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# Investigation of the efficiency of MaxEnt, topsis and invest models on site suitability and decline potential of Persian oak forests in Zagros, Iran (Ilam Province)

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FOREST ECOLOGY

## ABSTRACT

**Background:** Over the last decade, a significant area of Zagros forests, especially in Ilam Province, west of Iran, has been affected by the phenomenon of oak decline. The most basic item for fighting the decline of these forests is to know site suitability, the parameters affecting it, determining the criteria affecting the decline and preparing a map of the decline potential of these forests. In this study, the efficiency of Maxent on preparing site suitability map of Dalab and Bankol and the most important criteria affecting P.Oak decline was investigated by TOPSIS. The integrated valuation of ecosystem services and tradeoffs (InVEST) was used to prepare a zoning map of decline potential of P.Oak site. Validation of maps was done with receiver operating characteristic curve (ROC) and field visits.

**Results:** The results showed that pc-forest, distance from rivers and temperature are the most important criteria of the distribution of P.Oak. In addition, many parts of both sites were found to lack site suitability. The results of TOPSIS showed that the most important criteria of P.Oak decline are socio-economic criteria.

**Conclusions:** Decline potential in Bankol was much higher and the pressure caused by stressful criteria was higher in this site. The results showed 6 general stresses of land use change, grazing, pests, charcoal disease, fires and tourism in two sites. Dalab has shown a better condition in terms of decline potential. The reason for this is the operation of conservation management in this site. The obtained results show the efficiency of the used methods.

## HIGHLIGHTS

The results of Jackknife analysis and MaxEnt software modeling showed that pc, distance from the river and temperature are the most effective parameters in determining the species distribution of P.Oak and the high accuracy of the used model was proven.
A large area of both study sites has low suitability.
In the Dalab, due to protection and afforestation operations, it has decline less. In the Bankol, the pressure of stressors has been higher than in Dalab, and a larger area of the site has a high and very high decline potential.

**Keywords:** Quercus brantii; Zagros; maximum entropy; TOPSIS; InVEST; Iran.

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## INTRODUCTION

Zagros forests on the slopes of the Zagros Mountains, in the west of Iran, are 5500 years old and considered as important biological resources of Iran and the second largest natural forest ecosystem in Iran (Ghanbari Motlagh et al., 2020; Naghipour et al., 2021). The creation and expansion of the forest in this area is due to the rainfall caused by the Mediterranean system and the Black Sea (Mollaei, 2019; Zandebasiri et al., 2017). With an area of equivalent to 41.9% of Iran's forests, it covers 1300 km length and 200 km width on average. The most prominent tree species of these forests is the *Quercus brantii* (Persian Oak) (P.Oak) with a patch distribution that characterizes the physiognomy of these forests (Nourinejad and Rostami, 2014; Shiranvand and Hosseini, 2020). The increase in destruction rate, lack of proper protection, an increase in the area of agricultural land and land use changes, grazing, intentional and unintentional fires, increase in poverty and unemployment of local populations cause intensifying exploitation and decline of forest resources (Goodarzi et al., 2019; Hamzehpour et al., 2011; Zandebasiri and Pourhashemi, 2016). In addition, in recent decades, Zagros forests have dried up due to environmental stresses such as reduction in precipitation, an increase in temperature, fine dust, soil erosion, pests and diseases imposing a serious threat to the future of the region (Imanyfar et al., 2019; Karami et al., 2018; Attarod et al., 2017).

P.Oak decline is one of the basic problems of the Zagros region, and for the first time, alarming reports have been presented in the two provinces of Ilam and Lorestan. Today it covers almost the entire area of these forests (Zandebasiri and Pourhashemi, 2016; Mollaei, 2019; Ahmadi et al., 2014). Of course, this phenomenon has occurred in many forests around the world in the last few decades, as this disease is known as "sudden Oak death" (Gonzalez Alonso and Johansson, 2008; Ahmadi et al., 2014; Kabrick et al., 2008; Keča et al., 2016; Touhami et al., 2019; Thomas et al., 2002). The prevalence of this phenomenon, which has been mentioned under different titles such as decline, mortality and dieback, is a result of the mutual and complex effect of trees to pests and plant diseases and environmental stresses. According to literature review, the death of forest trees is not in the same in the world (Goodarzi et al., 2019; Linares et al., 2011; Fan et al., 2012; Touhami et al., 2019; Nourinejad and Rostami, 2014; Costa et al., 2010).

For finding the cause of this phenomenon, generally several categories of factors including biological, ecological and human factors as well as biotics and abiotic factors are involved (Hosseini et al., 2017; Keča et al., 2016; Gonzalez Alonso and Johansson, 2008; Fan et al., 2012; Mollaei, 2019). It is necessary to understand the death and decline of forest and trees, because it is referred to as an index of the health of the forest ecosystem (Thomas et al., 2002; Hosseini et al., 2017). Knowing the causes of the decline of these trees are difficult and complicated because in addition to the many effective factors, their interaction also adds to the complexity of the issue (Ghanbari Motlagh et al., 2020; Costa et al., 2010).

One of the important and key factors for predicting the response of the forest to the phenomenon of mortality and decline of the forest is the assessment of the potential of tree death. In this regard, different methods based on geographic information system (GIS) and remote sensing (RS) have been used in various studies. So far, several studies have been conducted using models such as MCDM (Ghanbari Motlagh et al., 2020; Ahmadi et al., 2016), correlation and regression (Hosseini et al., 2017; Costa et al., 2010; Karami et al., 2018; Attarod et al., 2017; Nourinejad and Rostami, 2014), indices and satellite data (Imanyfar et al., 2019; Shiranvand and Hosseini, 2020; Goodarzi et al., 2019) and artificial neural network (Alesheikh and Mehri, 2019). However, no study has been conducted to map the forest decline potential using InVEST model. Extraction of site decline map and sensitivity to various threats is one of the important abilities of this model. Estimating the relative effect of threats is also one of the most important functions of this model (Sharma et al., 2018). For instance, Christin et al. (2016), Nguyen et al. (2020), and Sharma et al. (2018) have used this model in forestry and forest management.

Another step of assessing the decline of the Oak species is to have information on site suitability of the species in relation to environmental parameters. Such information will make it possible to identify the sensitivity of decline and its effect on different parts of the site that have different ecological capabilities (Mahmoudvand et al., 2021; López-Tirado et al., 2018). Knowledge of the range of P.Oak distribution and the factors affecting is also very important in their management, sustainable exploitation and protection, especially now that the sites and population of this species have been limited due to the increase in human destruction, climate change, pests and diseases. Nevertheless, generally, due to the limited time and budget available for study, there is not enough information about the distribution of this species (Mahmoudvand et al., 2021).

Today, using GIS and RS has been increased for species distribution modeling (SDM), producing site suitability maps, and assessing the phenomenon of decline, which are all complex processes and under the simultaneous influence of several factors or criteria (Mahmoudvand et al., 2021; Çoban et al., 2020). Species distribution models are an important category of ecological models that are used to investigate the ecological niche of species, find potential regions of their presence, determine the most important environmental factors affecting their distribution and presence, and find new sites for species at risk in remote regions, and for planning and protection. These models are based on ecological niche theory (Charrua et al., 2020; Naghipour et al., 2021). In one of the most important models, Maximum Entropy (Maxent model), species presence data are used to determine species distribution, and the most important factors affecting it, and model site suitability (Phillips and Dudík, 2008; Smith et al., 2012). Various studies have been conducted around the world using species distribution models for modeling the distribution of different forest species and determining the factors affecting it. McLaughlin and Zavaleta (2012) for modeling the distribution of *Q. lobata* by GARP, Bioclim and Maxent showed that seedlings of this species were more sensitive to heat and the site was generally limited to the proximity of water sources. Çoban et al. (2020) modeled the species distribution of *Q. libani* by Maxent under climate change scenarios in Turkey. López-Tirado et al. (2018) investigated the species distribution of Q. ilex, *Q. suber* and *Q. coccifera* in Western Europe using GCM algorithm under climate change scenarios. Vessella and Schirone (2013) investigated the prediction of the potential distribution of *Q. suber* in Italy using GARP and Maxent ecological niche models and ROC curve. Mahmoudvand et al. (2021) investigated the modeling of site potential and environmental parameters affecting the distribution of Q.brantii in the forest sites of Lorestan using Maxent. Naghipour et al. (2021) also predicted the geographical distribution of Crataegus azarolus L. under the influence of climate change in Chaharmahal and Bakhtiari Province in the central Zagros region in Iran by 7 species distribution models (GLM, Maxent, ANN, GBM, FDA, MARS and RF) and physiographic, land and bioclimatic variables.

Ilam Province in the west of Iran has 642 thousand hectares of forest considered one of the semi-arid forests of the Zagros Mountain Range. Its dominant type is Persian oak (*Quercus persica*) (P.Oak), which accounts for about 90% of the forest cover of the province. Unfortunately, reports of the General Directorate of Natural Resources of Ilam Province show that the number of trees decline in the forests of Ilam Province is more than that of other Zagros provinces. The goals of this research include: -Preparation of habitat suitability map of P.Oak in Dalab and Bankol satands using Maxent model and comparing two stands; - Investigating parameters affecting the suitability of two sites based on the jackknife test and response curves; - Investigating the most important factors affecting P.Oak decline using the TOPSIS method; - Modeling the decline potential of these sites using the InVEST model and comparing the two stands.

## MATERIAL AND METHODS

### Study area

In this study, after the primary study and field visits, we selected the two forest stands with signs of decline, Bankol and Dalab, in the north of Ilam Province and near Ilam in the west of Iran. The geographical location of Dalab site is 46° 23′ 00″ East and 33° 42′ 03″ North, with an average elevation of 1564 m, slope of 16.66 degrees and area of 598 hectares. The geographical location of Bankol site is 46° 15′ 40″ East and 33° 54′ 45″ North, with an average elevation of 1327 m, slope of 8 degrees and area of 427 hectares (Figure 1). The forests of the region are generally pure forests of Persian Oak (*Quercus brantii*) (P.Oak) in the form of seeding forests and in some places in the form of seeding and coppice forests. The climate of these regions is semi-arid based on Embereger classification. The total annual rainfall is 595 mm, the maximum and minimum-recorded temperatures are 40.6 and -12.6 ° C, respectively. The rainfall regime of the province is such that about 50% of the rainfall falls in the winter, 20% in the spring, 29% in the autumn and 1% in the summer. In the division of the main soil types, the studied area is placed in the mountains type and its soil is placed in the category of shallow to semi-deep gravelly soils, Lithosols, and Calcaric Regosols. From the geological point of view, Ilam Province is located in the folded Zagros region (IDNRWM Report, 2013).

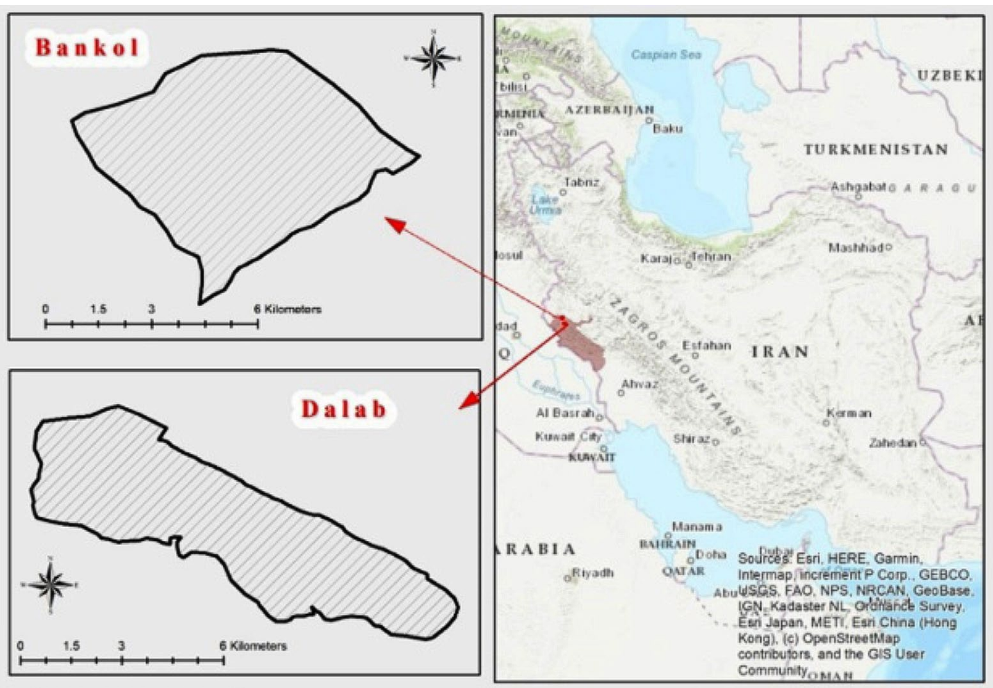


**Figure 1:** Location of P.Oak sites studied in western Iran.

### Site suitability map and the most important variables affecting P.Oak distribution

The species distribution of P.Oak site in this study was modeled using Maxent and maxium Entropy. In Maxent, it is not necessary to have complete data of all presence points, but an introduced sample of presence points that covers most or the entire site is sufficient (Smith et al., 2012). This model is used for both continuous and discrete variables and its output is a continuous raster prediction map (Phillips and Dudík, 2008; Naghipour et al., 2021). The output of the software is site suitability output map, ROC curve, species suitability response diagrams to environmental variables and Jackknife diagram. Biological data included the location of P.Oak species in the site. These data are obtained from statistical and geographical registration of species presence regions in inventory plots. Thus, according to the area of the stands, several transect lines were determined. A number of sample plots with dimensions of 50 × 50 m$^2$ were located along each transect. The coordinates of each plot were recorded again by GPS. Environmental data included ecological layers as input and in the form of a raster in ArcGIS or TerrSet IDRISI. These criteria are given in Table 1.

Jackknife method is response curve is used to determine the importance of environmental variables in the model. The predicted models were validated using ROC curve (Receiver Operating Characteristic) and the area under the curve (AUC). Models with AUC=0.5 are completely random models, models with AUC>0.7 have useful efficiency, models with AUC>0.9 are considered as models with excellent efficiency (Charrua et al., 2020; Yi et al., 2022; Ghanbari Motlagh et al., 2020).

### Modeling and zoning decline potential of P.Oak and determining the most important factors affecting it

In this study, the primary criteria affecting the decline of P.Oak were identified using study articles, field visits and the opinions of forest experts. TOPSIS model was used to investigate the factors affecting the decline of P.Oak to determine the extent of their influence on the decline phenomenon. The basis of this technique is that the selected option should have the smallest distance with the positive ideal solution ($A^+$) and the largest distance with the negative ideal solution ($A^-$). The index value is between 0 and 1 (Chen 2000; Ertugrul and Karakasoglu 2007). Ranking in this method is based on the distance from the positive and negative ideal solution (Ertugrul and Karakasoglu, 2007; Mohammadi et al., 2011). Stages of TOPSIS in this study were performed as follows (Muhammadi et al., 2011):

1) Forming a decision matrix from the collected data of the criteria and a data matrix based on n criteria and m options. i represents options and *j* represents criteria. is the *i* index value for the *j-th* option (equation 1);

$$(i = 1,\ldots m),\ (j = 1, \ldots n) = \begin{bmatrix} x_{11} & x_{12} & \ldots x_{1n} \\ x_{21} & x_{22} & \ldots x_{2n} \\ \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \ldots x_{mn} \end{bmatrix} \quad (1)$$

2) Unscaling the decision matrix and standardizing the criteria;

3) Determining the weight of each of the criteria based on (Equation 2);

**Table 1:** Information of the parameters used in site suitability and decline potential maps in the studied sites.

| Criteria | Resource/ formula/ methods/ software |
|---|---|
| Elevation | DEM elevation model/ Aster/ ArcGIS |
| Slop | DEM elevation model/ Aster/ ArcGIS |
| Aspect | DEM elevation model/ Aster/ ArcGIS |
| Total annual Rain | 30-year statistical data of Meteorological stations in the regions/ Kriging Interpolation / ArcGIS |
| Mean annual Temperature | 30-year statistical data of Meteorological stations in the regions/ Kriging Interpolation / ArcGIS |
| Evaporation | 30-year statistical data of Meteorological stations in the regions/Kriging Interpolation / ArcGIS |
| Distance from the rivers | Mapping Organization of Iran/ ArcGIS |
| Land use change map | Sentinel 2/ TerrSet with field visit and Google Earth images |
| forest land use disturbance (ne) | Land use change map/ TerrSet |
| forest edge changes (ed-forest) | Sentinel 2/ Forest/ non forest map/ TerrSet |
| forest patch density (pc) | Sentinel 2/ NDVI map/ TerrSet |
| Soil texture | Geological Organization of Iran/ ArcGIS |
| Grazing | Field data, consutation with experts and local people, and data from the IDNRWM / ArcGIS |
| Charcoal diseases | Field data, consutation with experts and local people, and data from the IDNRWM / ArcGIS |
| Pests | Field data, consutation with experts and local people, and data from the IDNRWM / ArcGIS |
| Fires | Field data, consutation with and data from the IDNRWM / ArcGIS |
| Tourism | Field data, consutation with experts and local people, and data from the IDNRWM / ArcGIS |

$$\sum_{j=1}^{n} W_j \quad (2)$$

4) Turning Stage 2 decision matrix into a weighted unscaled matrix;
5) Obtaining the positive ideal solution ($A^+$) by determining the maximum value. $v_j^+$ is the ideal value + for the j criterion and the negative ideal solution ($A^-$) by determining the minimum value based on $v_j^-$ is the ideal value - for the j criterion;
6) Calculating the distance from the positive and negative ideal. $S_i^+$ the distance of the *i* option from the positive ideal based on (Equation 3) and $S_i^-$ the distance of the ith option from the negative ideal based on (Equation 4), where $V_{ij}$ is the weighted normalized matrix elements.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2} \quad (3)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \quad (4)$$

7) Calculating the relative proximity of each option to the ideal solution based on index, whose value varies between 0 and 1, and finally ranking the options based on their proximity to the ideal solutions and the index ($C_i^+$).

The criteria included charcoal disease, grazing, pruning, slope, aspect and elevation, rainfall, temperature, land use change, tourism, fire and pests. Pests included wood- and bark-boring insects and they are secondary pests. These pests are mainly identified from Buprestidae and Cerambycidae families. In the following, the results of ranking the criteria affecting the decline obtained from TOPSIS were mapped. Most of the data related to these criteria were obtained from field inventory described at the previous stage. Physiographic and climatic criteria and the land use change map were explained in the previous section. The map of charcoal disease, pruning, fire and grazing and tourism was also prepared from field inventory data, opinions of experts and local people and the data of the IDNRWM. Data layers made from the criteria were transferred to InVEST ecosystem services software to obtain decline potential model of two sites. The raster file of all threats or decline factors is an information source. The weight of each threat or decline factor that was obtained from the previous stage and TOPSIS was entered the software in the form of an Excel file. Then, site sensitivity to each threat was determined.

### Validation of final maps

After preparing site decline potential maps, we had field visits of regions with high and very high decline potential to investigate the accuracy of these output maps, having the maps. This work was done by having the maps and checking the appearance of the trees in terms of health and degree of decline at random points in the sites. A classification with 4 deterioration codes 1 (no decline and healthy trees), 2 (low decline/ less than 25% of the crown), 3 (moderate decline / 25-50% of the crown) and 4 (very high decline / more than 50% of crown) was used.

## RESULTS

According to the results of site suitability modeling by Maxent, in the study area, 11 important criteria played a key role in the distribution and suitability of the studied sites. The response curve of topographical parameters, including slope, aspect and elevation, showed that P.Oak had a higher tendency to settle in flat regions, and by changing the aspect to the north, the ecological capacity of the species to establishment increased, and it finally reduced towards the east and southeast. In contrast, a higher suitability has been recorded in the western and southern aspects compared to the northern aspect (Figure 2a). In addition, elevation had a multiple response to the P.Oak establishment, high site suitability at 1000 m, then by increasing up to 1300 m, site suitability increased and finally at 1300-1400 m, site suitability has shown a decreasing trend (Figure 2b). For the slope, site suitability has reduced by increasing the slope. In slopes less than 5%, site suitability for the establishment of P.Oak was above 60%. But, by increasing the slope up to 45%, the study area becomes practically unsuited for P.Oak (Figure 2c). The relationship between climatic factors including evaporation, rainfall and temperature and the distribution of P.Oak has shown that by increasing the evaporation from 94 to 95 mm in the study area, site suitability has practically improved (Figure 2d). In addition, rainfall played a key role in site suitability of the P.Oak. For rainfall less than 400 mm, site suitability was practically very low, and by increasing rainfall, site suitability reached a high level (Figure 2e). Temperature response curve showed that the optimum temperature for the growth of P.Oak is 14°C. Then, for every 0.1°C increase in average temperature, site suitability reduces by 15% (Figure 2f). Rivers and drainages of the study area showed an interesting response to the establishment. At distances of 50-700 m in the study area, due to the airflow of water evaporation and the flow of subsurface water, the most suitability for P.Oak has been identified. Accordingly, as we get closer to the river, the competition of the species with other species reduces. Meanwhile, at distances of 700-2000 m, site suitability for P.Oak is relatively constant, and as the distance increases, site suitability reduces exponentially (Figure 2g).

The response curve of forest alnd use disturbance (ne) shows that the higher the variety of land uses, the more challenging the entropy of the ecological structure of the site, shown linearly in the model. By reducing ne, the disturbance increases and site suitability reduces (Figure 2h). The response curve of site suitability to ed-forest shows that reducing pc-forest from 200 m to 1 m leads to destruction and this increases the lack of site suitability. This issue also plays a role in the decline

(Figure 2i). When pc-forest reaches from 0.1 to 0.2 in a site, this ecological island maintains its suitability for the growth of P.Oak for years, and can play a key role in the further growth of P.Oak. Although the islands are shown with the density of patches, the ecological relationship with other species in isolated areas is practically cut off. The reasons for the recent issue are fires, grazing, pests and decline (Figure 2j). The importance of bedrock and soil showed that the priority of P.Oak suitability was in sandy and loamy soils, respectively (Figure 2k). The results of Jack-knife showed that the most important criteria affecting the distribution of P.Oak in the study areas are site continuity (pc), distance from rivers, temperature and evaporation (Figure 2l).

The preliminary assessment of site suitability of Dalab and Bankol showed that given the above criteria and ROC curve, the accuracy is 88% for Dalab and 90% for Bankol, which indicates the high accuracy of site suitability maps. These maps can be referenced and cited (Figure 3, right). The assessment results of site suitability showed low and very low suitability to high and very high suitability in both regions. 19.57% (117 ha) and 6.35% (38 ha) of Dalab had very high and high suitability, and 16.63% (71 ha) and 11.48% (49 ha) of Bankol had very high and high suitability, respectively. 3.01% of Dalab and 10.54% of Bankol had moderate suitability (Figure 4). More than half of the area of both regions has low and very low suitability. Low or limited suitability is significantly different in the two regions. According to the spatial maps, in Dalab there is concentrated site suitability, while in Bankol, there are scattered forest patches (Figure 3, left).

To present a spatial model of P.Oak decline and find and assess the most effective criteria according to experts' opinion, TOPSIS was used and finally, a map of P.Oak sites decline potential model was prepared from InVEST. According to the results of TOPSIS, the criteria of land use change, grazing, pests, charcoal disease, fires and tourism have obtained the highest negative points from TOPSIS solution, which were included in the decline potential model, respectively (Figure 5).

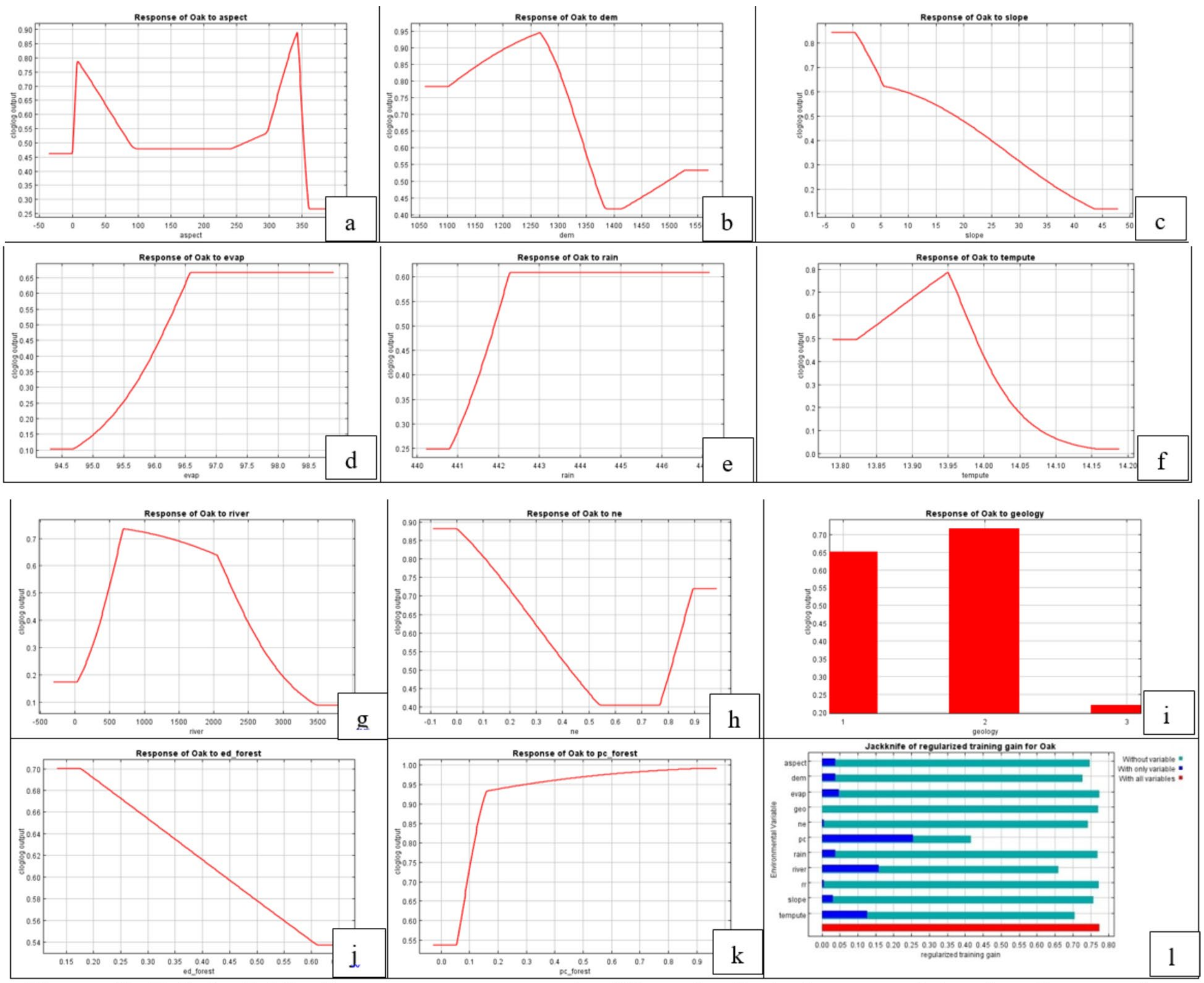


**Figure 2:** P.Oak distribution response curve to different criteria (a: aspect, b: elevation, c: slop, d: evaporation, e: rainfall, f: temperature, g: distance to rivers, h: ne, i: soil, j: ed-forest, k: pc-forest, l: Jackknife analysis output).

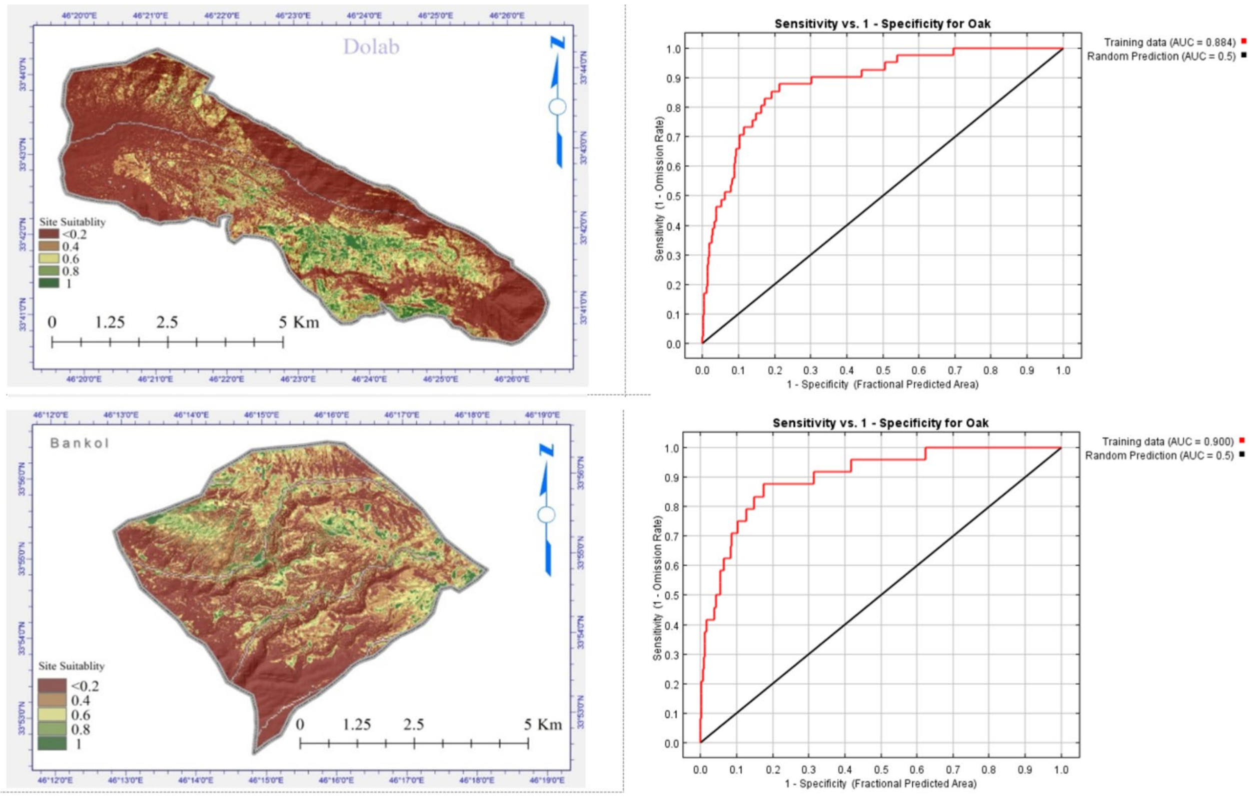


**Figure 3:** ROC curve of site suitability model (right), site suitability map of two regions (left).

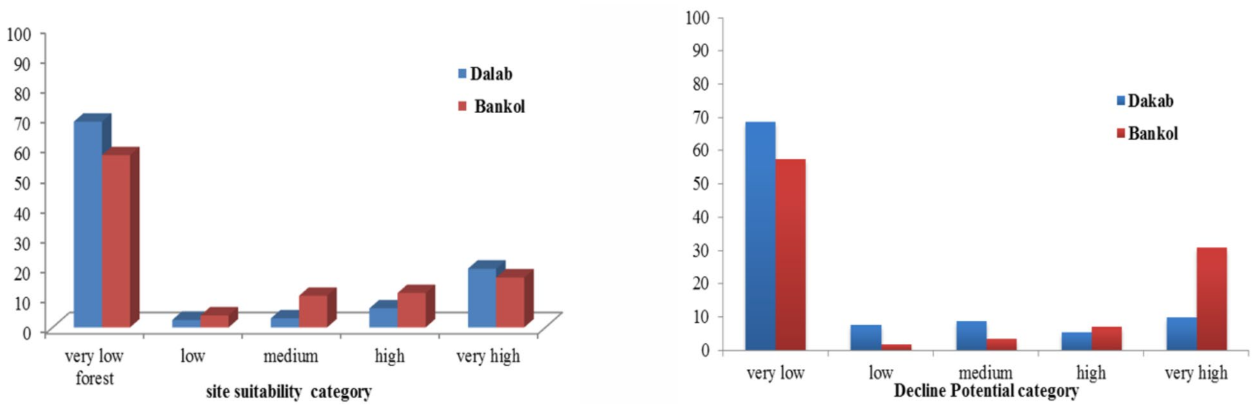


**Figure 4:** Suitability classification of P.Oak sites in the study area (left), and classification of P.Oak Decline potential classes in the study sites (right).

According to the study results of the pressure and stress of site decline in two regions (H1: Bankol and H2: Dalab), the cumulative P.Oak decline potential is much higher in Bankol. The pressure caused by stress in Bankol is 13 on 13, which is the highest decline score in the ecosystem service model. Accordingly, threats and risks here are worrying. In Dalab, this number is about 8 on 8 (Figure 6, right). The study results of 6 general stresses in the site showed land use change (S6), grazing (S5), pests (S4), charcoal disease (S3), fires (S2) and tourism (S1), respectively. In the study of the sites, changes in agricultural use, the potential threat of the region was determined from every point of view. In the next ranks, the greatest pressure on the environment was caused by grazing, pests and diseases. In relation to fires and tourism, there is also pressure due to lack of management, which should be considered (Figure 6, left).

According to the results of P.Oak decline potential model in Bankol, more than 37% of the area had high and very high decline potential. 3% of the area had moderate decline potential, and about 40% of the area was in a worrying environmental situation, which are mostly located in the eastern, northwestern and central regions (Figure 4). In the afore-mentioned area, according to time-management criteria, there is severe stress or decline in 351 patches. Therefore, if no quick management operation is taken, the decline will spread from the west to the east of the site (Figure 7 right). While Dalab had more optimal conditions and only in the central part of the site there is a major concern of decline, where an area of 91 hectares (about 14% with high and very high decline potential) experiences the highest level of decline (Figure 7 left and Figure 4). In this site, due to the elevation and protection management, there is no serious risk of P.Oak decline in most of its area, and only due to agricultural interference (land use change), which is weak in terms of ecological strength and suitability, more decline was seen (Figure 7, left). It should be noted that the high area of the regions with low decline is due to the low density of the forest and the interference of other uses, not because of the good condition of the sites.

## DISCUSSION

### Site suitability of P.Oak and the criteria affecting it

According to the results of Jack-knife, the most important criteria affecting the distribution of P.Oak are pc-forest, distance from rivers, temperature and evaporation, respectively. According to the study results, reducing the patch density (pc-forest) and increasing discontinuity, which can be due to many reasons, including land use changes, fires, grazing, and pests, were effective on reducing site suitability of P.Oak in Zagros. According to the semi-arid climate of the study area, the increase in temperature caused a reduction in the humidity for plant growth, which can be one of the growth limiting factors. Radmehr et al (2014) reported that increasing temperature reduced the growth of P.Oak. In a study by Mahmoudvand et al. (2021) in the forest sites of Lorestan, using Maxnet, the average temperature of 16 °C showed the highest suitability, and by increasing temperature, the probability of species presence reduced. While the present study reported 13-14 °C. Water shortage in trees occurs due to the increase in temperature. As a result, high temperature along with water shortage causes drought stress in the tree, reduces water storage and carbon absorption, and finally reduces growth. For the climatic variable of rainfall, Mahmoudvand et al. (2021) have recorded the maximum probability of the presence of the species with 330 mm of rainfall, while the present study reported 400 mm. Vessella et al. (2017) considered

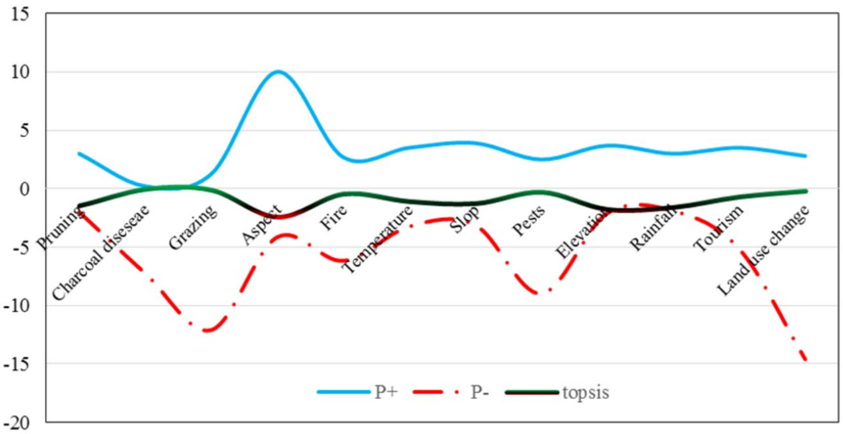


**Figure 5:** Selected criteria for the preparation of the map of the decline potential of P.Oak sites.

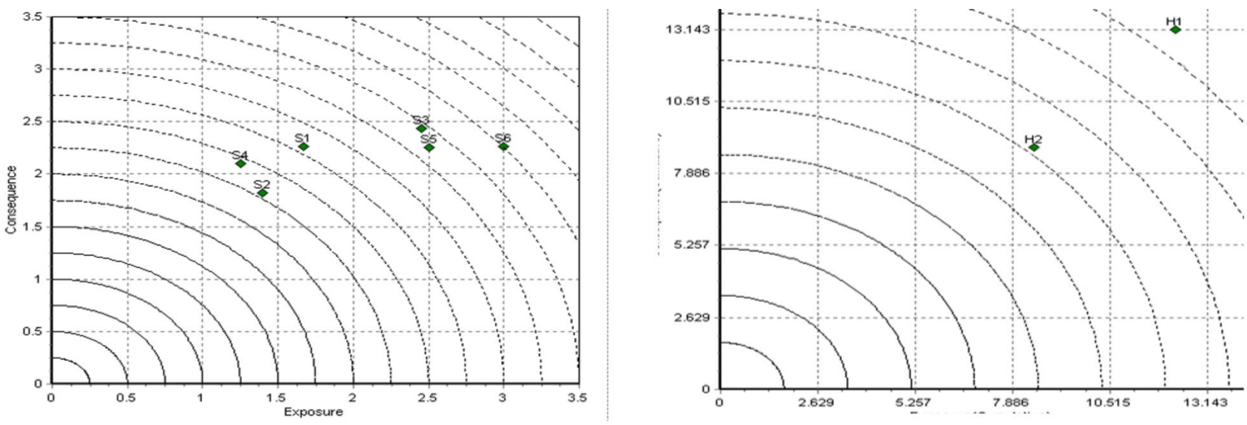


**Figure 6:** The position of two sitess in the P. Oak decline potential diagram Invest (H1: Bankol and H2: Dalab) (right), general stress criteria for the decline of P.Oak species in the study sites (left).

drought and cold stresses as the main factors affecting the distribution of *Q. suber* in Italy. In addition, proximity to rivers plays an important role in water availability of P.Oak. Thus, we observed an increase in N/ha in the valleys and near the rivers. Increasing the rainfall increases P.Oak site suitability. In a study, McLaughlin and Zavaleta (2012) by modeling the distribution of *Q. lobata* species in California, USA showed that the site of this species was generally limited around rivers by increasing temperature. The models used for predicting site index by Paulo et al. (2015) reported the importance of water availability and soil water storage for the spatial distribution of *Q. suber* L. in Portugal. The response curve of ecological parameters to the establishment of P.Oak showed that P.Oak tend to establish in flat areas, north, west and south aspects, elevation range of 1100-1300 m, low to medium slopes, sandy and loamy soils. Soil variables have significant effects on soil water availability throughout the year (Paulo et al. 2015).

For land use change, as expected, forestland use disruption and the influence and interference of other land uses, including agriculture, will reduce Oak site suitability. A study by Costa et al. (2009) reported land use changes and forest conversion to agricultural areas and the abandonment of these lands as the main determinant of *Q. suber* forest growth in the Bartolomeu da Serra, southwest Portugal. They have stated that the slope, aspect and type of soil were also important factors. In a study by Mahmoudvand et al. (2021) on the forest sites of Lorestan, using Maxnet, the average annual temperature, the rainfall of the wettest 3 months, and the minimum temperature of the coldest month were the most important variables affecting the distribution of the P.Oak species, respectively, and ROC value of the model was 0.669. The studies by Vessella and Schirone (2013) and Hidalgo et al. (2008) showed that the minimum temperature of the coldest month could be effective in predicting the distribution of *Q. suber* species.

According to site suitability maps, many parts of the two study areas had very low site suitability. About 30% of Dalab had moderate to very high suitability, and about 40% of Bankol had moderate to high and very high suitability. The results showed low site suitability of the region for the establishment of P.Oak. In Dalab, site suitability was concentrated in the southern and many parts are found to be unsuitable. In Bankol, site suitability was observed more in scattered patches in the northern, western and eastern parts, especially along the valleys. In this study, for the first time, other parameters such as forestland use disturbance (ne), forest edge changes (ed-forest), and forest patch density (pc-forest) have been included in estimating site suitability of P.Oak. Other studies have investigated more climate or soil parameters. The strength of this study is the use of more parameters, including continuity of forest patches.

## Decline potential of P.Oak and its affecting factors

According to results of TOPSIS, experts' opinions and pressure and stress in the occurrence of P.Oak decline based on InVest in the two sites studied, the most important criteria are economic-social and human pressure (land use change, grazing) and biological pressure (pests and charcoal disease). The next two criteria (fire and tourism) are also following the human criteria. Research results of Ahmadi et al. (2014), in the same province (Ilam), based on the AHP, have reported the climatic factors with the premier role in the P.Oak decline. Attarod et al. (2017) also in a study introduced significant correlation of climatic factors and Hosseini et al. (2017) introduced the parameters of slope, aspect and elevation as effective criteria on decline of P.Oak in Lorestan Province, Iran. In a study, Karami et al. (2018) showed the highest correlation between the severity of decline and the decline parameters of aspect and soil bulk density. The results of Pearson's correlation regarding the relationship between topographical factors and the decline of P.Oak in a study by Nourinejad and Rostami (2014) in the mountains of Bankol in Ilam Province showed that the effect of elevation and aspect on the decline of P.Oak forests was insignificant and the effect of slope was positive and significant. Ghanbari Motlagh et al. (2020) in the forests of Kohgiluyeh and Boyer Ahmad Province, southwest of Iran, have reported that the criteria of pests, average annual temperature and distance from agricultural lands had the highest score in

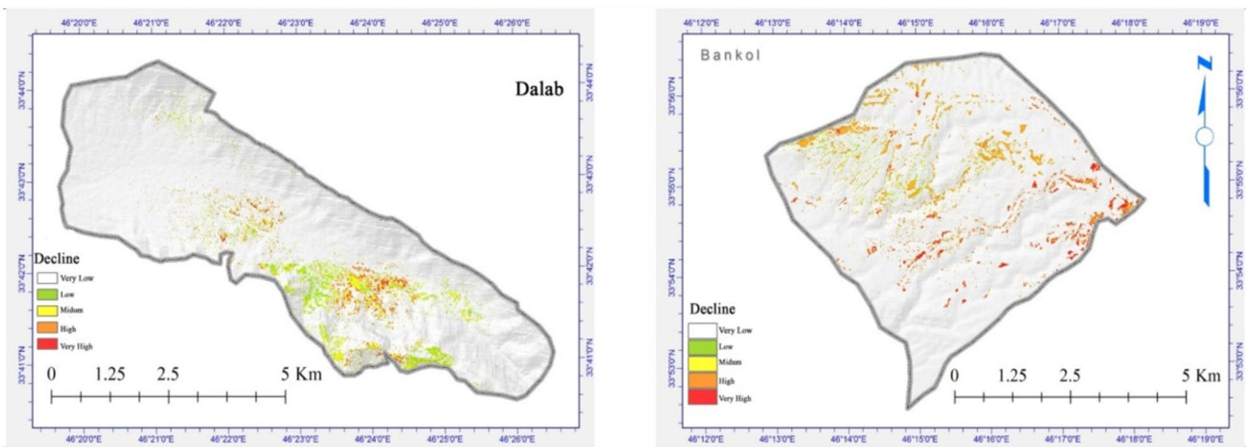


**Figure 7:** Map of P.Oak decline potential in Bankol (right) and Dalab (left).

the assessment of the decline of the area. Touhami et al. (2020) have reported climate change (high temperature and drought) as the reason for the decline of cork Oak forests in the Mediterranean basin in northwestern Tunisia. In a study on Spanish Oak forests, Galiano et al. (2012) concluded that the drying of the crown due to the drought phenomenon had a multifactorial nature and individual characteristics of trees, such as the number of trees/ ha, play an important role in the spatial pattern of drought in the forest.

Inconsistent with the present study, most of the afore-mentioned studies focused more on climatic and physiographic criteria and ignored the role of socio-economic factors. Many researchers in different parts of the world have searched for the main source of the decline phenomenon in droughts and heavy drought stress. However, other cases (pests, various diseases or reduction in N/ha) have also been found to be effective on its occurrence (Linares et al. 2011; Guarın and Taylor 2005; Gentilesca et al. 2017; Touhami et al. 2020; Mollaei 2019).

In the forests of Zagros, charcoal disease (Biscogniauxia mediterranea) and all kinds of wood- and bark-boring insects have erupted after the droughts and lack of rainfall. On the other hand, human disturbances in the form of land use changes and the increase in agricultural lands, grazing and deforestation, fires, and tourism have weakened the forests of Zagros for many years. With the weakness of the trees and susceptibility to pests and diseases, the process of drying and death of P.Oak has accelerated (Sepahvand and Zandebasiri 2014; Hamzehpour et al. 2011; Nourinejad and Rostami 2014; Hosseini et al. 2017; Mollaei 2019).

Nevertheless, the above factors in the form of in the long term cause this phenomenon despite the low site suitability. The pressure of these socio-economic criteria is much higher in Bankol than in Dalab. This is shown in the form of a larger area with high and very high decline in Bankol. For this reason, in this site, despite having a higher site suitability, more decline is observed. On the other hand, Dalab showed a better state of decline due to the conservation management applied there in the last 10 years. In this site, afforestation and cutting of the infected trees has been done in recent years. In a large part of the area of Bankol, N/ha of P.Oak is very low and a large area is under the influence of agriculture and grazing due to the poverty of the people in the region and the high livelihood dependence on these forests. This is currently considered as the most important challenge for the protection of these forests. In a study on drought P.Oak trees in Fars Province by Hamzehpour et al. (2011), the effects of agriculture and pruning on dried trees were observed and they reported the highest decline of P.Oak in forest areas close to agricultural lands. Zandebasiri et al. (2017) showed that 74.58% of the local people consider their livelihood dependent on the forest.

In addition, the low income of the local people and their dependence on agriculture has been the main socio-economic problem and the main cause of the destruction of forestlands and the phenomenon of decline. In a study, Costa et al. (2010) by logistic regression in the Mediterranean region also reported a higher decline potential of *Q. suber* in areas where forestland use disturbance was more due to the expansion of agricultural lands.

According to the results, it is suggested that protection in these forests should be put on the agenda. The sustainable agriculture and agroforestry systems are among other solutions. Animal husbandry in these regions should not be traditional and forest-dependent as soon as possible. Operation such as more efficient management of water resources, preventing agriculture and deforestation, identifying drought-resistant genotypes and using their seeds for afforestation, cutting dried trees infected with pests to prevent transmission to other trees, using biological methods to fight pests in these regions can reduce the rapid spread of P.Oak decay phenomenon in the short term. Continuous monitoring of these sensitive, susceptible and infected forests is also very necessary to provide long-term management plans.

## CONCLUSION

The results of Jack-knife analysis showed that the most important criteria affecting the distribution of P.Oak in the studied sites were site continuity (pc), distance from rivers, temperature and evaporation. P.Oak distribution response curve to different criteria showed that this species has the highest site suitability in flat regions, north-west and south aspects, low slopes, up to 1300 m and sandy and loamy soils. The optimal point of rainfall, temperature and evaporation and distance from surface water for P.Oak were 400 mm, 14 °C, 95 mm and distance from 50 to 700 m, respectively. By reducing ne-, ed- and pc-forests, site suitability of the site has reduced. The ROC curve for both sites showed the high accuracy of Maxent for assessing site suitability and the efficiency of this model. A total of 29 and 39% from Dalab and Bankol had medium, high and very high site suitability, respectively. A large area of both study areas had low suitability. In general, the conditions indicate the poor suitability of the studied sites due to the lack of optimal ecological conditions. There are 6 general stresses in sites included land use change, grazing, pests, charcoal disease, fires and tourism, respectively, more acute in Bankol. In Bankol site, more than 37% of the region has high and very high decline potential. In Dalab site, the conditions were more optimal and about 14% has high and very high decline potential. In the Dalab site, despite the lower site suitability for P.Oak, due to the protection of protection and forestry operations in the past years, less decline has been observed. The pressure of socio-economic criteria such as land use changes and grazing in Bankol is much more than in Dalab.

## AUTHORSHIP CONTRIBUTION

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Processing: SBK, HB

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Review: HK, SBK, HB

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