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# Influence of some ecological variables on wild mushroom (*Boletus edulis*) productivity

## Bazı ekolojik faktörlerin doğal mantar *(Boletus edulis)* verimliliği üzerine etkisi

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**Abstract**

Wild mushrooms, *Boletus edulis* in particular are among the most important non-wood forest products (NWFPs) all over the world due to their nutritional, medicinal, ecological and recreational importance. Increasing socioeconomic value of wild mushrooms is made consider these products as an alternative for timber. Integrating mushroom-based ecosystem services into sustainable forest management plans requires understanding of the relationships between mushroom yields and its ecological drivers. This study evaluated the influence of some ecological variables such as slope, aspect and altitude on the productivity of wild mushroom, *Boletus edulis*. Mushroom data was collected from 75 permanent plots in Bicik planning unit covered by mixed even aged forest. Significant differences were found among aspect and slope classes whereas there were no differences among elevation classes with one-way ANOVA analysis. According to the results lower mushroom productivity was found in the areas of north aspects or slopes between 20-30% with 6.5 kg/ha-116.7unit/ha and 33 kg/ha-333.3unit/ha respectively than the other aspect and slope groups. This study showed that to obtain general knowledge relating to the effects of more ecological factors on mushroom productivity further research efforts is needed for all valued wild mushrooms, in the different ecosystems.

**Özet**

Yabani mantarlar, özellikle de ayı mantarı (*Boletus edulis*) yiyecek ve ilaç sanayiinde kullanılmalarının yanı sıra ekolojik ve rekreasyonel önemlerinden ötürü en kıymetli odun dışı orman ürünleri arasındadır. Yabani mantarların giderek artan sosyoekonomik değerleri, bu ürünlerin odun üretimine bir alternatif olarak düşünülmesine neden olmaktadır. Mantar ürünlerine dayalı ekosistem hizmetlerinin sürdürülebilir orman amenajman planlarına entegrasyonu, mantar verimliliği ile ekolojik değişkenler arasındaki ilişkilerin sayısal olarak anlaşılması ile mümkündür. Bu araştırmada, eğim, bakı ve yükseklik gibi bazı ekolojik değişkenlerin ayı mantarı (*Boletus edulis*) verimliliği üzerindeki etkisi değerlendirilmiştir. Çalışmada kullanılan mantar envanter verileri Bicik Planlama birimi sınırları içerisindeki 75 adet devamlı örnekleme alanından elde edilmiştir. Tek yönlü varyans analizi sonuçlarına göre ilgili mantar verimliliği ile meşcere eğim ve bakısı arasında anlamlı bir farklılık gözlemlenirken, meşcere yükseltisi ile anlamlı bir farklılık tespit edilememiştir. Buna göre, kuzey bakılı alanlar ile eğimin %20-30 arasında olduğu meşcereler sırasıyla 6.5 kg/ha-116.7adet/ha ve 33 kg/ha-333.3adet/ha değerleri ile diğer eğim ve bakı gruplarına göre daha düşük miktarda mantar verimliliğine sahip olmaktadır. Elde edilen bu sonuçlar mantar verimliliği ile farklı ekolojik değişkenler arasındaki ilişkilerin net olarak belirlenebilmesi için mevcut analizlerin farklı ekosistemlerdeki değerli tüm doğal mantar türleri için yaygınlaştırılması gerektiğini göstermektedir.

## INTRODUCTION

Wild mushrooms are valuable non-wood forest products (NWFPs) worldwide. Mushrooms are important food source with their nutritional value comparing many vegetables. Due to their medicinal properties, they are used traditional medicine in many country (Boa 2004; Lelley 2005). Furthermore, they contribute to ecosystem functions such as leisure, biodiversity conservation and tourism (Boa 2004; Martinez de Aragón et al. 2011; Buntgen et al. 2017) as well as their contribution to nutrient and carbon cycles (Mohan et al. 2014; Stokland et al. 2012). Mycological tourism attracts many people willing mushroom picking for leisure activity liked to nature every season in some country such as Spain, Canada, and Finland.

Turkey wild mushroom industry is valued at about 25-45 million dollars with an estimated harvest of 250-400 tons annually (TUIK 2016). This value would be higher if the recreational value of this product were considered (Latorre 2016). Therefore, mushrooms become strategic in the conservation and management of forest ecosystems. Over the last decade, because the market value and consumer demand have increased, the socioeconomic value of wild forest mushroom may be higher than the economic value of timber in a managing forest (Palahi et al. 2009; Kucuker 2014; Kucuker and Baskent 2017a). The increase in the socioeconomic values of wild mushrooms caused forest owners and forest managers to consider these products as an alternative to timber products.

Sustainability of mushroom products cannot be ensured without a detailed knowledge about mushroom. Identifying the habitat of mushrooms is one of the most important steps for the sustainable planning. Thus, the integration of mushroom production into forest management plans requires quantitative knowledge of the mushroom yields and its environmental drivers. These relationships are basis of predictive models, decision support systems using to select optimal forest management alternatives and joint production of mushroom and timber (Palahi et al. 2009; Tahvanainen et al. 2016; Tahvanainen et al. 2018; Kucuker 2014; Kucuker and Baskent 2017a;b).

Recently mushroom occurrence and productivity have been focused of many studies and wide ranges of variables have been indicated as effective factors on mushroom yield. These variables can be grouped in main three points, which are: stand characteristics (e.g. stand age, crown closure), topographic characteristics (e.g. elevation, slope and aspect) and climatic characteristics (e.g. temperature, precipitation). The existence of a number of variables related to mushroom emergence and their interactions with each other make it difficult to understanding of mushroom productivity.

Factors influencing mushroom production such as genes and environmental conditions are not clear (Murat et al. 2008) because the literature on interdependence between mushroom emergence and these characteristics is quite rare. Because of the ecology of mushrooms is changeable even for the same genus, it is not easy to make a general judgment for these products.

It is known that weather conditions have an impact on mushroom occurrence and productivity. Because water availability in the soil or weather is main reactor for sporacarp formation, mean monthly rainfall, mean temperature, mean monthly evapotranspiration and soil temperature and moisture are strongly important variables for mushroom production (Bonet et al. 2010; Bonet et al. 2012; Martínez-Peña et al. 2012a; De La Varga et al. 2013; Kucuker and Baskent 2015; Taye et al. 2016; Karavani et al. 2018; Castaño et al. 2017).

Since most mushrooms have a mycorrhizal relationship with trees, stand characteristics such as stand age, stand density, canopy closure and tree species influence mushroom emergence. The growth rate and average weight of picked *Boletus edulis* sporocarps is the highest in the first age class (Ortega-Martínez et al. 2011). A number of studies detected that maximal productivity of *Lactarius* can be changed under different tree species and forest condition (Fernández-Toirán et al. 2006; Smith et al. 2002). Although the light entering the stand based on canopy cover is not direct effective factor for mushroom occurrence and productivity, it affects temperatures, moisture, physical and chemical properties of soil (Egli et al. 2010). The occurrence probability and the productivity of mushrooms show an increasing range with decreasing canopy closure (Kucuker and Baskent 2015; Kucuker and Baskent 2018).

Also, topographic characteristics affect mushroom dynamics. Slope, aspect and altitude are important ecological factors affecting the productivity of mushrooms. Martínez de Aragón et al (2007) observed that total mushroom production probably because of more rapid loss of surface water on these areas. Similarly, Bonet et al (2010) Kucuker and Baskent (2018) obtained that elevation and aspect on the contrary to slope have a positive effect on mushroom productivity. They evaluated the effects of these topographic variables as a reflection of water availability of soil and soil quality. The effect of related variables may be changed based on mushroom species and forest condition. For example, it is explained that while *Lactarius deliciosus* is emergence on dry southwest slopes, *Tricholoma terreum* can be found on north facing slopes in Pyrenees, Spain (Bonet et al. 2004).

*Boletus sp.* mushroom is considered to be one of the commercially most important wild mushroom species in the Europe. This species is an ectomycorrhizal mushroom that is symbiotically associated with a large number of host trees and scrubs. It has many names in the different regions such as king, cep, porcini and penny ban. To date several studies have tried to analyze the effects of some environmental variables such as climate, stand and topographic factors on productivity and spatial distribution of some mushroom species with various statistical analysis and modeling techniques. However, very limited studies have been reported for *Boletus* mushrooms. These studies demonstrated that sporocarp production of king bolete are related to not only climatic variables but also stand and site characteristics. Though Hernández-Rodríguez et al. (2015) have described mean temperature is key driver for sporocarp production of *B. edulis*, Parladé at al. (2017) have detected no linear correlation between *B. edulis* mycelium biomass and monthly mean temperature. However, the same study showed that mean precipitation is significantly correlated with sporocarp productivity. Similarly, de la Varga et al. (2013) found no correlation between *B. edulis* sporocarp production and weather parameters. Martínez-Peña et al. (2012a; b) obtained significant effects stand and local site characteristics such as stand age, dominant height and basal area on *B. edulis* productivity. According to Tahvanainen et al. (2016), *B. edulis* needs warm weather before fruiting and wet conditions during the main fruiting season as well as the young stand age with 25-30 years a stand basal area near to 25 $m^2$/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 $m^2$/ha are more predictive for king bolete production.

This study seeks to improve lack of knowledge about habitat of *Boletus* mushroom that is serve integrated forest management plans. From this purpose, permanent sample plots were established randomly throughout the forested areas representing a range of different topographic and stand characteristics. This study aims to identify and compare the influence of some ecological variables such as slope, aspect and altitude on wild king bolete productivity.

## MATERIAL AND METHODS

### Study area

The study site is located in Bicik Planning Unit in Giresun, North-west Turkey. The area is approximately 11,554 ha in size, 76% of which is forested. *Picea orientalis* and *Fagus orientalis,* are the dominant trees in the area. The altitude ranges between 330 and 2375 m. a.s.l. and the average slope is about 44% (Figure 1). Average annual rainfalls changes from 1400 mm to 2400 mm and mean annual temperature change from 13°C to 3°C based on long-term measurements from 1975 to 2005 taken at the Giresun meteorology station (TSMS 2006).

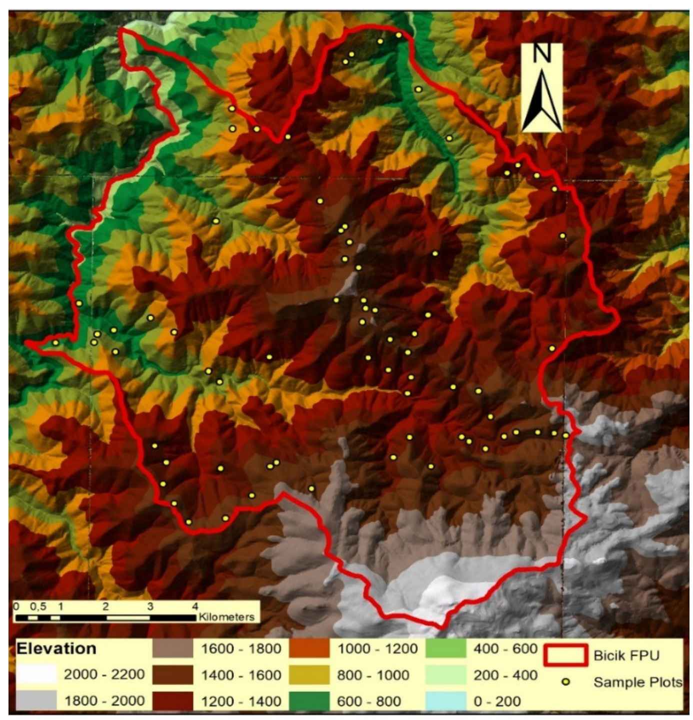


**Figure 1**. The spatial layout of the study area

### Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 $m^2$ with a square shape were distributed throughout the forested areas representing a range of different topographic and stand characteristics. To prevent any possible effects of rural pickers, the plots were located at least 10 meters from roads and surrounded with a tape. Field survey was performed from August to November with about ten days interval in 2013. When the plots were visited, all *Boletus edulis* sporocarps were collected and fresh weight (gram) and the numbers of collected Boletus species were recorded. Some ecological variables such as slope, elevation and aspect in each plot were obtained with Digital Elevation Model (DEM) by using GIS.

**Statistical analysis**

The effects of some ecological variables on *Boletus* yield and amount were analyzed by using ANOVA. Comparisons between different groups of each ecological variable were carried out by one-way anova analysis. In case the normal distribution was not provided, significances of ecological variables were tested by using Kruskal-Wallis test. In event of homogeneity hypothesis was not ensured, Welch test was used instead of Anova test. In order to ensure normality assumption of fresh weight and number of *Boletus*, dependent variable was transformed as log (weight) and square root (weight). Differences between the ecological groups were detected by Tukey HSD or Dunn-Bonferroni test ($p<=0.05$) for parametric or non-parametric tests respectively. Shapiro-Wilk test statistic was used to determine of normality of variables. All data analyses were carried out with SPSS statistical package version 23.0 (SPSS 2014).

## RESULTS AND DISCUSSIONS

King bolete yield productivity varied among sample plots and by sampling period. King bolete was presented in only twenty-four sample plots of all plots. A total of 609 king bolete sporocarps corresponding to 71.8 kg were collected per hectare. One-way anova and Kruscal Wallis analysis showed precise results on the infect of elevation, slope and aspect in king bolete productivity as number and weight.

**Effect of Elevation**

General descriptive statistics of king bolete weight (kg/ha) and sporocarp number (unit/ha) for elevation groups are shown in Table 1. The mean maximum productivity both of weight and number were detected in the second elevation class between 1450-1650 meter (144.0 kg/ha and 775.0 sporocarps/ha) and the mean minimum productivity were detected in the first elevation class under 1450 meter (25.8 kg/ha and 375 sporocarps/ha) (Table 1).

**Table 1**. Descriptive statistics for king bolete weight (kg/ha) and number (unit/ha) by elevation groups

| | Elevation groups | n | Mean | Std deviation | Min | Max | Range | Coefficient of variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Weight (kg/ha)** | <1450 | 4 | 25.8 | 15.0 | 5 | 39 | 34.0 | 58.1 |
| | 1450-1650 | 4 | 144 | 194.5 | 3 | 425 | 422.0 | 135.1 |
| | 1650-1750 | 11 | 52.4 | 38.1 | 3 | 109 | 106.0 | 72.7 |
| | >1800 | 5 | 79.4 | 77.9 | 7 | 180 | 173.0 | 98.1 |
| **Number (unit/ha)** | <1450 | 4 | 375 | 359.4 | 100 | 900 | 800.0 | 95.8 |
| | 1450-1650 | 4 | 775 | 623.8 | 100 | 1400 | 1300.0 | 80.5 |
| | 1650-1750 | 11 | 445.5 | 294.5 | 100 | 1000 | 900.0 | 66.1 |
| | >1800 | 5 | 900 | 744.9 | 200 | 1700 | 1500.0 | 82.8 |

Because the king bolete data as fresh weight ($kg/ha^{-1}$) and sporocarp amount within each elevation group have normal distribution ($p>0.05$), but homogeneity of variances based on levene's test was not ensured ($p=0.002$ and $p=0.001$ respectively), robust test equality of means, Welch test was used to investigate differences between the means of each elevation group. The results showed that there is no significant differences between four elevation groups in terms of *Boletus edulis* yield ($F(3, 7.683)=1.895$, $p=0.212$) and sporocarp amount ($F(3,6.614)=0.825$, $p=0.523$) (Table 2). Although elevation is an important factor for sporocarp production, in the present work there is no significant differences between elevation groups in terms of king bolete productivity. When the results of present study about influence of ecological variables on mushroom productivity were compared with previous studies, similarly Martínez-Peña et al. (2012a) detected that elevation did not explained differences in *B. edulis* yield in the pure even aged *Pinus sylvestris* stands.

**Table 2**. Welch test results for variations of king bolete weight (kg/ha) and number (unit/ha) among elevation groups

| Elevation | Weight (kg) | | | | Number/ha | | | | Homogenous groups |
|---|---|---|---|---|---|---|---|---|---|
| | Median | Statistic | df2 | *p* | Median | Statistic | df2 | *p* | |
| <1450 | 29.5 | 1,895 | 7,683 | *0,212* | 250 | 0.825 | 6,614 | *0.523* | a |
| 1450-1650 | 74.0 | | | | 800 | | | | |
| 1650-1750 | 65.0 | | | | 500 | | | | |
| >1800 | 44.0 | | | | 600 | | | | |

## Effect of aspect

General basic statistics of king bolete weight (kg/ha) and sporocarp number (unit/ha) for aspect classes are shown in Table 3. The mean maximum and minimum yields were detected from East and North aspects with 147.8 kg/ha$^{-1}$ and 6.5 kg/ha$^{-1}$ respectively (Table 3). Since fresh weight (kg/ha$^{-1}$) of mushroom yield within different aspect groups did not show normal distribution (*p<0.05*), the yield data was transformed as log (kg/ha$^{-1}$). Significant differences of the mean fresh weight (kg/ha$^{-1}$) of *Boletus edulis* within different aspects were analyzed by ANOVA tests. ANOVA test showed that the differenceof mean mushroom yield is significant for aspect groups ($F(3, 20)=13.451$, $p=0.00$). Tukey's post-hoc test divided the samples two homogeneous groups: North aspect (3.698) and east (5.005), west (4.596) and south (4.7778) aspects (Table 4).

**Table 3**. Descriptive statistics for king bolete weight (kg/ha) and number (unit/ha) by aspect groups

| | Aspect classes | n | Mean | Std deviation | Min | Max | Range | Coefficient of variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Weight (kg/ha)** | East | 5 | 147.8 | 159.8 | 44 | 425 | 381 | 108.1 |
| | South | 7 | 77.9 | 57.9 | 21 | 180 | 159 | 74.3 |
| | West | 6 | 54.8 | 39.5 | 7 | 109 | 102 | 72.1 |
| | North | 6 | 6.5 | 6.3 | 3 | 19 | 16 | 96.9 |
| **Number (unit/ha)** | East | 5 | 980.0 | 531.0 | 600 | 1700 | 1100 | 54.2 |
| | South | 7 | 771.4 | 521.9 | 300 | 1700 | 1400 | 67.7 |
| | West | 6 | 500.0 | 322.5 | 200 | 1000 | 800 | 64.5 |
| | North | 6 | 116.7 | 40.8 | 100 | 200 | 100 | 34.9 |

On the other hand, because normality assumption was not provided (*p<0.05*) despite all transformations, Kruscal-Wallis test was used to analyze the significant differences between medians within aspect groups for sporocarp amount ($F(3)=14.410$ $p=0.002$). Similarly, the mean maximum and minimum sporocarp amount were detected from east and north aspects with 980.0 and 116.7 sporocarps per hectare respectively (Table 3). Post hoc test divided aspects into two groups as north aspect and the other aspects (Table 5).

**Table 4**. Anova and Tukey post hock test results for king bolete weight (kg/ha) among aspect classes

| Aspect classes | n | df1 | df2 | Mean | F | *Prob>F* |
|---|---|---|---|---|---|---|
| East | 5 | 3 | 20 | 5.005 | 13.451 | *0.000* |
| South | 7 | | | 4.778 | | |
| West | 6 | | | 4.596 | | |
| North | 6 | | | 3.698 | | |

**Table 5**. Kruscal-Wallis test results for variations of king bolete sporocarp number (unit/ha) among aspect classes

| Class | n | df | Mean rank | $X^2$ | *Prob>F* | Homogen groups |
|---|---|---|---|---|---|---|
| East | 5 | 3 | 18.400 | 14.410 | *0.002* | a |
| South | 7 | | 15.571 | | | a |
| West | 6 | | 12.833 | | | a |
| North | 6 | | 3.667 | | | b |

*Boletus edulis* productivity is highly influenced by aspect in the mixed forest. The higher and lower production of *B. edulis* is in the east and north aspect respectively. The average productivity of *B. edulis* are clearly different in the north aspect and north-facing slopes are not favored for production. Although aspect may be significant factor for mushroom fruiting, what aspect favored is changeable for each individual mushroom species and different ecosystems. For example, while north slopes are convenient for *T. magnivelare* in Cascade Range of USA, southwest slopes are better in Japan and Korea (Amaranthus et al. 1998).

**Effect of Slope**

General descriptive statistics of king bolete weight (kg/ha) and sporocarp number (unit/ha) for slope groups are shown in Table 6. While the mean maximum mushroom yield and amount (197.0 kg/ha and 1133.3 sporocarps/ha respectively) were produced from the areas under 20% slope, the mean lowest mushroom yield and amount (33.0 kg and 333.3 sporocarps respectively) were produced from the areas between 20-30% slope (Table 6). Significance influence of slope were analyzed using the Kruskal-Wallis test for comparing medians because of the normal distribution ($p<0.05$) and homogeneity hypothesis were not provided although logarithmic and square root transformations were implemented. *Boletus edulis* sporocarp productivity as the number and weight are significantly different between each slope groups ($p=0.028$ and $p=0.049$ respectively) (Table 7). Post hoc test separate the slope groups into two groups. While the first group is included second slope class between 20-30% slope, the other group is included the other slope classes based on mean ranks of each group for both mushroom fresh weight (18.0 and 7.6) and the number (18.3 and 7.1).

**Table 6**. Descriptive statistics for king bolete weight (kg/ha) and number (unit/ha) by slope classes

| | Slope classes | n | Mean | Std deviation | Min | Max | Range | Coefficient of variation (%) |
|---|---|---|---|---|---|---|---|---|
| **Weight (kg/ha)** | <20% | 3 | 197 | 206.9 | 21 | 425 | 404 | 105.0 |
| | 20-30% | 9 | 33 | 59.3 | 3 | 180 | 177 | 179.7 |
| | 30-40% | 6 | 72 | 35.0 | 25 | 123 | 98 | 48.6 |
| | >40% | 6 | 55.3 | 30.5 | 25 | 109 | 84 | 55.2 |
| **Number (unit/ha)** | <20% | 3 | 1133.3 | 737.1 | 300 | 1700 | 1400 | 65.0 |
| | 20-30% | 9 | 333.3 | 522.0 | 100 | 1700 | 1600 | 156.6 |
| | 30-40% | 6 | 666.7 | 280.5 | 400 | 1200 | 800 | 42.1 |
| | >40% | 6 | 600 | 316.2 | 200 | 1000 | 800 | 52.7 |

The results of our study showed that the productivity of *B. edulis* is significantly different for four slope classes considered. The maximum production is observed in the first slope class under 20% slope, 197.0 kg/ha, and decreases for the other slope classes 33, 72, 55.3 kg/ha respectively. The average productivity of *B. edulis* is significantly different in the second slope class between 20-30% slope. Although our study obtained significantly differences among aspect and slope classes for king bolete productivity, Martínez-Peña et al. (2012a) reported no significant differences between king bolete productivity and site variables such as slope, aspect and elevation.

**Table 7.** Kruskal-Wallis test results for variations of king bolete weight (kg/ha) and number (unit/ha) among slope classes

| Class | n | df | Weight | | | Amount | | | Homogenous groups |
|---|---|---|---|---|---|---|---|---|---|
| | | | Mean Rank | $X^2$ | *Prob>F* | Mean Rank | $X^2$ | *Prob>F* | |
| <20 | 3 | 3 | 18.00 | 7.869 | *.049* | 18.33 | 9.124 | *.028* | a |
| 20-30 | 9 | | 7.56 | | | 7.11 | | | b |
| 30-40 | 6 | | 16.00 | | | 15.75 | | | a |
| >40 | 6 | | 13.67 | | | 14.42 | | | a |

**CONCLUSION**

Given the growing demand on mushroom products regarding their socioeconomic value, identifying the relationships between king bolete productivity and climatic, environmental and site characteristics is essential for multiple-use forest management planning. In this study, identify and compare the influence of some ecological variables such as slope, aspect and altitude on wild king bolete productivity were investigated. This study is the known first research analyzing the relationships between king bolete productivity and site variables in the mixed forests. It is important that this study was obtained only for king bolete in homogeneous even-aged stands and a restricted region. According to the results the higher production of *B. edulis* was obtained by the second elevation class between 1450-1650 meters, east aspects and slope under 20%. However significant differences were not found among elevation classes in terms of king bolete productivity for bodies and yield. On the other hand, differences among aspect and slope classes for king bolete productivity were significant. Although a previous study did not detect any significant differences between king bolete productivity and site variables, this study figured out significantly differences among aspect and slope classes except elevation classes for king bolete productivity.

The present study was conducted in the permanent sample plots to analyze king bolete productivity in the mixed forest. The effects of some ecological factors on king bolete productivity can be detected with reliable datasets delivered from long term observation, thus these longer observations over two years would be better to confirm these patterns.

Analyzing of some relationships between mushroom productivity and ecological characteristics can be very useful for understanding mushroom habitats and fungal dynamics for forest managers and mushroom pickers. Also, such research provides valuable knowledge for integration of non-wood forest products into forest management plans and facilitate complex decision-making process.

Further research is needed for a better understanding of combined effects of different drivers on mushroom productivity due to the fact that single factors rarely explain ecosystem response. Additional research should focus on annual dynamics of important wild mushrooms in different forest ecosystems by modifying the other ecological factors such as climatic and edaphic factors.

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