysis. A pairwise comparison of the images was performed.

Mann-Whitney-U-tests were used twice, first to determine the differences between male and female respondents and second between tourists and locals regarding the type of forests and recreational activities. In addition, the Mann-Whitney-U-test was used to analyse whether the choice of forest correlated with recreational activities respondents were engaged in. In this study, the primary interest was to investigate whether men and women, or tourists and locals, rate the questions asked differently. Regardless of the fact that age and salary were not of interest, the data was examined in this context and no correlation was found.

4 Results

4.1 Survey sample

Out of 342 questionnaires, 338 were completely filled out in this study. This is a response rate from 98,8%. Table 1 gives an overview of some classification features. 245 of the interview partners were from Austria, 56 from Germany, 22 from the Netherlands and 15 from other countries. Consequently, 71% of the tourists surveyed came from Austria and 29% were from abroad. All participants from the district of Murau and the neighbouring districts (Tamsweg, St. Veit, Murtal and Liezen) were considered as locals. 33% of the tourists visited Murau for the first time. 26 % of the tourists are regular guests and visit Murau almost once a year. On average, tourists stayed 7.2 nights in the region (min. 1 night; max. 28 nights).

The participants included 150 (44.4%) women and 180 (53.3%) men. 8 people did not state their gender. The respondents were between 14 and 82 years old, with an average age of 49 years. The majority of respondents were visiting with their partner (41.3%). 36.3% were accompanied by their children or other family members and 5.4% travelled on their own.

Table 1: Overview of classification features.

Tabelle 1: Überblick über die Klassifizierungsmerkmale.

Overview of classification features		Female Local	Female Tourist	Male Local	Male Tourist	not specified Local	not specified Tourist
		47	103	50	130	1	7
Age in years	mean value	41,7	49,2	51,0	51,3	45,0	50,0
Current state of residence	not specified	0	1	0	1	0	0
	Australia	0	1	0	0	0	0
	Austria	47	64	50	81	1	2
	Belgium	0	0	0	1	0	0
	France	0	0	0	1	0	0
	Germany	0	24	0	28	0	4
	Hungary	0	3	0	2	0	0
	Italy	0	1	0	1	0	0
	Latvia	0	1	0	0	0	0
	Netherlands	0	8	0	13	0	1
	Slovenia	0	0	0	1	0	0
	USA	0	0	0	1	0	0
Where did you stay?	De Luxe Class	0	1	0	0	0	0
	First Class	0	14	0	11	0	0
	Comfort class	1	22	0	35	0	3
	Standard	0	46	0	52	0	3
	Accommodation with family/friends or relatives	0	11	0	16	0	1
	At home - Local	46	8	50	13	1	0
What is your highest completed education or training?	Compulsory school leaving certificate	0	0	0	1	0	0
	Apprenticeship and apprenticeship certificate	16	17	24	35	0	1
	School leaving certificate without high school graduation	5	20	11	12	1	0
	School leaving certificate	17	26	9	34	0	1
	University degree	9	39	6	47	0	4

4.2 Recreational activities and forest perceptions

The first step was to investigate the motives for a stay in the forest. The most popular activities in the forest are mainly recreational activities with low intensity such as hiking (97.6%), relaxing (72.4%), enjoying the nature (68.5%) or walking (43.6%). Recreational activities with high intensity would be for example mountain biking, climbing and skiing (table 2). The data show that the respondents actively use the forest for recreation and that the recreational activities are broad, ranging from more intensive to not-intensive recreational activities. Table 2 illustrates the differences between female and male respondents and between locals and tourists in terms of recreational purposes. There are significant differences between female and male respondents in the following activities: rest and relaxation, walking, collecting berries and mountain biking. For the other activities such as hiking, enjoying nature, collecting mushrooms, skiing climbing and hunting, no significant difference could be found between the recreational purposes preference of women or men. Among locals and tourists there is a significant difference in the activity of collecting mushrooms. Moreover, there are significant differences in the activities of hiking and collecting berries and highly significant differences in the activities of skiing and hunting. All mentioned activities are mainly practiced by locals. Among the interviewed tourists, none uses the forest for hunting.

Table 2: Differences in recreational purposes between women and men as well as between locals and tourists [n = 330].

Tabelle 2: Unterschiede in der Freizeitgestaltung zwischen Frauen und Männern sowie zwischen Einheimischen und Touristen [n = 330].

Recreational purposes	Number of respondents selecting this purpose	Female	Male	p-value	Local	Tourist	p-value
Hiking	322	96%	95%	0.66	90%	98%	**0.00**
Enjoying the nature	239	77%	65%	0.02	67%	72%	0.39
Rest and relaxation	226	74%	61%	**0.01**	65%	68%	0.70
Walking	144	50%	36%	**0.01**	54%	38%	0.06
Collecting mushrooms	122	41%	33%	0.11	49%	31%	**0.02**
Skiing	88	28%	23%	0.33	40%	20%	**0.00**
Collecting berries	59	25%	12%	**0.03**	49%	31%	**0.00**
Mountain biking	49	10%	18%	**0.04**	19%	13%	0.10
Other activities	36	9%	12%	0.49	15%	9%	0.08
Climbing	19	7%	4%	0.38	7%	5%	0.44
Hunting	13	2%	6%	0.10	12%	0%	**0.00**

Figure 4 illustrates the semantic differential based on characteristics respondents attribute to the forest. The graph illustrates a clear pattern of how respondents perceive the forest. There are only minor differences between locals and tourists and between female and male respondents, which is recognisable because the individual icons are close to each other. When choosing the attributes, it is obvious that the forest is characterised on the one hand as quiet, slowly relaxing. On the other hand, the forest can be used for fun, play and movement. The forest is characterised as something exciting, as adventure. The forest was not characterised with negative attributes. This diverse positive characterisation is reflected in the diverse use of forests. Table 3 illustrates the characteristics with a significant difference between women and men as well as the mean for women and men. Between locals (mean, 0.55) and tourists (mean, 1.27) there is a highly significant difference (p-value, 0.00) in the characteristics adventure (more tourists) and everyday life (more locals). All other characteristics indicate no statistically significant differences between locals and tourists.

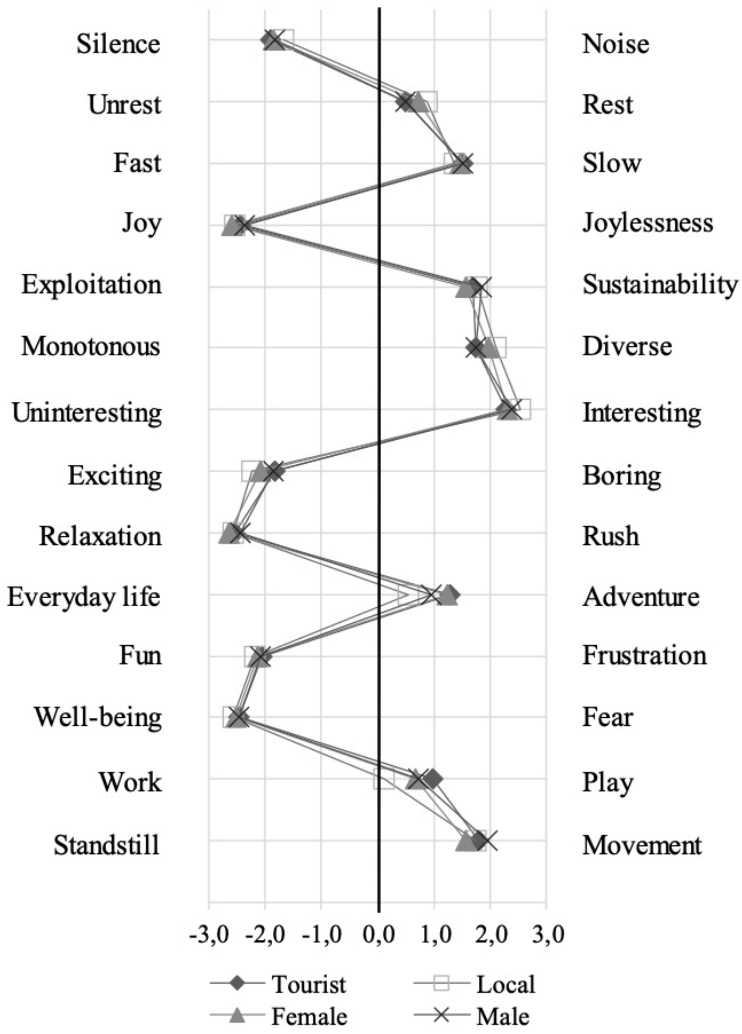

Figure 4: Semantic differential in which the characteristics of the perception of a forest are presented according to women, men, locals and tourists.

Abbildung 4: Semantisches Differential, in dem die Merkmale der Wahrnehmung eines Waldes nach Frauen, Männern, Einheimischen und Touristen dargestellt sind.

Table 3: Mean value and statistical significance of the characteristics of how a forest is perceived between men and women.

Tabelle 3: Mittelwert und statistische Signifikanz der Merkmale wie ein Wald empfunden wird zwischen Männern und Frauen.

Comparison	Sig.	Mean	
		Female	Male
Silence-Noise	0.55	-1.85	-1.83
Unrest-Rest	0.82	.71	.50
Fast-Slow	0.56	1.47	1.51
Joy-Joylessness	**0.02**	**-2.60**	**-2.36**
Exploitation-Sustainability	**0.03**	**1.56**	**1.85**
Monotonous-Diverse	0.33	1.98	1.75
Uninteresting-Interesting	0.32	2.31	2.38
Exciting-Boring	0.10	-2.07	-1.84
Relaxation-Rush	**0.01**	**-2.63**	**-2.44**
Everyday life-Adventure	0.47	1.23	0.95
Fun-Frustration	0.97	-2.13	-2.07
Well-being-Fear	0.68	-2.50	-2.47
Work-Play	0.51	0.66	0.74
Standstill-Movement	**0.00**	**1.58**	**1.95**

With the help of an explorative factor analysis, the variables of the semantic differential, which strongly correlate are summarized into four factor groups (first factor group: "impression" (Cronbachs Alpha 0.625), second factor group "forest image" (Cronbachs Alpha 0.592), third factor group "activity"(Cronbachs Alpha 0.470), fourth factor group "motion" (Cronbachs Alpha 0.559). One variable, namely movement and standstill, could not be assigned to any factor group (table 4). The importance of the factor groups can be derived from the indexation. The weakest Cronbach's alpha was calculated for the factor group "activity". The highest priority was calculated for the factor group "impression"with an average index of 2.25. The factor group "forest image" with an average index of 1.97 represents a similar priority. Finally, the factor groups "motion" with an average index of 1.04 and "activity" with an average index of 0.90 represent a similar priority. The factor group "impression" (relaxation, well-being, fun, silence ...) represents the most relevant characteristics of the forest for visitors, whereas the factor group "activity" (play, adventure ...) represents the most irrelevant characteristics of the forest for visitors. For this part of the survey, it can be summarised for the two factors with the highest priority that the factor "impression" had the greatest importance. It mainly comprised characteristics of the forest that were linked to a personal impression and feeling of oneself. In other words, how the effect of the forest affects personal feeling. The factor "forest image", on the other hand, mainly included the characteristics that described the forest and had nothing to do with human perception.

Table 4: Explorative factor analysis for the semantic differential, in which the characteristics of how a forest is perceived are listed.

Tabelle 4: Explorative Faktorenanalyse für das semantische Differential, im welchen die Merkmale wie ein Wald empfunden wird, dargestellt sind.

Rotated component matrix[a]					**Name of factor group**	**Index**
	component					
	1	2	3	4		
Rush_Relaxation	.69				Impression	2.25
Fear_WellBeing	.68					
Frustration_Fun	.59					
Noise_Silence	.55					
Boring_Exciting	.55					
Joylessness_Joy	.47					
Interesting_Uninteresting		.75			Forest image	1.97
Diverse_Monotonous		.74				
Sustainability_Exploitation		.58				
Play_Work			.77		Activity	0.90
Adventure_EverydayLife			.75			
Movement_Standstill			.40		-	-
Slow_Fast				.81	Motion	1.04
Rest_Unrest				.79		
Extraction method: principal component analysis. Rotation method: Varimax with Kaiser normalization.[a]						
a. The rotation has converted into 5 iterations.						

4.3 Forest stand preferences

In this study, four images with different forest attributes were used to determine the preferred type of forest for recreational purposes. As illustrated in figure 5, image 1 (estimated parameter 1.244; standard deviation 0.075) is the image most often ranked in 1st place. Image 4 (estimated parameter 1.063; standard deviation 0.066) and image 2 (estimated parameter 1.052; standard deviation 0.064) are ranked second together. Image 3 (estimated parameter 0.640; standard deviation 0.053) is ranked last by most respondents. To make this result clearer, figure 6 shows the ranking for each image. Image 1 has been mentioned 154 times as the most popular forest for recreational purposes. Image 2 was ranked 104 times on place 1. Images 3 and 4 were selected 21 and 64 times respectively as the preferred types of forest. Although Image 2 and image 4 in the BTL-model were equally ranked, figure 6 shows that the selections by the respondents were different. Furthermore, image 3 was clearly voted at last place with 233 votes. The Mann-Whitney-U-test was not able to calculate a significant difference between women and men and between locals and tourists in the selection of images. The two groups prefer the same type of forests for their recreational activities.

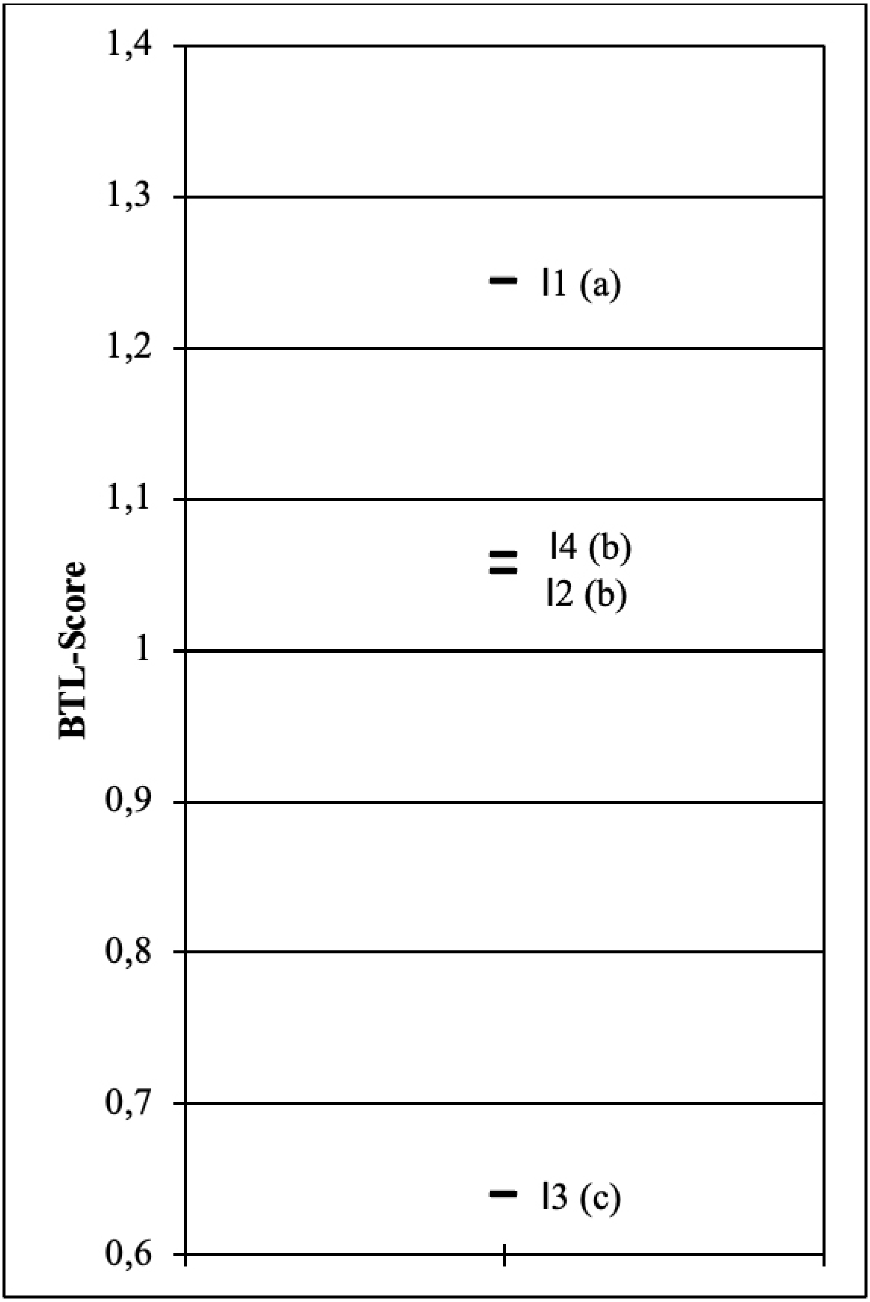

Figure 5: BTL-model [I1 = image 1; I2 = image 2; I3 = image 3; I4 = image 4].

Abbildung 5: BTL-Modell [I1 = Bild 1; I2 = Bild 2; I3 = Bild 3; I4 = Bild 4].

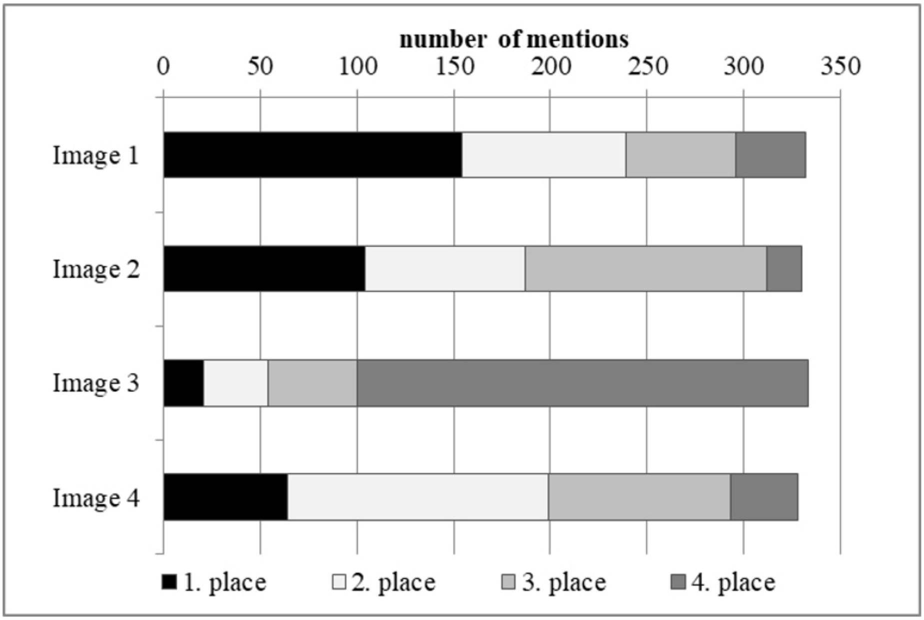

Figure 6: Ranking analysis about the four forest types that were available for selection.

Abbildung 6: Ranking-Analyse über die vier Waldtypen die zur Auswahl standen.

The preferred type of forest was the open mixed stand. The closed single tree stand was the least favoured. With regard to the preference of certain types of forests, no difference between men and women and between locals and tourists was identified. The Kendall's coefficient of concordance gave a value of 0.285 (kendall-w) for the model and was with 0.000 highly significant. The pairwise comparison of the images showed that the ranks of the images of images 1 and 2 differ significantly (0.027), of image 2 and 4 not significantly (0.178), all other pairwise comparisons of the images differ highly significantly from each other.

In addition, the Mann-Whitney-U-test was used to analyse whether the choice of forest correlated with recreational activities respondents were engaged in. There were two statistically significant results. Interviewees, who prefer picking mushrooms (with a statistical significance of 0.03) or berries (with a statistical significance of 0.05) do not prefer the closed mixed forest type in image 2. There was no statistical significance with the other types of forests and recreational activities.

5 Discussion

5.1 Recreational activities and forest perceptions

A big trend of active recreational activities, as described by Burgin and Hardiman (2012) or Wilkes-Allemann and Ludvig (2019), could not be confirmed in this study. 27% of the interviewees go skiing in forest-like areas (skiing slopes are not forest per se). Other active recreational activities, such as mountain biking, which is referred to by Wilkes-Allemann and Ludvigs (2019) study, were only mentioned by 15% of the respondents. The fact that the interviewees mainly come to the forest for passive activities is also underlined by the semantic differential. Among other things, the respondents characterized the forest as quiet, slow and restful. However, Opaschowski (1991) already pointed out that it is above all trees that shape the aesthetics and benefits of the forest when, a few decades ago, the death of the forest in Europe was a topical issue and various tree species were affected to varying degrees.

5.2 Forest stand preferences

Several studies have already shown that stands with different tree species are preferred by those seeking recreation (Edwards *et al.*, 2012b, 2012a; Filyushkina *et al.*, 2017). Furthermore, Filyushkina *et al.* (2017) and Edwards *et al.* (2012a) proved in their study that deciduous forests are preferred over coniferous forests. An investigation of this relation was not part of this study, since there is a very low proportion of hardwood in the study area (6.8%) (Bundesforschungszentrum für Wald, 2009). The difference between men and women and between locals and tourists was also not further surveyed in other available studies (Filyushkina *et al.*, 2017; Giergiczny *et al.*, 2015).

Edwards *et al.* (2012b) point out that the type of tree species itself does not have a strong influence on the selection of forests for recreational purposes. Liu *et al.* (2023) were able to find out in their study that the autumnal colour change of deciduous trees is highly attractive for tourists. In the region studied here, this can be a positive indication for promoting *Larix decidua*, as it turns golden yellow in autumn. According to Ribe (1989) moderately stocked more open stands are preferred by recreation seekers. In addition, Giergiczny *et al.* (2015) state that forests with irregularly spaced trees are preferred. They also found out that respondents prefer older stands with a vertical structure (Giergiczny *et al.*, 2015).

All mentioned results and studies lead to the discussion how forests for recreational purposes should be treated from a silvicultural point of view. For forest owners, adapted silvicultural measures can create an aesthetic type of forest both in a sustainable and touristic way. On the one hand different tree species must be used. On the other hand, open spaces are important, that the appearance of a forest does not give a too dense and dark impression (see image 3 at figure 3) (Edwards *et al.*, 2012b, 2012a; Giergiczny *et al.*, 2015; Ribe, 1989). Füger *et al.*, (2021) discovered that pure and dense spruce forests scored worst among respondents. Forests with several tree species scored best in their survey. Especially regarding climate change, it is important to spread the risk among different tree species (Gilsa von, 2008; Spellmann *et al.*, 2011). Furthermore, it is important to structure the stand (Giergiczny *et al.*, 2015). This measure is often used in forestry as principle of adaptation for climate change (Brang *et al.*, 2016).

Both from a forestry point of view and from a touristic point of view, it is important that forest measures do not cause any damage to the stand or the soil (Edwards *et al.*, 2012b; Kaae *et al.*, 2010; Ribe, 1989). It is important to pay attention to a well thought design in intensively managed forests, such as feeling areas, forest roads and other managed features (Kaae *et al.*, 2010). In the end, it must be noted that many forest owners are currently aiming to adapt their forests to climate change. However, it certainly shows that many of these measures make the forest more inviting for recreation seekers. This double benefit is advantageous for everyone in terms of the various functions that the forest is supposed to fulfil.

6 Conclusion for tourism and forest management

When interpreting the results, it should be noted that this is a regional study. The study was conducted once in a limited period of time. For a more in-depth study, it is therefore suggested to consider other regions in order to be able to represent a broader visitor clientele and their interests. Forest management should adapt silvicultural strategies that focus on the landscape level and the stand level. Measures focusing on the landscape level may include the spatial distribution of different mixed forest and/or agroforest types (*e.g.* figure 3/image) and at the stand level they may include the conservation and promotion of different tree species through thinning and/or regeneration activities in different stages of growth (*f.e.* figure 3/image). They should be stands that are stable and healthy against the background of climate change and thus also have an aesthetic effect on recreational users.

For forest owners, adapted silvicultural measures can create an aesthetic type of forest both in a sustainable and touristic way. Especially with regard to climate change, it is essential to spread the risk among different tree species. It is important to structure the stand; this measure is often used in forestry as principle of adaptation for climate change. Open spaces are crucial for tourism, so that the appearance of a forest does not appear too dense and dark. Both from a forestry point of view and from a touristic point of view, it is important that forest measures do not cause any damage to the stand or the soil. It is important to pay attention to a well thought design in intensively managed forests, such as feeling areas, forest roads and other managed features. The forest has many functions to fulfil that are in demand by society and thus compensation can be considered in the case of intensive use of the forest by tourism.

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Physiological responses of different Oak species to dust in Northern Zagros Forests, Iran

Physiologische Reaktion von verschiedenen Eichenarten auf Staub im nördlichen Zagroswald, Iran

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Keywords: dust, *Quercus libani*, *Quercus infectoria*, *Quercus brantii*, Photosynthesis, Chlorophyll, Proline, Zagros Forest, Reforestation

Schlüsselbegriffe: Staub, *Quercus libani*, *Quercus infectoria*, *Quercus brantii*, Photosynthese, Chlorophyll, Prolin, Zagros Wald

Abstract

This study was conducted to examine the impacts of dust on leaf mineral elements and selected physiological responses of three different Oak species in Western Zagros, Iran. Three-year-old seedlings of the Oak species *Quercus brantii*, *Q. libani* and *Q. infectoria* were exposed to dust under natural conditions. Photosynthesis, chlorophyll, proline and selected leaf mineral elements were examined in a two-factorial experiment including species (*Q. brantii*, *Q. libani* and *Q. infectoria*) and dust exposure (dust-exposed and without dust as control). The results showed that dust had a significant effect on photosynthesis rate of all species. Dust decreased photosynthesis rate to about 38%, 13% and 32% for *Q. brantii*, *Q. libani* and *Q. infectoria*, respectively. Dust also had a significant effect on

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proline and chlorophyll content of Oak leaves. *Q. infectoria* had the lowest total chlorophyll content with 42%. Among the studied species, *Q. libani* appears to be most suitable for growing under dust exposure, as this species had the lowest reduction in chlorophyll and photosynthesis. Planting *Q. libani* on northern slopes in Zagros forests, where Oak forests receive higher precipitation, presumably enhances the success of forest restoration under the combined effects of climate change and dust exposure.

Zusammenfassung

Diese Studie hat das Ziel die Auswirkungen von Staub auf Blattmineralelemente und ausgewählte physiologische Reaktionen von drei verschiedenen Eichenarten im westlichen Zagros, Iran, zu untersuchen. Drei Jahre alte Sämlinge von *Quercus brantii*, *Q. libani* und *Q. infectoria* wurden unter natürlichen Bedingungen Staub ausgesetzt. Photosynthese, Chlorophyll, Prolin und ausgewählte Blattmineralelemente wurden in einem zweifaktoriellen Experiment untersucht, hinsichtlich Baumart (*Q. brantii*, *Q. libani* und *Q. infectoria*) und Staubexposition (staubexponiert und ohne Staub als Kontrolle). Die Ergebnisse zeigten, dass Staub einen signifikanten Einfluss auf die Photosyntheserate aller Arten hatte. Staub verringerte die Photosyntheserate für *Q. brantii*, *Q. libani* und *Q. infectoria* auf etwa 38 %, 13 % bzw. 32 % im Vergleich zu Kontrollvariante. Staub hatte auch einen signifikanten Einfluss auf den Prolin- und Chlorophyllgehalt der Eichenblätter. *Q. infectoria* hatte mit 42 % den niedrigsten Gesamtchlorophyllgehalt. Unter den untersuchten Arten scheint *Q. libani* am besten für das Wachstum unter Staubeinwirkung geeignet zu sein, da diese Art die geringste Reduzierung von Chlorophyll und Photosynthese aufwies. Die Anpflanzung von *Q. libani* an Nordhängen in Zagros-Wäldern, wo Eichenwälder höhere Niederschläge erhalten, steigert vermutlich den Erfolg von Aufforstungen unter den kombinierten Auswirkungen von Klimawandel und Staubexposition.

1 Introduction

Dust particles is an important source of air pollution including a mixture of particles suspended in the atmosphere. Overall, particulate matter (PM) includes different types of materials ranging from fine solid materials like soil dust, various types of micro-organisms, ashes, plant pollens, soot and many others (Pandey and Singh, 2012). Anthropogenic activities such as mining and land use changes are one of the most important sources of PM (Schelle-Kreis *et al.*, 2007; Ghaffari and Mostafazadeh, 2015). In general, two types of pollutants have been detected in aerosols: the first type includes SO_2, NO_2, CO compounds and heavy metals, especially lead and cadmium, and the second type including physical, chemical and biological components in dust (Zarasvandi *et al.*, 2011). Since 1990 with the development of precise measuring equipment, particles with an aerodynamic diameter smaller than 10 micrometers (PM10) could have been detected and are now called suspended particles (Particulate Matter) by United States Environmental Protection Agency (Irene *et al.*, 2009).

Dust and sand storms sweep the western parts of Iran every year from March to June, endangering human health, fauna and flora. An important source of these fine particles are neighboring countries, where misuse of water resources and severe drought contributed to soils erosion even at low-speed winds (Boloorani *et al.*, 2020; Jahanbakhsh *et al.*, 2022). Over the last few decades, due to different reasons including war, agricultural activities and natural drought, dust flux into Iran has intensified in terms of both frequency, duration and severity (Javanmard *et al.*, 2019, Moradi *et al.,* 2017). Dust threatens ecology, economic activity and even the social life of inhabitants in the frontier cities where people are directly exposed to continuous flows of particles (Moradi *et al.*, 2017). Because of their immobility, trees and plants are heavily exposed to dust deposition (Javanmard *et al.*, 2020). Depending on the deposition rate, chemical composition of the particles, particle size and tree age, the reaction of trees to the dust will vary (Darley, 1996; Chaturvedy *et al.*, 2013). Some tree and plant species appear to have a higher potential for dust accumulation on their surfaces. For example, *Celtis caucasica* compared to *Melia azedarach* and *Fraxinus rotundifolia* accumulated more dust, but was also more vulnerable to the effects of dust. *Morus alba* was recognized as desirable tree for dust reduction and has been suggested to be the most suitable species for urban forests of semiarid zones, where dust pollution is high (Javanmard *et al.*, 2020).

The dust-retention capability of trees is determined by tree age and structure of the leaves, presence or absence of trichomes and wax on the leaf surface, height of plant, surface geometry, phyllotaxy, epidermal and cuticular features, orientation of the leaf and length of petiole (Chaturvedi *et al.*, 2013; Javanmard *et al.*, 2020). Studies show that dust affects trees and plants through depositing on their leaves and also by making chemical changes to soil characteristics in the habitats where they grow. When particles cover tree leaves, leaves receive less light and this leads to lower photosynthesis and in consequence less biomass produced (Wijayratne *et al.*, 2009). Moreover, lower photosynthesis in fruit trees is associated with lower productivity in terms of grains and fruit. Studies show that different species react differently to dust flux. For example, in *Q. infectoria*, dust has the greatest impact on photosynthesis, stomatal conductance, leaf internal CO_2, transpiration and mesophyll conductance (Siqueira-Silva *et al.*, 2016), while for *Q. brantii*, dust has a greater effect on photosynthesis and mesophyll conductance.

Considering that Iran and its Western neighbors are in the dry and semi-arid belt of the world, more than two-thirds of Iran's area is in the dry and semi-arid climate. Moreover, recording annual rainfall less than 250mm, Iran is at risk of dust phenomenon. Studies show that dust storm events have dramatically changed in terms of the amount and size of suspended particles, duration, extent and time over the past two decades. And compared to the previous events, the number of dusty days in the west of the country increased from less than 16 days until 2005 to more than 130 days in 2010. Measuring chlorophyll is an important tool for evaluating the effects of air pollutants on plants, because it plays an important role in plant metabolism. With the deposition of fine dust particles on the surface of the leaf, a shadow is created on the outer surface of the leaf, and it probably causes a decrease in light absorption and subsequently decreases the concentration of chlorophyll. The amount of proline increases in different plants under different stresses. In comparison with other common osmolytes, especially common and alcoholic sugars, proline has a higher efficiency for protection against stress and with a direct effect in stabilizing macromolecules and their water absorbing layers and also because Its antioxidant properties indirectly show a protective effect (Delauney and Verma, 1993). Air pollution weakens trees and reduces their resistance to natural stresses. The increase in pollution, which includes dust, disrupts the process of photosynthesis and the amount of production of organic compounds in trees and causes the trees to weaken.

Zagros forests or western oak forests are in the west of Iran covering 6 million ha (Sadeghi *et al.*, 2017). Along with grasslands in Kurdistan, oak forests in Kurdistan are important natural environments which provide habitats for wild animals and endemic plant species and for recreational opportunities for people in the region (Karami et al. 2021). In addition, numerous springs contribute to water resources that are used for agricultural, recreational and household purposes (Karami *et al.*, 2019; Jahanbakhsh *et al.*, 2022). The forests are composed of different communities of plants and trees and act like a natural filter on which dust is deposited every year. These oak woodlands have been continuously experiencing flows of dust over the last few decades. It has been reported that being exposed to dust flux may in the long run facilitate a loss of these valuable woodlands (Moradi *et al.*, 2017). Studies on the effects of dust on oak trees showed that dust flux disrupted physiological activities of oak species, decreased leaf gas exchanges and increased leaf internal CO_2 concentration (Moradi *et al.*, 2017). Although previous studies reported some of the effects of dust on specific plant species, aspects relating to the leaf mineral elements and physiological properties of the western oak forests have not yet been investigated.

The objectives of this study are

(1) quantifying dust deposition on three *Quercus* sp., which are the dominant species of Zagros forests,
(2) exploring the effect of dust deposition on leaf nutrient, proline and chlorophyll content and
(3) investigating the impact of dust on photosynthesis.

2 Materials and methods

2.1 Study area

This investigation was carried out in 2020 in a wooded area approximately 35 km from Mariwan (46°17'28.96'' to 46°20'32.04'' E and 35°36'12.97'' to 35°39'57.86'' N latitude) at an altitude of 1700 m (Fig. 1). An area of 1705 hectares directly exposed to dust was selected for study. Mean annual precipitation is 800 mm (Iran Meteorology Organization, 2021; Sadeghi *et al.*, 2021; Balist *et al.*, 2022). In most years the maximum monthly precipitation occurs in February and the minimum in June. The mean annual temperature is 16 °C and the study area is described as "Csa" (Mediterranean Climate) in the Köppen Climate Classification. Soils have a sandy loam texture, with a pH of 6.5-7. The common tree species in the area include *Quercus brantii*, *Q. libani* and *Q. infectoria*, the species selected for this study, and *Pistacia atlantica*, *Pyrus* Sp., *Crataegus* sp., *Acer monspesulanum*, *Amygdalus* sp., and *Cerasus* sp.

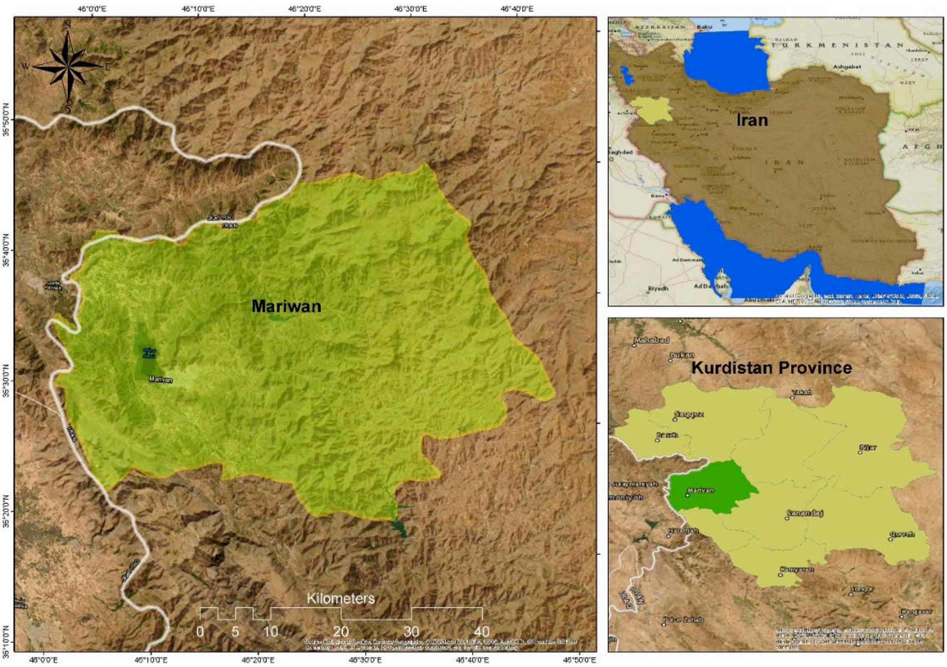

Figure 1: Location of the studied sites in Mariwan County, Kurdistan Province, Iran.

Abbildung 1: Lage des Untersuchungsgebietes in Mariwan, Provinz Kurdistan, Iran.

2.2 Field design and statistical analysis

To assess the effects of dust, three-year-old seedlings of oak trees *Quercus brantii*, *Q. libani* and *Q. infectoria* were used. The potted seedlings from Rikhlan nursery in Mariwan (Iran) were transferred to the study region in Chenare district of the Mariwan forests (Spring, 2017). Seedlings were divided into two groups of 45 pots. Fifteen potted seedlings of each species were placed in individual groups. One group was set as the dust treatment and the other was assigned as control. The seedlings were irrigated once every 4 days from 9th April until 10th July. To irrigate the pots, every three days 0.5 liter of water was applied to each pot. The leaves of seedlings in the control pots were washed during irrigation to remove dust while water was only poured in the pots with no leaf contact in the dust treatment pots. To increase the accuracy in the research procedure, the direction of wind on the pots was marked. To evaluate the real impact of dust particles on the studied species of seedlings, the studied species were exposed to the dust in a part of the forests of Chanare Marivan. No artificial pollination was done on the seedlings, and they were exposed to dust during the dust period. For this purpose, five-year-old seedlings of three studied species were used. For this purpose, the seedlings were transferred to the study area in April (before the beginning of the growing season and before the dust storms). The seedlings were divided into two groups after establishment in the study area. Group one as dust treatment and one group as control. To increase the accuracy in the research process, the direction of pollen blowing was marked on the pots.

Figure 2: Three-year-old seedlings of oak trees Quercus brantii, Q. libani and Q. infectoria.

Abbildung 2: Drei Jahre alte Bäume der Eichenarten *Quercus brantii*, *Q. libani* und *Q. infectoria*.

2.3 Photosynthesis, chlorophyll, proline and mineral elements assessment

IRGA (Infrared Gas Analyzer, ADC Company) was used to measure the photosynthesis rate for the studied species. The Arnon (1949) method was used to investigate the possible effect of dust on leaf chlorophyll content. To evaluate the status of the species exposed to dust compared to control samples and whether the dust caused stress in the studied plants, the Bates (1973) method was used to measure leaf proline content. Leaf nitrogen content was measured using the Kjeldahl method, a spectrophotometer was used to measure phosphorus level, and other mineral elements were measured using an atomic absorption spectrophotometer (AAS) to evaluate the effects of dust on mineral elements of the leaves.

Assess the amount of dust deposited on leaves

To estimate the amount of deposited dust, 20 leaves from the plucked leaves containing dust of each species were washed separately with distilled water (both sides of the leaves). Then the resulting dust solution was placed in a centrifuge (for 15 minutes at a speed of 5000 per minute) and its precipitated part was separated by depositing dust particles. Then, the separated sediment part (dust particles) was placed in an oven at a temperature of 70 °C for 48 hours. After drying, the dust particles were carefully weighed for each species separately in the laboratory. Then, using the average area of the collected leaves, the weight of the amount of dust deposited in the average area of the leaf was estimated separately for each of the species.

2.4 Statistical analysis

After checking the normality of the data and residuals using the Kolmogorov-Smirnov test, data were analyzed in a factorial approach with two factors: type of species (*Q. branti*, *Q. libani* and *Q. infectoria*), and dust at two levels (one containing dust and the other without dust as control). Then, a Duncan test was performed to study the difference between means when the assumption of the equality of variances was confirmed. All analyses were conducted using SPSS software, version 23.

3 Results

3.1 The amount of dust deposited per leaf

Table 1 shows the amount of dust deposited per leaf and tree surface area. As it can be seen, the highest deposited dust was recorded for *Quercus brantii* with 12 mg per leaf.

Table 1: The amount of dust deposited deposited (mean ± standard deviation) per leaf per leaf by species. Similar Roman letters after parameters indicates no difference at 5% level (same applies for the following tables).

Tabelle 1: The Staubmenge pro Blatt und die Blattfläche (Mittelwert ± Standardabweichung) für die untersuchten Arten. Ähnliche Buchstaben nach Parameter zeigen keine signifikanten Unterschiede auf 5-%-Niveau an (das selbe gilt für die folgenden Tabellen).

Variables	*Q. infectoria*	*Q. libani*	*Q. brantii*
Dust (mg/leaf)	5.5±0.01 [b]	5.0±0.00 [b]	12.00±0.02 [a]
Dust (mg/cm^2)	0.23±0.01 [b]	0.21±0.00 [b]	0.30±0.02 [a]
Mean leaf area (cm^2)	23.21±0.98 [b]	23.27±0.89 [b]	39.73±2.10 [c]

3.2 Leaf photosynthesis rate

The results showed that the type of species had a significant effect on the level of photosynthesis, with photosynthesis rates among the three species being significantly different. In addition, results showed that the presence of dust had a significant effect on the photosynthesis of the different oak species. It was also found that the interaction of species and dust at the level of the studied variable was not statistically significant, that is, each factor (species and dust) had an independent effect on photosynthesis.

The results in Table 2 showed that dust deposition on the leaves of the three studied species reduced photosynthesis rates (Figure 3). This reduction was statistically significant in the *Q. brantii* and *Q. infectoria* species, but not in *Q. libani*.

Table 2: Photosynthesis rates (mean ± sd) of the species studied exposed to dust.

Tabelle 2: Photosyntheseraten (Mittelwert ± Standardabweichung) der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
Photosynthesis	**Dust**	12.83±0.53 [bc]	8.77±1.05 [a]	9.86±1.59 [ab]
(µmol $CO_2/m^2/s^1$)	**control**	14.75±0.65 [c]	12.85±0.91 [bc]	15.91±0.44 [c]

3.3 Leaf chlorophyll content

The results revealed that in general, species type had no significant effect on the leaf chlorophyll content, that is, the difference in chlorophyll a, b and total chlorophyll among the three studied species (Figure 3) was not statistically significant. In relation to the presence or absence of dust on the leaves of the studied trees, the presence of dust had no significant effect on the amount of chlorophyll a, b and total chlorophyll pigment ($\alpha = 5\%$). It was also observed that species and dust interacted in the amount of chlorophyll and total chlorophyll pigments, but in the case of chlorophyll b, each factor (species and dust) had an independent effect.

The results in Table 3 and Figure 3 show that only in the *Q. infectoria* species did dust deposition on the leaves have a significant effect on the amount of chlorophyll pigment, in that dust significantly reduced the chlorophyll a, b and total chlorophyll in *Q. infectoria*. In other species, especially in *Q. brantii*, although there was a difference between the control and dust treatments in terms of chlorophyll pigments, this difference was not statistically significant compared to other examined species.

Table 3: Mean (±sd) Chlorophyll content (mg/g fresh tissue) in the studied species under the influence of dust.

Tabelle 3: Chlorophyllgehalt (Mittelwert ± Standardabweichung) der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
Chlorophyll a	**Dust**	1.66±0.15 [bcd]	1.09±0.14 [a]	1.33±0.14 [abc]
	Control	1.67±0.07 [bcd]	1.86±0.08 [d]	1.79±0.07 [cd]
Chlorophyll b	**Dust**	0.48±0.06 [ab]	0.31±0.04 [a]	0.37±0.03 [ab]
	Control	0.41±0.04 [ab]	0.55±0.03 [b]	0.47±0.03 [ab]
Chlorophyll Total	**Dust**	2.17±0.21 [bc]	1.42±0.18 [a]	1.72±0.18 [ab]
	Control	2.10±0.11 [bc]	2.44±0.12 [c]	2.29±0.10 [bc]

3.4 Leaf proline content

As indicated in Table 4, dust deposition on tree leaves had a significant effect on the leaf proline content only in *Q. infectoria*, with dust in *Q. infectoria* leaves increasing proline content. Dust had the same effect on *Q. brantii*, but the difference was not significant. In *Q. libani*, the amount of proline in the dust treatments and control was almost equal (Table 4 and Figure 3).

Table 4: Mean (± sd) of proline (mg/g dry weight) in the leaves of the studied species under the influence of dust.

Tabelle 4: Prolingehalt (Mittelwert ± Standardabweichung) der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
Proline	Dust	3.5±0.25 [a]	8.8±0.21 [b]	3.1±0.16 [a]
	Control	3.4±0.42 [a]	3.2±0.26 [a]	2.9±0.12 [a]

3.5 Leaf mineral element contents

The current results showed that all the studied elements in the three species had a significant difference with each other at the level of 1% probability. Except for phosphorus, nitrogen and manganese, exposure to dust had a significant effect on all elements. Species and particulate matter factors interacted with phosphorus, sodium, magnesium, calcium, iron, and zinc, but each factor (species and particulate matter) had an independent effect on nitrogen, potassium, manganese, and copper.

Examination of the differences between the means of measured elements in leaves showed that the amount of magnesium in the three oak species increased significantly when exposed to dust. Potassium levels increased in all three species, but it was significant only for *Q. libani*. Iron levels also increased in all three species, although this increase was significant only for *Q. infectoria*. Conversely, copper and zinc elements showed a decreasing trend under the influence of dust. Also, calcium was significantly reduced in *Q. brantii* and *Q. libani* species. Phosphorus significantly increased in *Q. infectoria* under the influence of dust. Nitrogen showed a decreasing trend under the influence of dust, but only in *Q. libani* was this decrease significant (Table 4). Manganese, however, increased under the influence of dust but not significantly.

Table 5: Amount (mean ± sd) of mineral elements in leaves of the studied species under the influence of dust.

Tabelle 5: Mineralelemente (Mittelwert ± Standardabweichung) in Blättern der untersuchten Arten unter Staubexposition und Kontrolle.

Variables	Treatment	*Quercus libani*	*Quercus infectoria*	*Quercus brantii*
P (%)	Dust	8.8±0.82 bc	7.9±0.51 b	9.5±0.49 bc
	Control	8.0±0.84 b	2.1±0.60 a	12.7±0.84 a
N (%)	Dust	0.63±0.02 a	0.57±0.04 a	0.69±0.04 ab
	Control	0.97±0.05 b	0.58±0.03 a	0.62±0.06 a
Na (ppm)	Dust	1.12±0.13 bc	1.72±0.18 d	0.67±0.03 a
	Control	1.37±0.14 c	1.34±0.09 c	0.83±0.06 ab
Mg (ppm)	Dust	23.18±0.75 c	30.10±0.34 e	27.05±0.65 d
	Control	20.17±0.58 b	23.25±0.73 c	16.91±0.77 a
K (ppm)	Dust	61.51±1.93 a	67.55±1.07 de	43.24±9.34 abc
	Control	38.32±1.54 ab	56.05±4.17 bcd	23.79±12.99 a
Ca (ppm)	Dust	0.61±0.06 cd	1.67±0.18 cd	0.71±0.04 a
	Control	0.89±0.34 e	1.24±0.14 de	0.72±0.07 de
Mn (ppm)	Dust	0.61±0.06 a	1.67±0.18 c	0.71±0.04 a
	Control	0.89±0.34 ab	1.24±0.14 bc	0.72±0.07 a
Fe (ppm)	Dust	1.23±0.33 ab	1.86±0.46 b	0.51±0.08 a
	Control	0.59±0.21 a	0.45±0.02 a	0.39±0.04 a
Cu (ppm)	Dust	0.01±0.00 a	0.02±0.01 a	0.01±0.00 a
	Control	0.02±0.01 a	0.07±0.02 bc	0.04±0.01 ab
Zn (ppm)	Dust	0.23±0.00 a	0.27±0.01 ab	0.23±0.01 a
	Control	0.33±0.02 b	0.29±0.01 ab	0.31±0.05 ab

3.6 Relative effect of dust removal in percent by species for photosynthesis, chlorophyll and proline

The results showed that dust particles reduce the amount of photosynthesis in oak species. dust particles have the greatest effect on the photosynthesis of the species of *Q. brantii* and *Q. Infectoria* (38 and 31.8%, respectively) (Fig. 3). Although the effects of dust on Q. libani was not as great as the other two species, it effects on the *Q. libani* was 12.8 percent. The greatest relative effect of dust on chlorophyll content was observed in two species *Q. brantii* and *Q. Infectoria*. In *Q. libani* species, it has no effect on the amount of chlorophyll (Fig. 3). Dust particles had the highest effect in increasing proline in *Q. Infectoria* species. The relative increase in this species was 177% (Fig. 3).

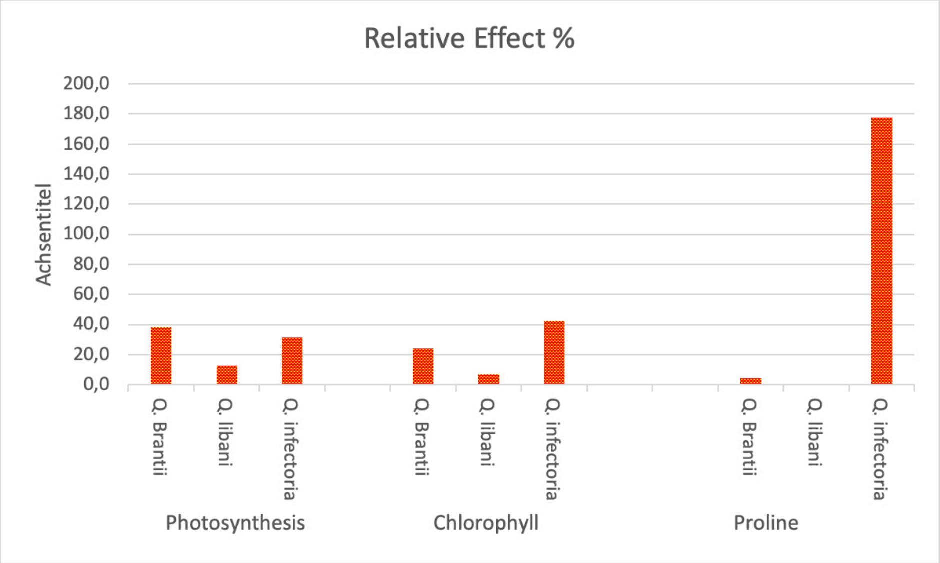

Figure 3: Relative effect of dust removal in percent by species for photosynthesis, proline and chlorophyll.

Abbildung 3: Relativer Effekt von Staubexposition in Prozent pro Baumart hinsichtlich Photosynthese, Prolin- und Chlorophyllgehalt.

Figure 4 shows the relative effect of dust on leaf nutrients. As this figure shows, the most changes are in the Fe, P, K and Cu elements.

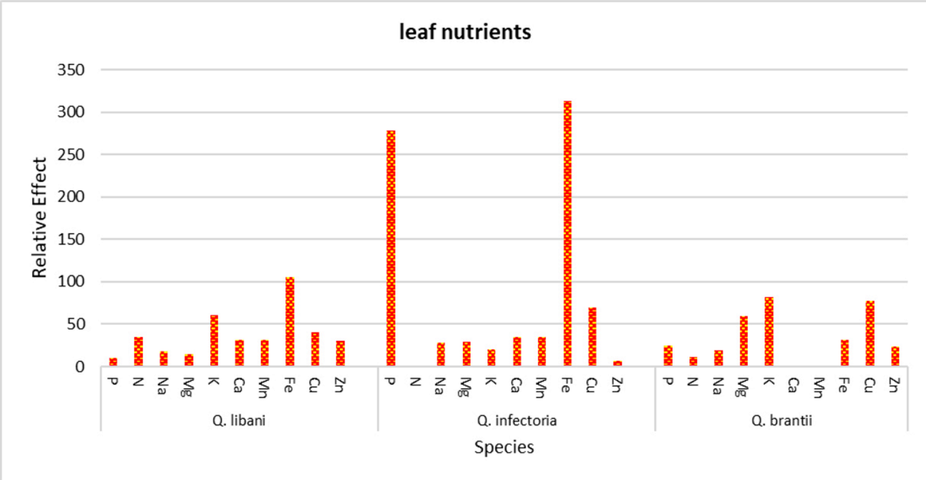

Figure 4: The relative effects on leaf nutrients for different Oak species.

Abbildung 4: Relativer Effekt von Staubexposition in Prozent pro Baumart hinsichtlich Mineralelemente in Blättern.

4 Discussion

4.1 Photosynthesis

The present study provides insight into the physiological responses of different oak species to dust exposure in Northern Zagros in the western oak forests in Iran. Based on our results, photosynthesis rates among the studied species were significantly different and were also significantly affected by dust deposition. Dust in all three studied species reduced the photosynthesis rates of the leaves (Table 1). In general, one of the reasons for decreases in plant growth is the limitation of photosynthesis due to various stresses, including air pollution (Eller, 1997; Thompson *et al.*, 1984). Photosynthetic limiting factors are divided into the two categories of stomatal factors, which reduce the entry of CO_2 into the intercellular space, and non-stomatal factors that limit photosynthesis through the direct effect on biochemical manufacturing processes. Fischer *et al.*, (1998) confirmed that closure of stomata is one of the most important factors in reducing photosynthesis, which in turn, reduces the stomatal conductance and ultimately the amount of photosynthesis. In addition to reducing the rate of photosynthesis, stomatal restriction also reduces the concentration of carbon dioxide in the intercellular space of the leaf, which consequently reduces plant biomass (Lawlor and Cornic, 2002). In the present study, the stomatal apertures were probably closed by dust particles and consequently the amount of gas exchange was significantly reduced, which may be an important reason why the rate of photosynthesis in all three species exposed to dust was lower than the control. The rate of reduction in photosynthesis depends both on the obstruction in stomata and the rate of reduction of light absorption by the plant leaves. Plants which are exposed to large and chronic sources of dust are at risk abiotic stresses. Photosynthesis and consequently a decrease in growth (Takashi, 1995; Woo *et al.*, 2007).

Previously published electron microscope images show that the type of leaf wax coating in *Q. infectoria* species is of an irregular platelet type which causes the retention of dust particles on the leaf and also traps dust particles between parts of this wax, and as a consequence blocks the stomata (Moradi *et al.*, 2017). In addition, a high accumulation of dust on the leaf surface causes leaf temperature to rise and as a result, photosynthesis in the leaves is reduced (Javanmard *et al.*, 2020).

Several investigations have pointed to differences in the shape and density of the trichome and also the special shape of the wax surface of the leaf in different oak species (Panahi *et al.*, 2012; Moradi *et al.*, 2017). These different leaf structures can determine the amount of dust settling on the leaf, so it can be concluded that the leaf structure along with the amount of dust on the leaf determine the degree of obstruction of the stomata in and following dust storms. Moradi *et al.* (2017) found that the rate of obstruction of leaf stomata due to dust was 61.6%, 48.4% and 38.1% in *Q. infectoria*, *Q. libani* and *Q. brantii*, respectively. The results of the present study are in agreement with this research and show that *Q. infectoria* species is more sensitive to dust than the other examined species.

It should also be noted that in all three studied species, depending on the position of the leaf, mass accumulation of dust particles occurred, causing stomata to be completely blocked, disrupting gas exchange, reducing the absorption of light over leaf surfaces and finally raising leaf temperature (Sharifi, 1997; Wijayratne *et al.*, 2009; Javanmard *et al.*, 2020). Blocked stomata lead to a reduction in photosynthesis and plant production (biomass). Sharifi *et al.* (1997) reported that the uncontrolled accumulation of dust on plants changes the air flow on plant organs and, most importantly, when the dust load becomes greater, a significant percentage of the stomates are blocked and consequently a reduction in gas exchange and an increase in leaf temperature takes place.

The results of the present research are consistent with those described by Darley (1966), Eveling (1969), and Borka (1980). In these studies, it was mentioned that one of the potential effects of dust on photosynthesis is that a thick coating of dust on the leaf surface reduces stomatal conductance, decreases evapotranspiration, and finally increases leaf temperature and reduces growth. According to Thompson *et al.* (1984), photosynthesis decreases dramatically when 5 to 10 grams of dust per square meter is deposited on the leaves. The results of another study showed that an ash covering of 1 mm on the leaf surface reduces the photosynthesis process by up to 90% (Sett,

2017) At thicknesses less than 1 mm, the reduction rate varies between 25 and 33%. Of course, this effect will be different depending on the conditions and type of plant. The presence of dust on the leaf surface, in addition to reducing photosynthesis, will cause premature leaf aging and delay in plant growth and consequently reduce plant yield (Arvin and Cheraghi, 2014).

Seyyed Nejad *et al.* (2011) noted that air pollution stress causes the stomata to close, thereby reducing the CO_2 content in the leaves and inhibiting carbon, which is consistent with the results of this study that indicate the important role of stomatal behavior in responding to the effects of dust.

Roshanfekr *et al.* (2012) stated that the most sensitive indicator for examining the physiological condition of the plant, especially under stress conditions, is the behavior of the stomata. Another important factor in the discussion of dust is the size of the leaf stomata (Liang *et al.*, 2016). Some studies have shown that very fine particles (<0.1 microns) can enter the leaves through the stomata (Song *et al.,* 2015; Lehndorff *et al.*, 2006), but larger particles are deposited on the stomata when they are open, disrupting the gas exchange process which in turn affects photosynthesis, water retention, and overall growth (Rai *et al.,* 2010). Heavy metals are transported into the stomata openings directly into the leaf, while to move through the cuticle heavy metals must be in ionic form (Uzu *et al.*, 2010).

4.2 Leaf chlorophyll content

One of the most common effects of air pollution is a gradual decrease in chlorophyll and yellowing of the leaves, which may be due to a decrease in the photosynthetic capacity of the leaves (Joshi and Swami, 2009). The results of this study showed that there was no significant difference in chlorophyll a, b and total chlorophyll pigments between controls of the three studied species, but the presence of dust on the leaves had a significant effect on the amount of chlorophyll a, b and total chlorophyll pigments (α=5%). The shadow effects caused by the deposition of dust particles on the leaf surface probably reduced light absorption and consequently the chlorophyll concentration. Sediment particles may block the stomata, thereby disrupting gas exchange and increasing leaf temperature, as well as reducing chlorophyll content (Sandelius *et al.*, 1995; Banerjee *et al.*, 2003). These findings are in agreement with some studies which reported a decrease in chlorophyll content under dust particles and air pollution (Prusty et al. 2005; Seyyednejad, 2011; Chen *et al.*, 2015; Tiwari *et al.,* 2006; Joshi and Swami, 2007; Tripathi and Gautam, 2007; Joshi *et al.*, 2009; Agbaire and Esiefarienrhe, 2009).

The results of this study showed that only in *Q. infectoria* did dust deposition on the leaves have a significant effect on the amount of chlorophyll pigment, significantly reducing chlorophyll a, b and total chlorophyll in this species. Similarly, a decrease in the amount of chlorophyll pigments has been reported due to air pollution (Sharma and Tripathi, 2009). A substantial reduction in chlorophyll between 35% and 60% has been noted in some tree and shrub species due to contamination in industrial areas (Nayek *et al.*, 2011). A relationship has also been found between contamination density and photosynthetic activity, total chlorophyll content, and premature leaf aging (Honor *et al.*, 2009). Decreased photosynthesis rates may be due to insufficient production of chlorophyll or oxidation of chlorophyll by free radicals (Shiazaki *et al.*, 1980). According to the current results, in the other two species, especially in *Q. brantii*, there was a difference between control and dust in terms of chlorophyll pigments, but this difference was not statistically significant. Chlorophyll synthesis in *Q. infectoria* was more sensitive to dust than the other two examined species.

4.3 Leaf proline content

Some studies have shown that free proline content increases in response to various environmental stresses in plants (Levitt, 1972) such that, under different stresses, the amount of proline in different plants increases. For example, in plant leaves exposed to SO_2, heavy metals and other environmental stresses (Wang, 2011), leaf proline level increased. In fact, proline accumulation is one of the metabolic methods used by plants in response to stress (Hua *et al.*, 1997; Levitt, 1972). In general, the amount of proline in the leaves of the species in this study were substantially different from each other. Dust had a significant effect on the leaf proline content of *Q. infectoria*, increasing the proline content. It had the same effect in *Q. brantii*, although this effect was not significant. Since proline content increases in response to various stresses in plants, it may play a role in plant defense mechanisms. However, in this study proline increased in response to dust exposure and the impact on the proline content among the examined species was different. *Q. infectoria* showed a significant increase in proline content compared to the control, which indicates the high sensitivity of this species to dust in comparison to the other two species.

Proline has been reported to act as a free radical scavenger to protect plants from oxidative stress damage (Wang, 2011). Numerous studies have reported an increase in reactive oxygen species (ROS) due to environmental stresses such as air and soil pollution, low and high temperatures, and drought. The ROS produced is highly reactive and toxic for all plants (Pukacka and Pukacki, 2000; Woo *et al.*, 2007; Alscher *et al.*, 2002). Since there was a significant decrease in photosynthesis and chlorophyll, and an increase in proline in *Q. infectoria* species under the effects to dust exposure, it can be concluded that the decrease in photosynthesis rate is possibly due to insufficient production of chlorophyll or oxidation of chlorophyll by free radicals. This is in agreement with the findings of Shimazaki *et al.* (1980). Accumulated proline in plants has a role in actions such as osmotic composition, nitrogen storage composition, free radical scavenging, regulation of cellular oxidation potential, pH regulation and maintenance of cellular turbulence, which ultimately makes plants more tolerant in facing different stresses (Hua *et al.*, 1997; Levitt, 1972; Nakashima *et al.*, 1998).

4.4 Leaf mineral elements

Examination of the results of EDS dust on the leaves as well as EDS of soil samples showed that the elements of iron, silica and calcium were present in many repetitions. Due to the increase in the concentration of iron, magnesium and potassium in the leaves of the species treated with dust, it can be concluded that dust has increased these elements. The current results are consistent with the findings of Zarasvandi *et al.* (2012), however, these researchers mentioned an increase in the concentration of the heavy metals by dust. Although considerable research has been conducted on the amount of leaf mineral elements of species under other stresses such as salinity, the trend of changes in leaf mineral elements under the influence of dust has not previously been reported.

In general, the observed increase or decrease of leaf elements under the influence of dust in this research was such that it can be concluded that dust did not have a significant effect on these elements in the investigated trees. It is important to note that the amount of leaf elements varies during the growing season and different ages of the plants and they are different from each other. Therefore, it is necessary to conduct further investigations to identify and assess the impacts of the changes in leaf mineral elements under the influence of dust.

5 Conclusions

Plants act as air pollution absorber. Air pollutant particles are deposited on the surfaces of plants and affect their morphological and physiological characteristics. Trees improve air quality by absorbing suspended air particles, but they are also negatively affected by the accumulation of dust particles on leaf surfaces. In turn, air pollution can reduce tree growth as well as crop yield, reduce photosynthesis, inhibit physiological processes, functional and metabolic changes. The results of the present study also showed the adverse effect of dust deposition on the growth and performance of selected tree species in the northern Zagros forests. Dust deposition may result in a reduction of biodiversity and the loss of goods and services provided by the forest ecosystems in dust-affected regions.

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