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Anatomical properties of four *Pilosella* Vaill. (Asteraceae) taxa from Eastern Black Sea Region of Turkey

Türkiye'nin Doğu Karadeniz Bölgesi'nden dört *Pilosella* Vaill. (Asteraceae) taksonun anatomik özellikleri

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Abstract

Anatomical features of four *Pilosella* Vaill. taxa (*P. officinarum* Vaill., *P. piloselloides* (Vill.) Sojak subsp. *bauhini* (Schult.) S. Bräut. & Greuter, *P. × hypeurya* (Peter) Sojak, *P. densiflora* (Tausch) Sojak) collected from Black Sea Region of Turkey were investigated. Anatomical studies include transverse sections of root, stem and leaf with their illustrations. Although the anatomical properties are similar to the typical anatomy of dicotyledons, some differences were observed among them. While root anatomy of *P. officinarum*, *P. piloselloides* subsp. *bauhini* and *P. densiflora* consist of a single layer exodermis, there is 2-3 layer exodermis in the natural hybrid *P. × hypeurya*. Additionally the root pith of this hybrid taxa completely composed of schlerenchyma cells in contrast to other investigated taxa. The stem anatomy of the investigated taxa is similar to each other except the number of the tracheidal elements. The numbers of the stomata per μm^2 distinctly differ in *P. piloselloides* subsp. *bauhini* from the rest examined taxa.

Özet

Bu çalışmada Türkiye'nin Doğu Karadeniz bölgesinden toplanan 4 *Pilosella* Vaill. taksonunun (*P. officinarum* Vaill., *P. piloselloides* (Vill.) Sojak subsp. *bauhini* (Schult.) S. Bräut. & Greuter, *P. × hypeurya* (Peter) Sojak, *P. densiflora* (Tausch) Sojak) anatomik yapıları incelenmiştir. Anatomik veriler kök, gövde, yaprak enine kesit ve yaprak yüzeyel kesitleri çizimleri ile birlikte verilmiştir. İncelenen türlerin anatomik yapıları tipik dikotiledon yapısına benzerlik göstermekle birlikte aralarında bazı farklılıklar tespit edilmiştir. *P. officinarum*, *P. piloselloides* subsp. *bauhini* ve *P. densiflora*'nın kök anatomilerinde tek sıra ekzodermis bulunurken, melez bir takson olan *P. × hypeurya* kök anatomisinde 2-3 sıra ekzodermise rastlanmıştır. Melez taksonun kök öz bölgesi diğer incelenen taksonlardan farklı olarak sadece sklerankima hücrelerinden oluşmaktadır. Trake sayıları dışında gövde anatomilerinin benzer olduğu görülmüştür. *P. piloselloides* subsp. *bauhini* 'de stoma sayıları belirgin şekilde diğer türlerden fazladır.

INTRODUCTION

According to the monograph of Zahn (1921-1923), the genus *Hieracium* L. is divided into four subgenera and two of these, *Hieracium* L., *Pilosella* Vaill. are present in Turkey but Sell and West (1974) who prepared the account of *Pilosella* for the Flora of Turkey recognised these subgenera as a distinct genera. Phytochemical (Petrovic et al. 1999) and molecular (Shi et al. 1996) studies on the genus *Hieracium* s.l. strongly support the morphologically based classifications, however now *Pilosella* is generally treated as a distinct genus, based on a whole range of morphological, biochemical, cytological and genetical characteristics (Bräutigam and Greuter 2007). *Pilosella* is well known for its taxonomic complexity and sufficiently different from the genus

Hieracium in its achene structure, stoloniferous habit and much higher capacity for sexual reproduction than *Hieracium* to merit elevation to generic status (Sell and West 1974; Sell 1987). The genus *Pilosella* was represented with 35 species including 13 hybrids between most species that grow together in Turkey (Coşkunçelebi 2012). *Pilosella* species are important for their medical value. It is reported that it is used for the treatments of bronchitis, bronchitic asthma and whooping cough (Grieve 1995).

In recent years, the genus *Pilosella* has been the subject of caryological (Bishop and Davy 1994; Gadella 1987), taxonomical (Sell 1987) and ecological (William et al. 1987) studies which improved our understanding of the systematics of this genus. There are also studies

undertaken in order to understand the ecology and evolution of this species, and to implement effective biological control (e.g. Jenkins and Jong 1997, Chapman et al. 2000).

The anatomical properties are generally useful for the classification and delimitation of taxa. However there are few anatomical studies reports on the genus *Hieracium* sensu lato (Qureshi et al. 2009; Talukdar 2015; Tavakkoli et al. 2017) and *Pilosella* sensu stricto (Sepet 2017; Umdü (2000), but only of them including *Hieracium lasiochaetum* (Bornm. & Zahn) Sell & West and *Pilosella hoppeana* subsp. *lydia* (Bornm. & Zahn) Sell & West (= *Pilosella hoppeana* subsp. *testimonialis* (Naegli ex Peter) P.D. Sell & C. West) distributed in Turkey. Thus the main objective of this study is to determine the anatomical properties of *Pilosella* species distributed in Black Sea Region of Turkey. Also we can discuss all findings in a systematic aspects within the the genus.

MATERIALS AND METHODS

Plant materials used in this study were collected from Black Sea Region of Turkey (Table 1). Some of the plant materials were dried according to the herbarium techniques and kept in the Herbarium of Biology, Karadeniz Technical University (KTUB). Some of the plant materials were preserved in FAA (Formalin-Glacial Acetic Acid-Ethyl Alcohol) at 24h and stored in ethyl alcohol (70%) for anatomical studies. Anatomical studies consist of several sections (cross, superficial) from root, stem, and leaf of *Pilosella* species identified according to the Flora of Turkey (Davis 1972). Sections were waited in sodium hypochloride at 5-10 minutes so as to loose their colour. Afterwards, these sections were stained with safranin-fastgreen (Algan 1981) and permanent slides were made by using entellene. All drawings (both morphological and anatomical) were made by using a lucida camera attached to a Olympus light microscope.

Table 1. Locality information of the examined taxa in the present study

<i>Pilosella densiflora</i> (Tausch) Sojak
A7: Trabzon, Hıdırnebi Yaylası, 1400-1500m, Coşkunçelebi 164, 01 vii 1999, KTUB
<i>Pilosella officinarum</i> Vaill.
A7: Trabzon, Haçka Yaylası, 1400m, Coşkunçelebi 191, 22 vii 1999, KTUB
<i>Pilosella</i> × <i>hypeurya</i> (Peter) Sojak
A7: Trabzon, Hıdırnebi Yaylası, 1400-1500m, Coşkunçelebi 163, 01 vii 1999, KTUB
<i>Pilosella piloselloides</i> (Vill.) Sojak subsp. <i>bauhini</i> (Schult.) S. Bräut. & Greuter
A8: Gümüşhane, Vavuk Dağı, 1800m, Coşkunçelebi 168, 09 vii 1999, KTUB

RESULTS

The anatomical properties determined by the microscopic examinations of root, stem and leaf sections in alphabetical order are in the following.

Pilosella densiflora (Tausch) Sojak

Root: Epidermis, exodermis, cortex and vascular cylinder take place from out side to the inner, respectively (Figure 1- A). Epidermis cells are quadrilateral or polygonal with smooth walls and have no intercellular space. The exodermis cells are polygonal and have smooth walls and no intercellular space. The cortex consists of parenchymatic cells. Diameters of parenchymatic cells are almost same and they have numerous intercellular spaces. The cells which are close to vascular cylinder are arranged concentric. Endodermis cells are visible and have no intercellular space. Pericycle cells have variable

diameters with thin walls. The root is tetraarch. The phloem arranged among the xylem poles and have thin walls. Cambium, located between xylem and phloem, are not visible. Xylem poles are closely in pith but not connected. The pith consists of parenchymatic cells.

Stem: Vascular bundles are placed in one line (Figure 1- B). The epidermis consists of one row cells. They are usually quadrilateral and the diameters are variable. A thin cuticle covers the epidermis. The paranchymatic cortex cells are located under the epidermis and have prominent intercellular spaces. The cortex consists of 6-7 rows cells and some of them which are close to epidermis have chloroplasts. Vascular bundles are located in one ring and they are very closely to each other. There are some schlerencymatic cells outside the phloem. Xylem takes 4 times larger place than phloem. Cambium, between xylem and phloem, is not visible. Trachea are in

radial rows and there are 5 tracheas in each row. There are some schlerenchymatic cells outside the xylem which faces to the pith. The pith of the stem consists of parenchymatic cells which are usually oval and have numerous intercellular spaces. Diameters of the parenchyma cells increase in the pith.

Leaf: The epidermis cells are quadrilateral and have no intercellular space (Figure 2- A). In mesophyll tissue, palisade parenchyma consist of one row cells (usually quadrilateral) and have numerous chloroplasts. Spongy parenchyma cells cover three fourth of mesophyll. Among them intercellular spaces are widespread and they are in

variable shapes and diameters. The midrib is developed, 3 times wider than the leaf lamina. There is only one vascular bundle. Xylem takes more place and there are 5-6 tracheas in each radial row. Phloem covers one third of vascular bundles. Around the vascular bundle there is thin starch sheath consist of 2-3 rows cells. The vascular bundle is in the parenchyma tissue. Both sides of the leaf have anomocytic stomata. The size of the stomata placed on upper epidermis are about $22 \times 30 \mu\text{m}$, the others are $24 \times 34 \mu\text{m}$. There are about 100 stomata on upper epidermis and 80 stomata on lower epidermis per/ mm^2 (Figure 2- B, C).

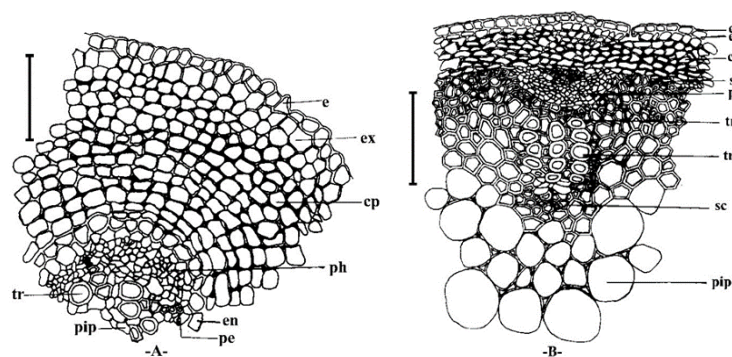


Figure 1. *Pilosella densiflora*. A- Cross section of root. B- Cross section of stem (c- cuticle, e- epidermis, ex- exodermis, cp- cortex parenchyma, is- intercellular space, en- endodermis, pe- pericycle, tr- trachea, trc- tracheid, ph- phloem, sc- sclerenchyma, pip- pith parenchyma. Scale bar: $100 \mu\text{m}$)

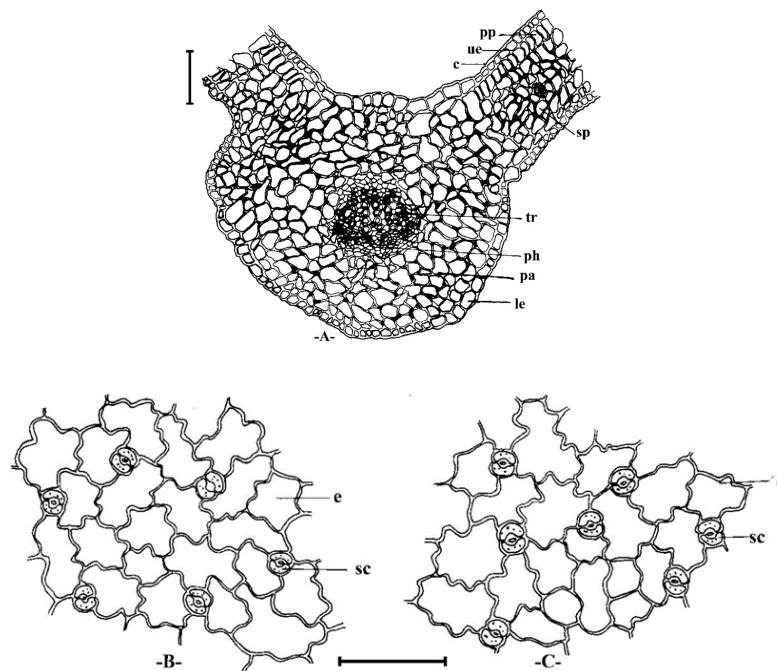


Figure 2. *Pilosella densiflora*. A- Cross section of leaf, B-The stomata from upper epidermal leaf, C- The stomata from lower epidermal leaf. (c- cuticle, e- epidermis, ue- upper epidermis, le- lower epidermis, pa- parenchyma, pp- palisade parenchyma, sp- spongy parenchyma, ph- phloem, tr- trachea, sc- stoma cell. Scale bar: $100 \mu\text{m}$)

Pilosella* × *hypeurya (Peter) Sojak (*P. hoppeana* × *P. officinarum*)

Root: Exodermis, located under the endodermis, consists of 2-3 rows polygonal cells (Figure 3- A). There are parenchymatic cortex consists of 14-16 rows cells under the exodermis. The parenchyma cells have variable shapes, diameters and numerous intercellular spaces. Endodermis cells are almost similar to parenchyma cells but the endodermis cells have little diameters and no intercellular space. Pericycle, outer layer of the stele, is unistratose. It has variable diameters and thin walls. In vascular bundles xylem poles are close to each other in the pith but not connected. The pith consists of schlerenchymatic cells. Phloem is located as a narrow band.

Stem: Epidermis consists of quadrilateral cells and cortex consists of 7-8 rows parenchymatic cells (Figure 3- B). The shape and the diameters of the parenchymatic cells are variable. They are oval, polygonal or quadrilateral and some are long with numerous intercellular spaces. Diameters of the cells increase from the epidermis to vascular cylinder. Vascular bundles are located in one ring and there is a schlerenchyma ring around them. The schlerenchyma ring consists of 4-5 rows cells. In vascular bundles, xylem takes more place than phloem and consists of 5-6 radial rows cells and there are 5-7 tracheas in each row. Among the vascular bundles, there are parenchymatic cells. The pith parenchymatic cells are usually oval and diameters of them increase to the pith. Among them intercellular spaces are widespread.

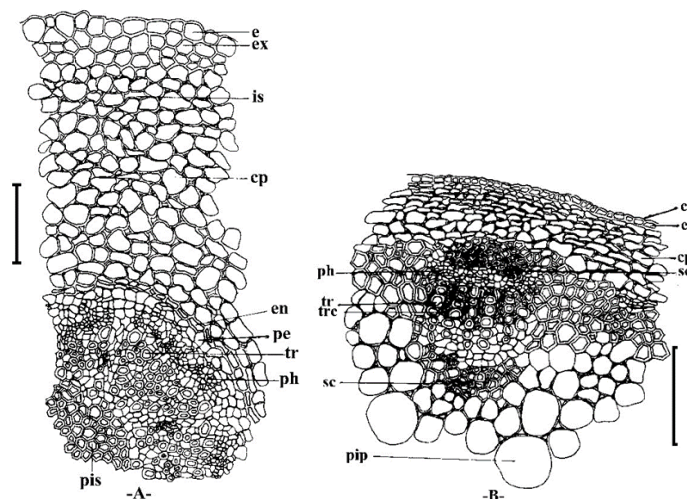


Figure 3. *Pilosella* × *hypeurya*. A- Cross section of root, B- Cross section of stem. (c- cuticle, e- epidermis, ex- exodermis, cp- cortex parenchyma, is- intercellular space, en- endodermis, pe- pericycle, tr- trachea, trc- tracheid, ph- phloem, sc- sclerenchyma, pip- pith parenchyma, pis- pith sclerenchyma. Scale bar: 100 μm

Leaf: Epidermis is uniseriate and have quadrilateral cells (Figure 4- A). Upper epidermis cells are similar to the lower epidermis cells in shapes but the upper epidermis cells are bigger than the others. Palisade parenchyma cells, under the upper epidermis, have numerous chloroplasts and under them there are spongy parenchyma cells consist of 3-4 rows variable shaped cells. They have less chloroplasts than palisade parenchyma cells and numerous intercellular spaces. The midrib are about 3 times wider than the lateral sides. In the middle there is a developed collateral bundle. Xylem faces towards upper epidermis and phloem faces towards

lower epidermis. In xylem, tracheas are in radial rows and there are 3-5 tracheas in each row. Phloem takes less place than xylem. Vascular bundles are among parenchymatic tissue. Parenchymatic cells that are close to vascular bundles have numerous chloroplasts and the others that are close to epidermis have less chloroplasts than the others. Among them intercellular spaces are widespread. Anomocytic stomata that placed on upper epidermis are of the size of 22×26 μm, the others placed on lower epidermis are of the size of 22×30 μm. The number of the stomata placed on upper epidermis are 30, the others are 80 per/ mm² (Figure 4- B, C).

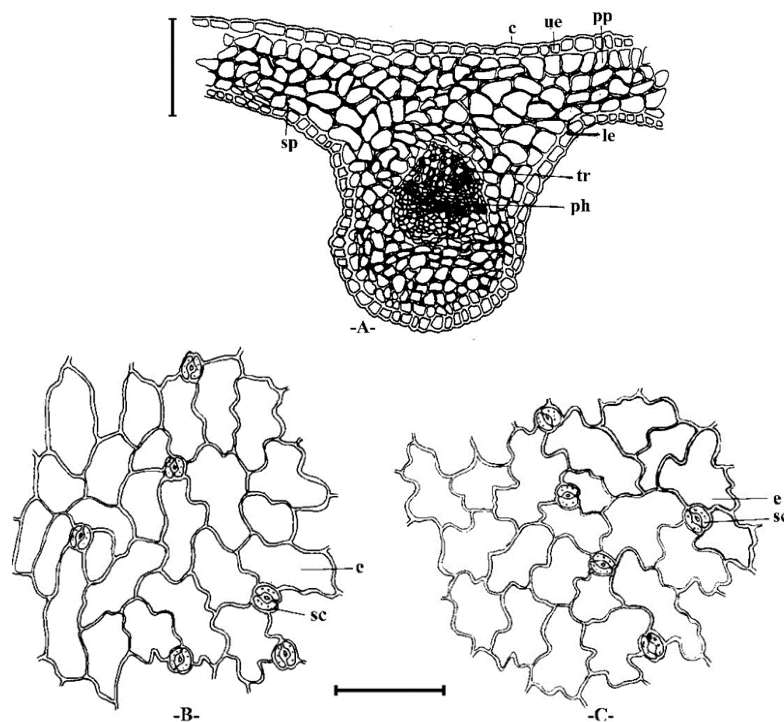


Figure 4. *Pilosella* × *hypeurya*. A- Cross section of leaf, B-The stomata from upper epidermal leaf, C- The stomata from lower epidermal leaf. (c- cuticle, e- epidermis, ue- upper epidermis, le- lower epidermis, pp- palisade parenchyma, sp- spongy parenchyma, ph- phloem, tr- trachea, sc- stoma cell. Scale bar: 100 μm)

***Pilosella officinarum* Vaill.**

Root: One row epidermis, 1-2 rows exodermis and 14-15 rows parenchymatic cortex are present. Parenchymatic cortex cells varies in shape but mostly oval or polygonal (Figure 5- A) and consist of numerous intercellular spaces. The endodermis does not separate from the parenchymatic cortex simply but the endodermis cells have little diameters and no intercellular space. Pericycle, placed under the endodermis, consist of 1-2 rows cells. Tetraarch root and the xylem poles are attached in the pith. Phloem takes less place than xylem. The pith consists of parenchymatic cells.

Stem: The cuticle covers all parts of the stem epidermal surface. The epidermis consists of one row cells with wavy periferal walls. Cortex consists of 5-7 rows of parenchymatic cells. The cells located inside of the cortex are bigger and variable in shapes. Cortex parenchymatic cells are commonly quadrilateral or oval with numerous intercellular spaces. The parenchymatic cells close to endodermis have prominent chloroplasts. There are discrete vascular bundles and among them there are schlerenchymatic cells in 2-3 rows. Schlerenchymatic

cells cover outside the phloem. Xylem is arranged in radial rows and tracheids placed among them. There are schlerenchymatic cells outside xylem towards central part. Among the vascular bundles, there are parenchymatic cells increasing from the vascular bundles to the pith. They are usually oval or polygonal in shape and consist of numerous intercellular spaces (Figure 5- B).

Leaf: Palisade tissue is not visible. Mesophyll, places near the leaf lamina, usually consist of 4-5 rows parenchymatic cells. These are oval, cylinder or sometimes long in shape with several intercellular spaces. Epidermal cells except the cells close to mesophyll are usually quadrilateral in shape. Leaf lamina is twice thicker than the lateral sides (Figure 6- A). In leaf lamina, there is only one vascular bundle. In xylem, tracheas are arranged in radial rows and among them there are tracheas. Phloem located as a thin band. The vascular bundle arranged in parenchymatic tissue. Anomocytic stomata are placed on upper epidermis and its size is 22×28 μm, and the others on lower epidermis are 22×26 μm. The number of them is about 160 per/mm² (Figure 6- B,C).

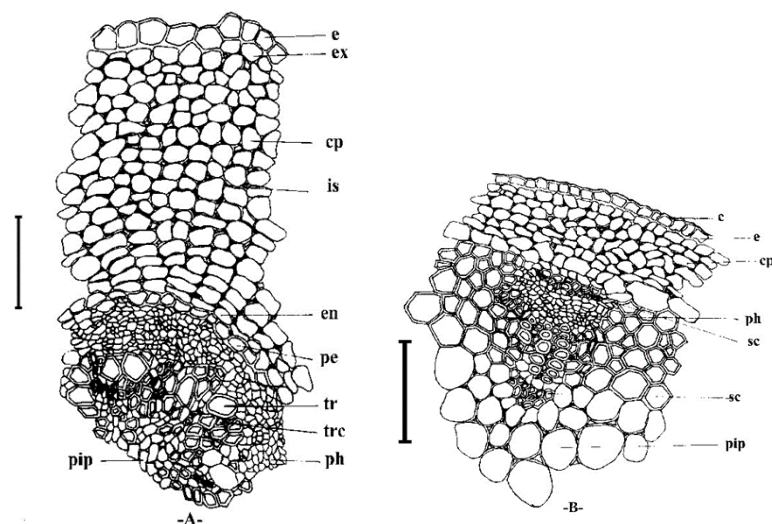


Figure 5. *Pilosella officinarum*. A- Cross section of root, B- Cross section of stem. (e- epidermis, ex- exodermis, cp- cortex parenchyma, is- intercellular space, en- endodermis, pe- pericycle, tr- trachea, trc- tracheid, ph- phloem, sc- sclerenchyma, pip- pith parenchyma. Scale bar: 100 μm)

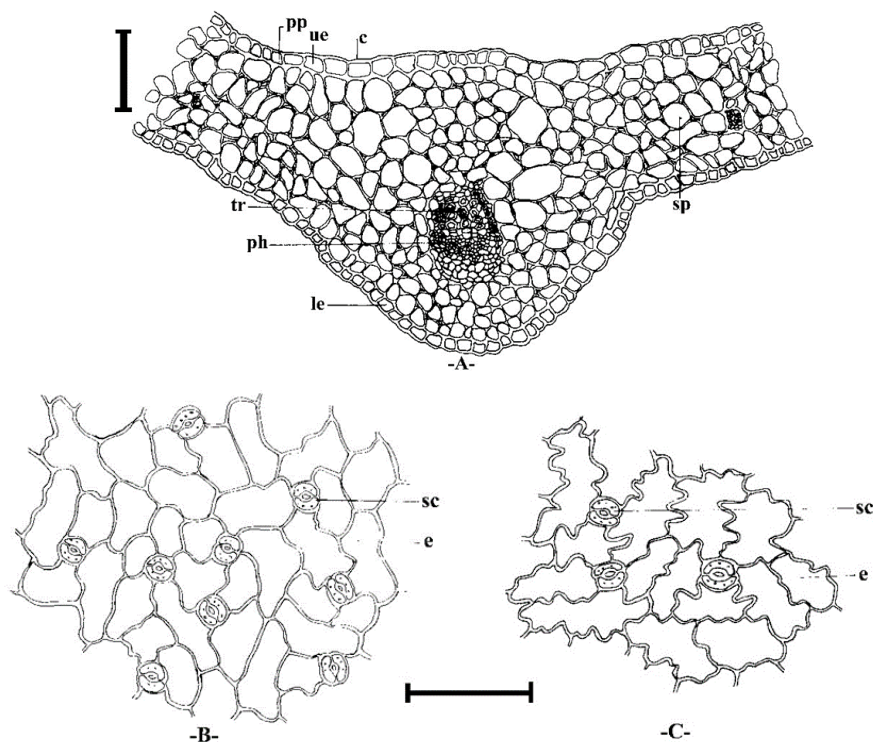


Figure 6. *Pilosella officinarum*. A- Cross section of leaf, B- The stomata from upper epidermal leaf, C- The stomata from lower epidermal of leaf. (c- cuticle, e- epidermis, ue- upper epidermis, le- lower epidermis, pp- palisade parenchyma, sp- spongy parenchyma, ph- phloem, tr- trachea, sc- stoma cell. Scale bar: 100 μm)

***Pilosella piloselloides* (Vill.) Sojak subsp. *bauhini* (Schult.) S. Bräut. & Greuter**

Root: Epidermis and exodermis consist of 1 row cells, but the exodermis cells are bigger than the endodermis cells (Figure 7- A). Parenchymatic cortex consists of 12-13 rows cells with numerous intercellular spaces. Endodermis, unistratose cylinder of cells line the inner boundary of

cortex, is clearly different with small cells. There are no intercellular space between endodermal cells and they have smooth walls. Pericycle is unistratose, pericycle cells are with thin walls and variable diameters. Phloem is located among the xylem poles. Xylem poles are placed closely to each other, but not connected. The pith is parenchymatic.

Stem: Epidermis cells are quadrilateral and the centrifugal walls are wavy (Figure 7- B). The cortex parenchyma, placed under the epidermis, consist of 5-6 rows oval or polygonal shaped cells. The cells close to epidermis have little diameters and numerous chloroplasts, the others close to vascular bundles have large diameters and have no chloroplast. Intercellular spaces are widespread among them. In this taxa vascular bundles are located in one ring. Outside the phloem there

are some schlerenchyma cells. Phloem has a thick cap of phloem fibers; the conducting phloem is quite abundant. Xylem arranged in radial rows (5) and each row consist of 4-5 tracheas. Among the vascular bundles there are schlerenchyma consisting of 2-3 rows cells. The pith is parenchymatic. The pith parenchymatic cells are usually oval or polygonal and have numerous intercellular spaces.

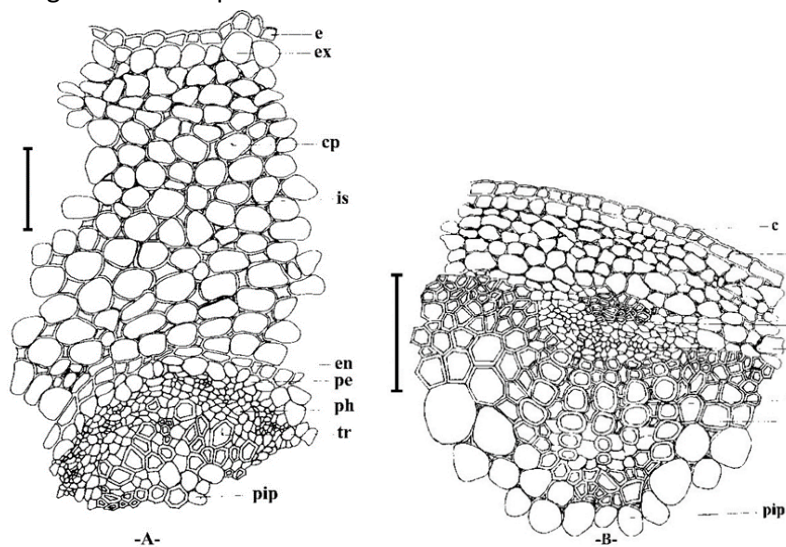


Figure 7. *Pilosella piloseloides*. A- Cross section of root, B- Cross section of stem. (c-cuticle, e- epidermis, ex- exodermis, cp- cortex parenchyma, is- intercellular space, en- endodermis, pe- pericycle, tr- trachea, trc- tracheid, ph- phloem, sc- sclerenchyma, pip- pith parenchyma. Scale bar: 100 µm)

Leaf: Epidermis consist of one row cells and the cells are usually quadrilateral (Figure 8- A). In the leaf mesophyll, palisade and spongy parenchyma cells can not be separate simply as *P. officinarum*. But it is seen that there is a palisade parenchyma consists of one row cells that have numerous chloroplasts and no intercellular space. Spongy parenchymatic cells have variable diameters and numerous intercellular spaces. The midrib is about twice thicker than the other sides of the leaf. There are 3 vascular bundles. The biggest one is in the middle. Above the vascular tissue is a mass of fibres, below that is xylem, in xylem tracheas arranged in radial rows and there are 3-

4 tracheas in each row. The vascular bundles are among the parenchyma tissue. Parenchyma cells that are close to vascular bundles have chloroplast while the others that are close to epidermis have not. Stomata are anomocytic as the other taxa and the stomata that placed on upper epidermis are of the size of 16×18 µm and the others placed on lower epidermis are 18×20 µm. The number of stomata placed on upper epidermis are about 280, the others are about 220 per/mm² (Figure 8- B, C).

Number of stomata in per/mm² from examined taxa are in Table 2 below.

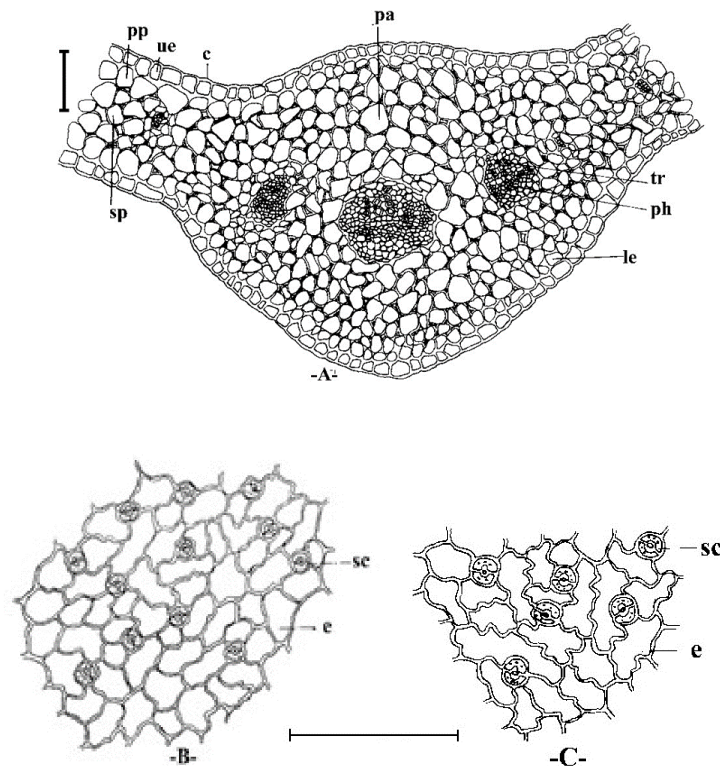


Figure 8. *Pilosella piloselloides* subsp. *bauhini*. A- Cross section of leaf, B-The stomata from upper epidermal leaf, C- The stomata from lower epidermal leaf. (c-cuticle, e- epidermis, ue- upper epidermis, le- lower epidermis, pa- parenchyma, pp- palisade parenchyma, sp- spongy parenchyma, ph- phloem, tr- trachea, sc- stoma cell. Scale bar: 100 µm

Table 2. Number of stomata in per/mm² from examined taxa.

Taxa	Number of stomata (per/mm ²) from upper epidermis	Number of stomata (per/mm ²) from lower epidermis
<i>Pilosella densiflora</i> (Tausch) Sojak	100	80
<i>Pilosella</i> × <i>hypeurya</i> (Peter) Sojak	30	80
<i>Pilosella officinarum</i> Vaill.	160	160
<i>Pilosella piloselloides</i> (Vill.) S	280	220
Sojak subsp. <i>bauhini</i> (Schult.) S. Bräut. & Greuter		

DISCUSSION

In this study, 4 *Pilosella* taxa (*P. officinarum*, *P. piloselloides* subsp. *bauhini*, *P. × hypeurya*, *P. densiflora*) collected from different localities in Northeast Anatolia were investigated in term of anatomy.

It is well known that general root anatomy does not vary much, and the taxonomic value of roots is very limited in many plant genera (Fahn 1990). It was found some differences among the root anatomy of the investigated taxa. For example; in *P. officinarum*, *P. piloselloides* subsp. *bauhini* and *P. densiflora* consist of a single layer exodermis, while *P. × hypeurya* is consist of 2-3 layer

exodermis. In addition to this, the root pith of *P. × hypeuryum* is completely composed of sclerenchyma cells in contrast to other investigated *Pilosella* taxa. Our results are generally congruent with the findings of Sepet (2017) however root characters are not useful at the specific level within the examined taxa.

Metcalf and Chalk (1972) indicated that sclerenchyma patterns in stem can be used as a taxonomic feature in grouping different plant taxa. The stem anatomy of the investigated taxa is generally similar to each other, however distribution of phloem sclerenchyma vary among taxa.

The leaf anatomy are almost similar but there are some differences among them. In *P. piloseloides*, there are 3 vascular bundles while the others have just one. In *P. × hypeurya* and *P. densiflora*, the palisade parenchyma is composed of a single layer and they are almost quadrilateral, however in *P. piloseloides* and *P. officinarum* to separate palisade parenchyma cells and spongy parenchyma cells is very difficult.

Tavakkoli et al. (2017) indicated that presence or absence of lateral vascular bundles; main midrib shape; the thickness of epidermis, the number of lateral vascular bundles and stomata size are generally in accordance with the phenetic differences in the genus *Hieracium* s. l. Our observations based on leaf anatomical characteristics partly support the findings of Qureshi et al. (2009), Tavakkoli et al. (2017) and Sepet (2017).

The leaves are amphistomatic. The stomata are in type of anomocytic like the other members of *Compositae* as described by Metcalfe and Chalk (1972). In *P. piloseloides*, the numbers of the stomata are noticeable more than the other examined taxa (Table 1).

P. × hypeurya is a natural between *P. officinarum* and *P. hoppeana* (Coşkunçelebi, 2012). The anatomical properties of hybrid taxon is generally similar with the one of the ancestor taxa (*P. officinarum*), but differs from it by having 2-3 layer of exodermis (not 1-2 layer) and unilayer of pericycle not 1-2 layer) and number of stomata on the lower epidermis.

In conclusion, the anatomical properties of the four *Pilosella* taxa investigated here are similar to the description of typical anatomy of dicotyledons except of some differences described above.

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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

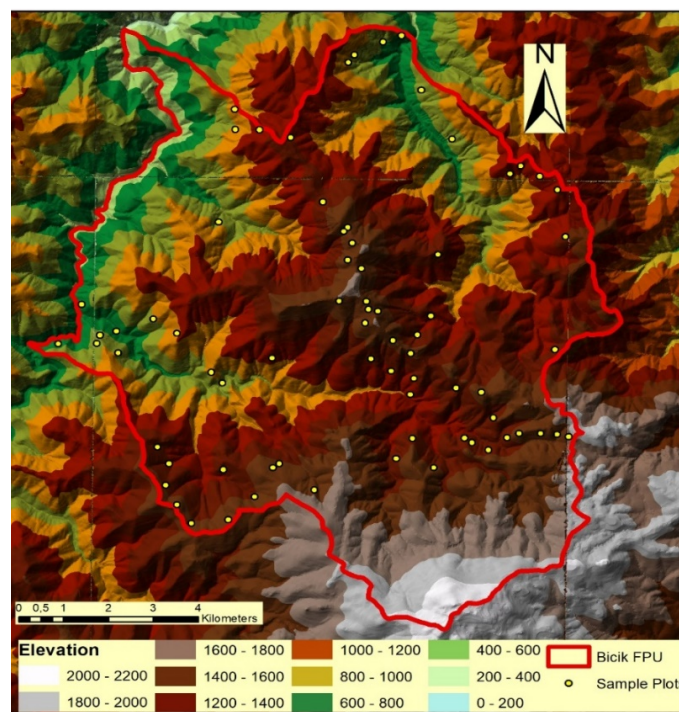


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

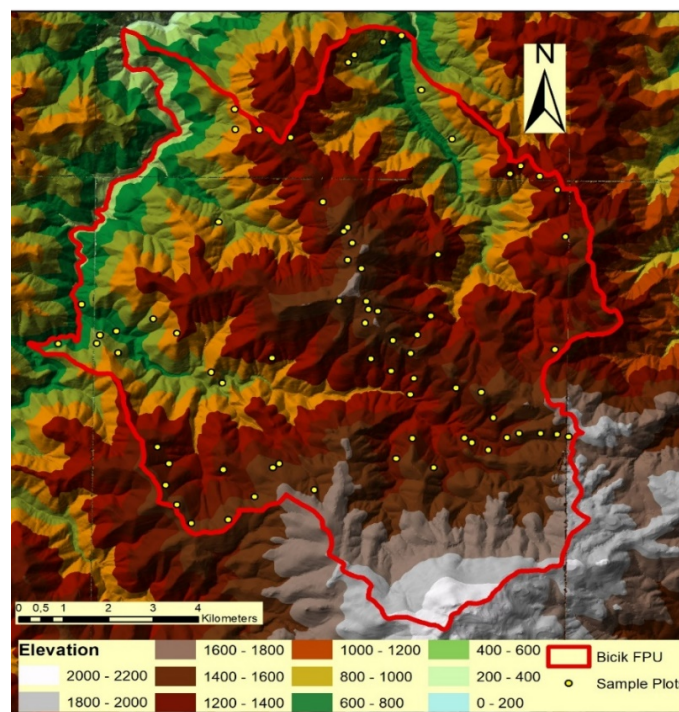


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

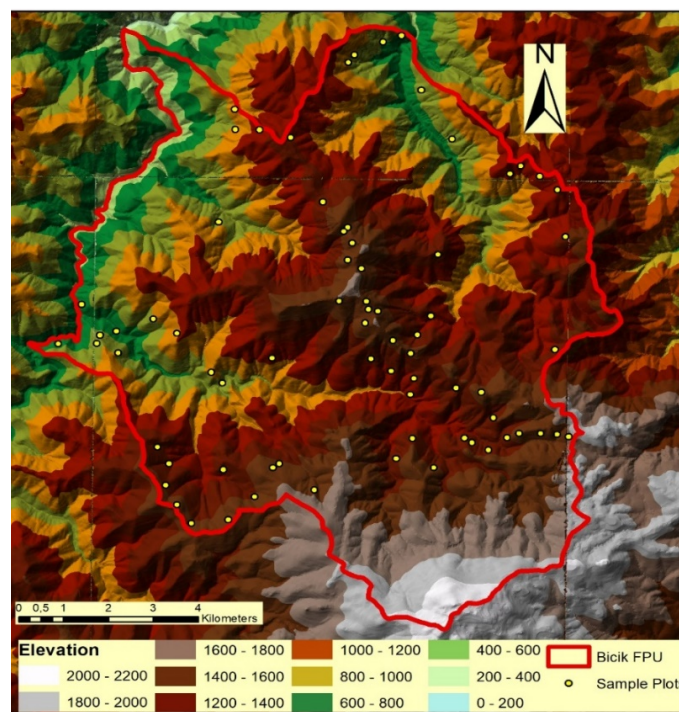


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

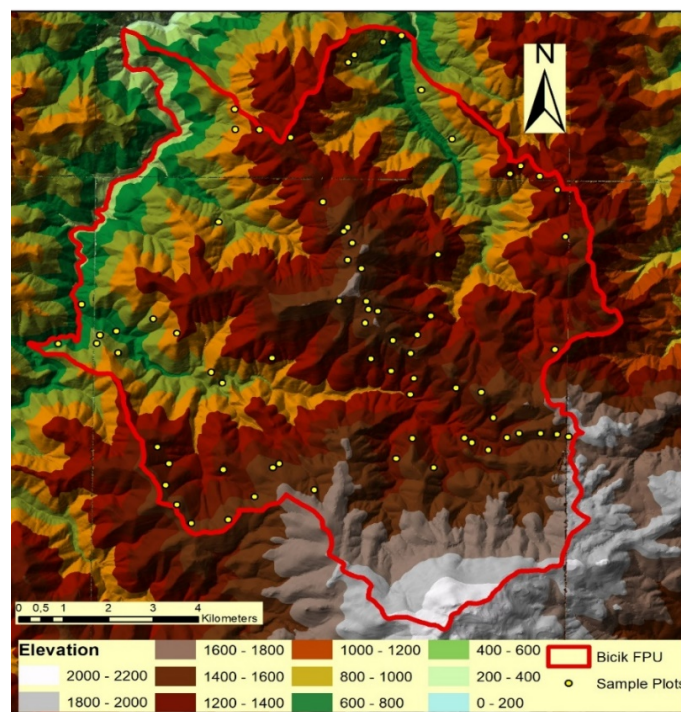


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

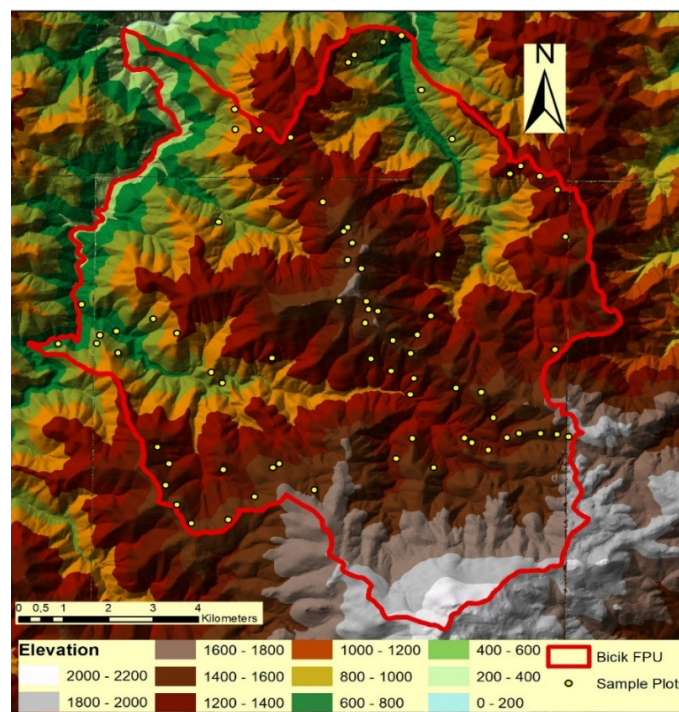


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

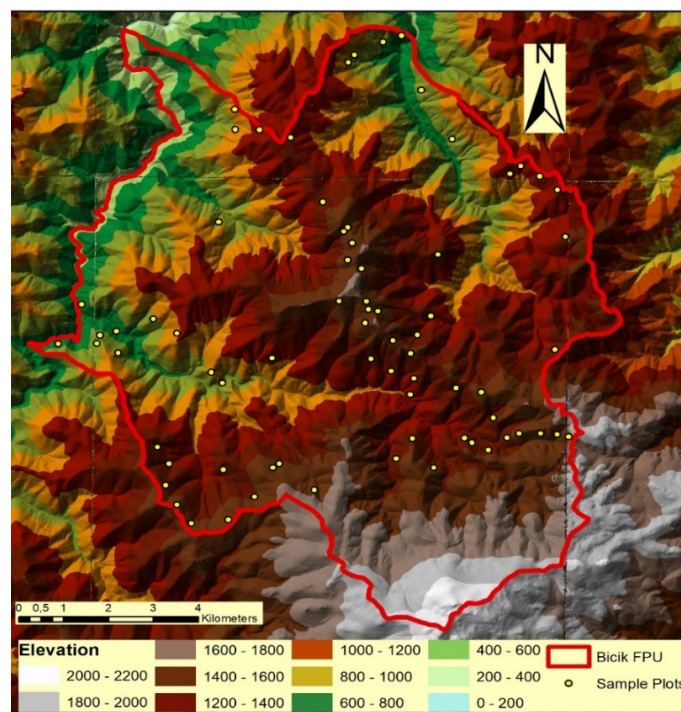


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

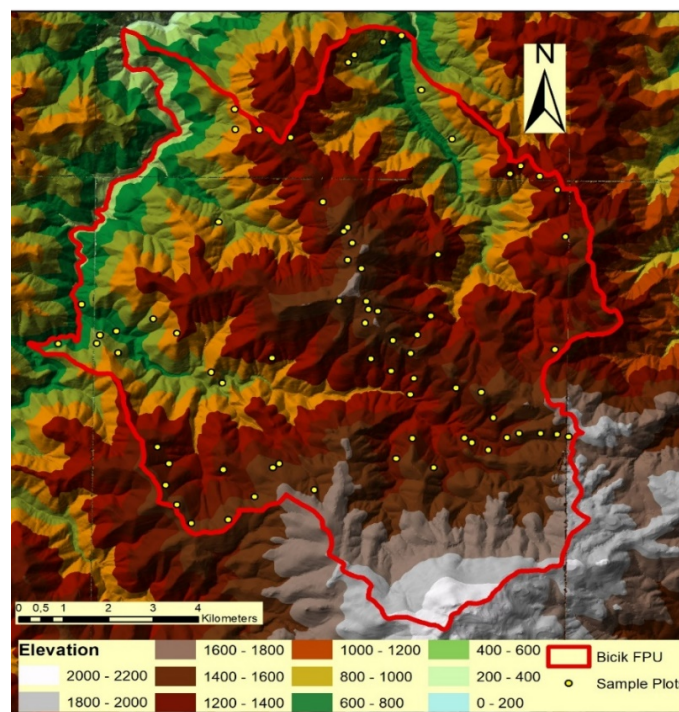


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

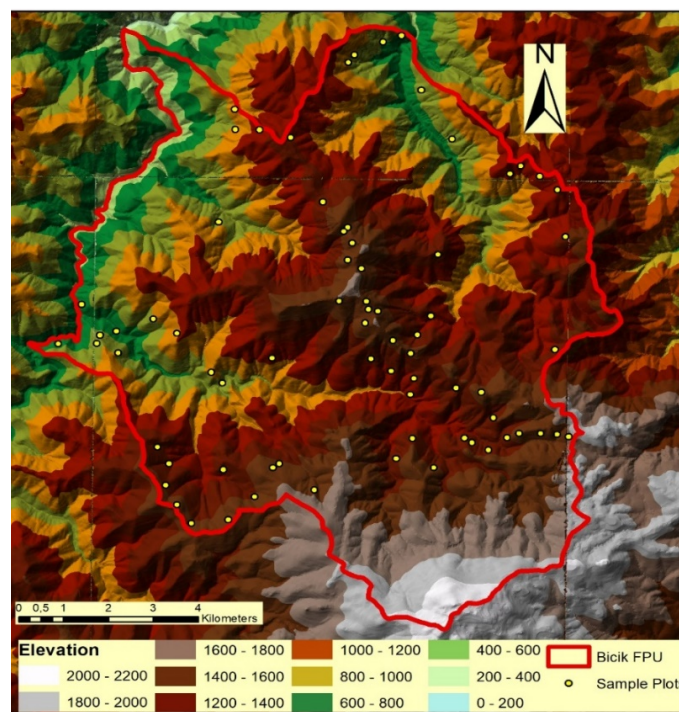


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

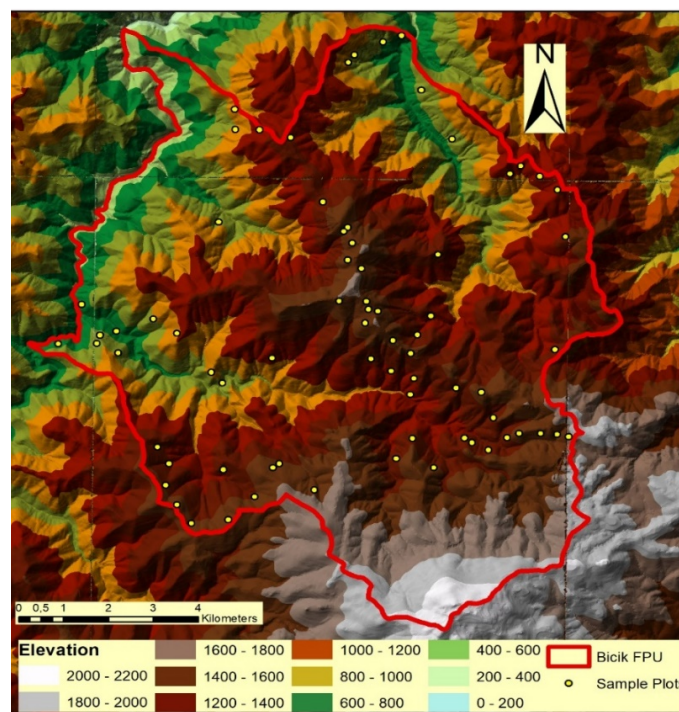


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

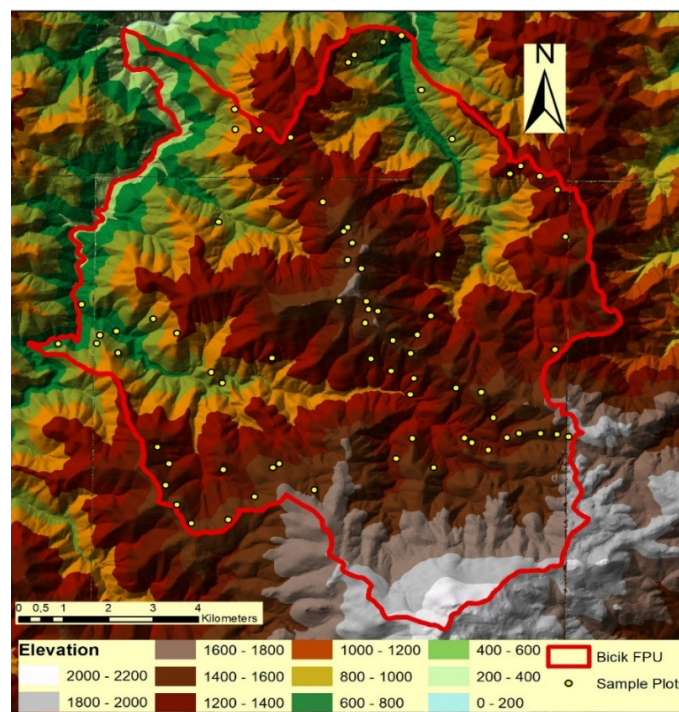


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

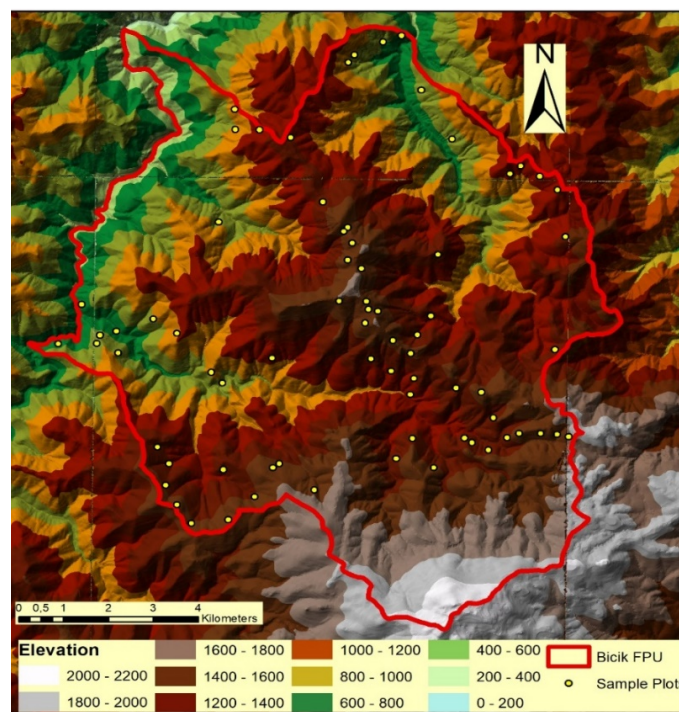


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

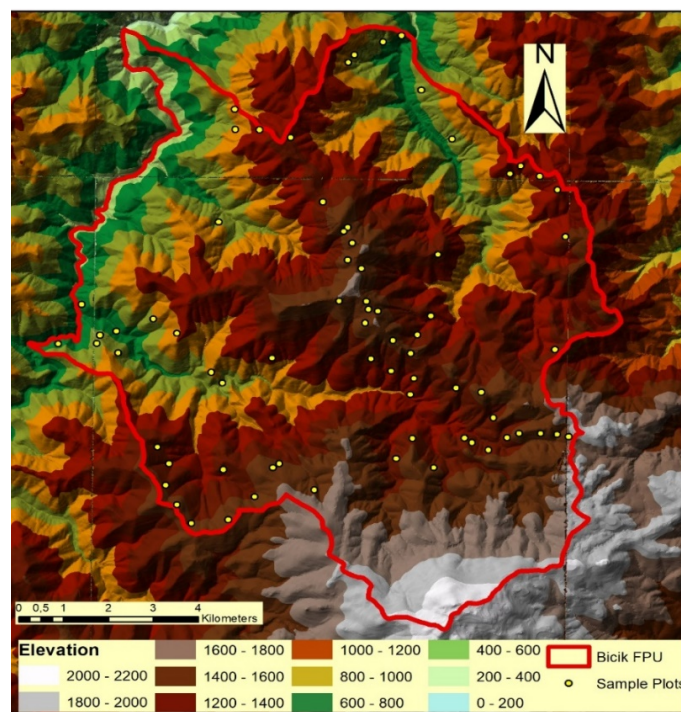


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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Bambudan nanofibril selüloz eldesi

Nanofibril cellulose production from bamboo

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Özet

Bambu tropikal iklim etkisi altında bulunan alanlarda en önemli doğal kaynaklardan birisidir. Diğer lignoselülozik kaynaklarla karşılaştırıldığında yüksek verim ve düşük maliyete sahiptir. Nanoselülozun yüksek mekanik kuvveti, biyoyuyluluğu, yüksek yüzey alanına sahip olması kompozit, gıda ve eczacılık gibi alanlarda kullanıma potansiyelini ortaya çıkarmış, ucuz kaynaklardan doğru metotlarla üretilmesi önem kazanmıştır. Bu çalışmada, ülkemizde de bulunabilen *Forgesia nitida* bambu türünden sülfürik asit yöntemiyle görünen ortalama 200 nm çaplarında selüloz nanofibrilleri elde edilmiştir. Öncelikle bambu selüloz liflerini izole etmek için sokslet ekstraksiyon yöntemiyle yağsı maddeler ve karışımında çözünen safsızlıklar sikloheksan (2:1) etanol kullanılarak 12 saatte ayrılmıştır. Alkali işlem için %8'lik potasyum hidroksit kullanılarak lignin ve hemiselüloz uzaklaştırılmıştır. Katı madde %10'luk asetik asit çözeltisiyle nötrale edilmiştir. Daha sonra TAPPI metoduna göre sodyum klorit ile tekrar ağartma işlemi uygulanmıştır. Selüloz nanofibrilleri 6,5M sülfürik asit çözeltisiyle 2 saatte 60°C'de reflaks yapılarak üretilmiştir. Nanofibrillerin kimyasal özellikleri FTIR spektroskopisi, termal özellikleri TGA-DTG analizi, morfolojik özellikleri de ışık mikroskobu ile incelenmiştir.

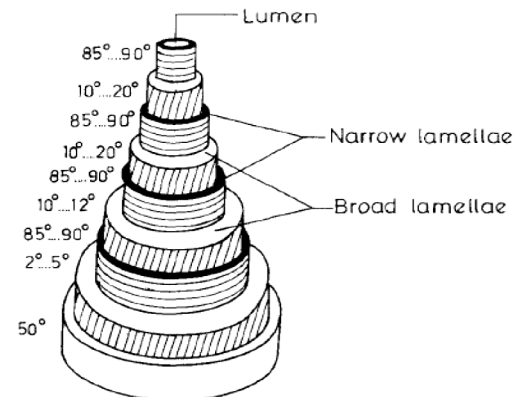
Abstract

Bamboo is one the important bioresources under the tropical climate. It has high growth efficiency with a low cost between other lignocellulosic resources. It has become important to produce nanocelulose with the right methods and from economical sources that reveal its potential with its high mechanical strength, biocompatibility in the areas such as composites or pharmaceuticals. Cellulose nanofibers were obtained at an observable minimal of 200 nm by the sulfuric acid method of *Forgesia nitida* bamboo. First, bamboo was soxlet extrated with cyclohexane (2:1) ethanol for 12 hours to dissolve and remove the leachate and waxy materials. Then 8% of potassium hydroxide was used for alkaline treatment. The solid was neutralized with 10% acetic acid solution. Then, re-bleaching with sodium chloride was applied according to TAPPI method. Cellulose nanofibrils were produced by refluxing at 60°C for 2 hours with 6.5 M sulfuric acid solution. Chemical properties of nanofibrils were investigated by FTIR spectroscopy, thermal properties TGA-DTG analysis, light microscopy with morphological characteristics.

GİRİŞ

Bambu, selüloz liflerinin lignin matris içine gömülü olduğu doğal bir lignoselülozik kompozittir. Bambu liflerinin ortalama uzunluğu 2 mm ve ortalama çapı 10-20 µm'dir. Bambunun kimyasal içeriği temelde selüloz, hemiselüloz ve ligninden oluşmaktadır. Bu temel bileşenler hücre çeperinin %90-98'ini oluşturmaktadır. Diğer kalan %2-10'luk kısım ise düşük molekül ağırlıktaki ekstraktiflerdir. Bambu sapında %60-70 holoselüloz, %20-25 pentosanlar, ayrı ayrı 20-30% oranlarında lignin ve hemiselüloz bulunmakla birlikte, eser miktarlarda rezinler, tanenler, yağlar ve inorganik tuzlar mevcuttur (Razak ve ark. 2013). Selüloz liflerinin mikrofibril açısı çok küçüktür ve bambu

polilamellar duvar yapısına sahiptir (Şekil 1) (Imadi ve ark. 2014).



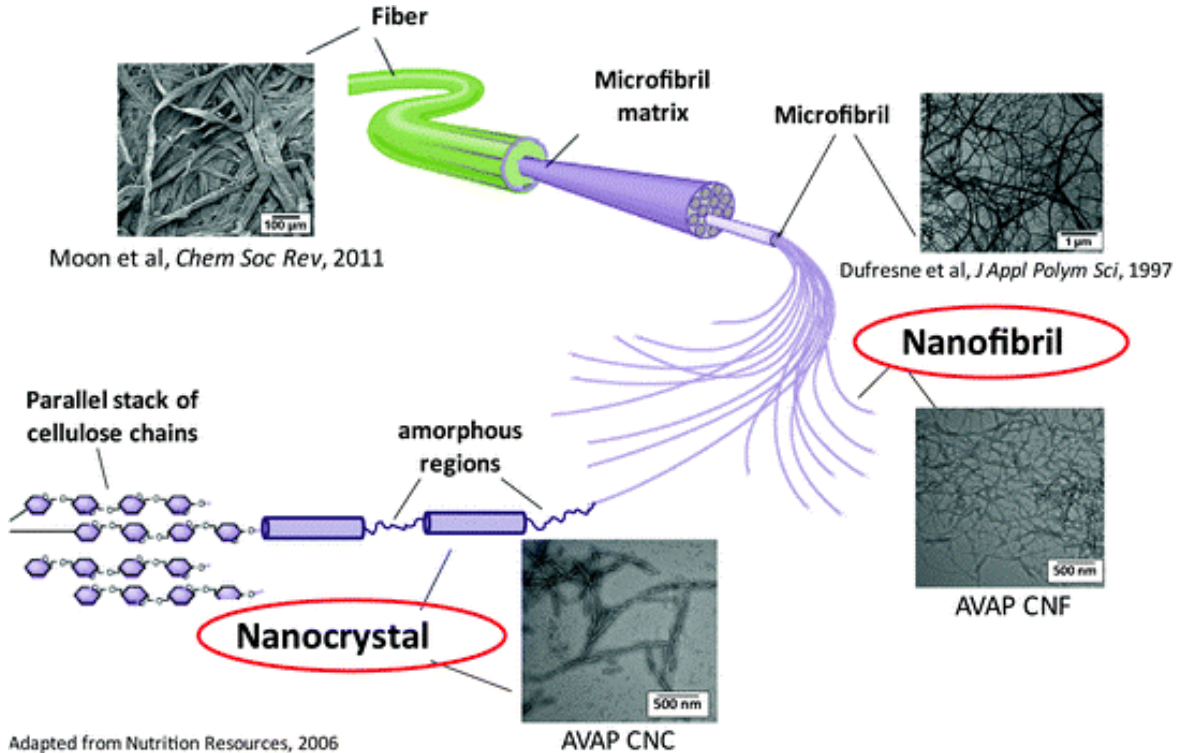
Şekil 1 Bir bambu lifinin polilamellar çeper yapısı modeli (Parameswaran and Liese 1981)

Bu faktörlerden dolayı fiber yönünde bambunun darbe, çekme ve eğilme dayanımı yüksektir (Jain ve ark. 1999). Bambu hızlı büyüyen ve yüksek verimle yenilenebilir bir kaynaktır. Bambunun hızlı büyümesi kullanımı için önemli bir teşvik edici özelliktir. Bambu günde 15-18 cm büyümeyle 4-6 ayda maksimum yüksekliğine ulaşabilir. Kalın çeperleri ve uzun sapından dolayı bambu, un, lif, pul, cips gibi birçok partikül haline dönüştürülebilir. Bambunun yoğunluğu 0.4-0.9 g/cm³ arasında anatomik yapısına göre değişiklik gösterir. Ağaca benzeyen bambu, heterojen ve anizotropik bir malzemedir. Bundan dolayı mekanik özellikleri mikroyapı özellikleri, sap uzunluğu, sap lokasyonu, yoğunluk ve nem içeriğiyle ilgili olarak son derece düzensizdir. Kopma direnci 50-120 MPa arasında değişebilirken, elastik modülü 1700-6300 MPa aralığındadır. Liflere paralel kesme direnci 4-14 MPa olabilirken, liflere paralel baskı direnci 24-70 MPa değerlerini gösterebilir (Pannipa 2013).

Nanoselüloz, bitkilerden veya bakterilerden elde nano boyutlu doğal selüloz olarak tanımlanmaktadır. Genellikle, nanoselülozlar 3 tür olarak ayrılırlar, selüloz nanokristaller (CNC), selüloz nanofibriller (CNF) ve bakteriyel nanoselüloz (BNC) (Tozluoğlu ve ark. 2015). CNC ve CNF çıkarma kaynakları ahşap, pamuk, kenevir,

keten, buğday samanı, şeker pancarı, patates yumruğu, dut kabuğu, rami, vb.dir. Asit hidrolizi gibi kimyasal olarak oluşturulmuş yıkım stratejisi, doğal selülozdan CNC'nin çıkarılması, amorf bölgelerin uzaklaştırılması ve yüksek kristalin yapının korunması yoluyla yaygın olarak gerçekleştirilir. Yayılmış nanopartiküller (CNC) 5–30 nm çapında ve 100-500 nm uzunluğunda (bitkisel selülozundan) veya 100 nm uzunluğa kadar birkaç mikrometre (tunik ve yosun selülozlarından) uzunluklarda elde edilebilmektedir (Ning ve Dufresne 2014). Asit hidrolizi yanında, oksidasyon yöntemleri özellikle TEMPO oksidasyonu adı verilen yöntem CNF üretiminde yaygın olarak kullanılmakta ve mekanik parçalanma işlemlerinin süresini azaltarak homojenizasyonu sağlamak amaçlanmaktadır (Poyraz ve ark. 2018). Nanoselüloz, gıda, kağıt, ambalaj, farmasötik, aerjel olarak bir çok farklı kullanım alanı bulabilecek özelliklere sahiptir (Bardak ve ark. 2016).

Mevcut çalışmada ülkemizde peyzaj amacıyla kullanılan *Forgesia nitida* bambu türünden ilk defa nanofibril selüloz üretimi sülfürik asit metoduyla gerçekleştirilmiş, karakterizasyonu için de FTIR, TGA ve ışık mikroskobu kullanılmıştır.



Şekil 2 Nanoselülozun hiyerarşik yapısı (Ning ve Dufresne 2014; Nelson ve ark. 2016)

MATERYAL ve YÖNTEM

Bambu odun öğütme makinasıyla (Fritsch pulverisette 19) öğütülmüş (Şekil 3), öğütülen bambulardan sokslet ekstraksiyon yöntemiyle sikloheksan (2:1) etanol karışımı kullanılarak çözünebilen safsızlıklar uzaklaştırılmıştır. %8'lik potasyum hidroksit ile alkali işlem uygulanmış ve daha sonrasında lifler %10'luk asetik asit

çözeltisiyle nötralize edilmiştir. Daha sonra sodyum klorit kullanılarak TAPPI metoduyla ağartma işlemi yapılmıştır. Ağartma işlemi yapılan selülozlara 6.5 M sülfürik asit çözeltisi 60°C'de 2 saat boyunca uygulanarak selüloz nanokristaller elde edilmiştir. Karakterizasyon için TGA analizi ve FTIR spektroskopisi, optik mikroskop kullanılmıştır.

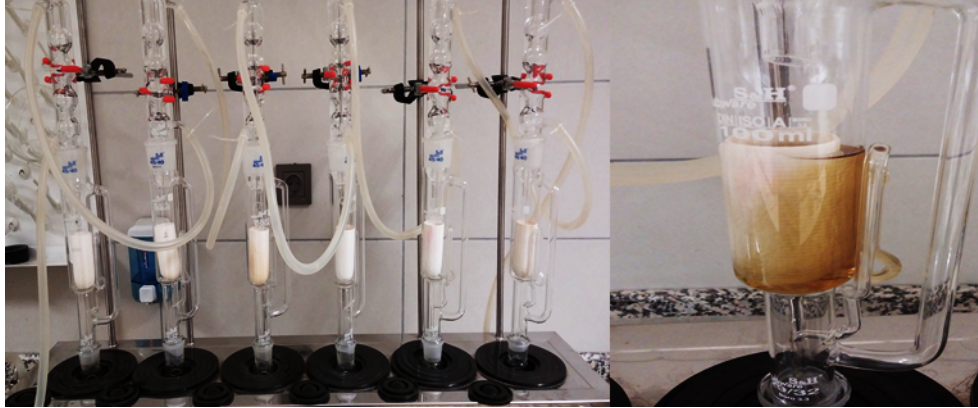


Şekil 3. Fotoğraf (a) işlem görmemiş bambu (b) öğütülmüş bambu

Sokslet Ekstraksiyonu

Bambu selüloz liflerinden yağsı maddeler ve çözülebilen safsızlıkları ayırmak için 90°C'de 12 saat boyunca sokslet

ekstraksiyonu uygulanmıştır. Sokslet ekstraksiyonunda sikloheksan (2:1) etanol karışımı kullanılmıştır (Şekil 4).



Şekil 4. Sokslet ekstraksiyonu

Potasyum Hidroksit ile Alkali İşlem

Alkali işlemde %8'lik potasyum hidroksit 1 L saf suda çözünmesi sağlanmıştır. Sokslet ekstraksiyon işlemi görmüş toz haldeki bambu %8 KOH çözeltisine eklenerek 90 °C'de manyetik karıştırıcıda 12 saat bekletilmiştir. Daha sonra %10'luk asetik asit çözeltisiyle süzme işlemi yapılmıştır ve 100 °C'de etüvde bekletilmiştir.



Şekil 5. Alkali işlem sonucu lifler

Sodyum Klorit ile Ağartma

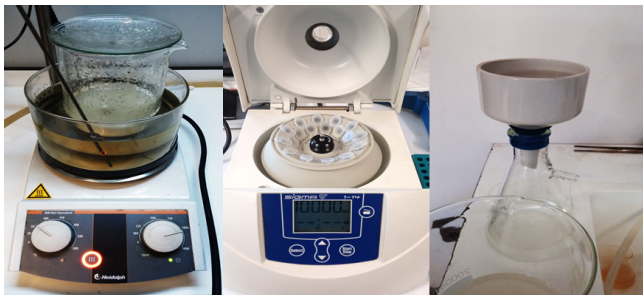
Ağartma işlemi TAPPI metodu esas alınarak yapılmıştır. Bu metotta toplam ağırlığı 27,5 g olan bambu ikiye ayrılmıştır. 14,2 g işlem görmüş bambu liflerine 500 mL saf su ilave edilerek homojenizatör yardımıyla küçük parçalara ayrılmıştır. Daha sonra manyetik karıştırıcıda 70°C’de 1000 rpm karıştırılırken saat başı 2,8 mL asetik asit ve 14,56 mL sodyum klorit eklenmiştir. Bu işlem 3 saat boyunca uygulanmıştır. Sonrasında karışım oda sıcaklığına düşürüldükten sonra sırasıyla saf su ve aseton ile süzme işlemi gerçekleştirilmiştir.



Şekil 6. Ağartma işlemi sonunda lifler

Nanokristal Üretimi

Ağartma işlemi yapılmış olan 7,4 g bambu selülozu 187,5 mL sülfürik asit çözeltisi (122,6 mL saf su- 64,9 mL sülfürik asit) içerisinde 60°C’de 1000 rpm manyetik karıştırıcıda bekletilmiştir. Uygulama sonunda oda sıcaklığına inildikten sonra karışımın 10 katı kadar soğuk saf su ilave edilmiştir. Analizler için kullanılmak üzere bu karışımdan 36 mL alınarak santrifüj cihazında (Sigma 1-14 Mikro Santrifüj) 1,5 mL’lik 24 parçaya ayrılmıştır. Santrifüj cihazında 12.000 rpm 3 dk’lık periyotlarla 15 defa yıkama işlemi yapılarak pH değeri 5-6 arasına getirilmiştir. Karışımın santrifüjde kullanılmayan büyük kısmı ise filtre kağıdı kullanarak kurutmadan süzme işlemi yapılmış ve pH 5-6 değerine getirilmiştir (Şekil 7). Süzme işlemi biten nanoselülozlar dolapta 4°C’de tutulmuştur.



Şekil 7. Nanokristal selüloz elde edilmesi

TGA Ölçümü

Bambu nanoselülozun termal kararlılığı TGA analizi ile belirlenmiş ve işlem görmemiş bambuyla karşılaştırılmıştır. TGA analizi 30-800 °C sıcaklıklarında 10°C / dk ısıtma hızında gerçekleştirilmiştir.

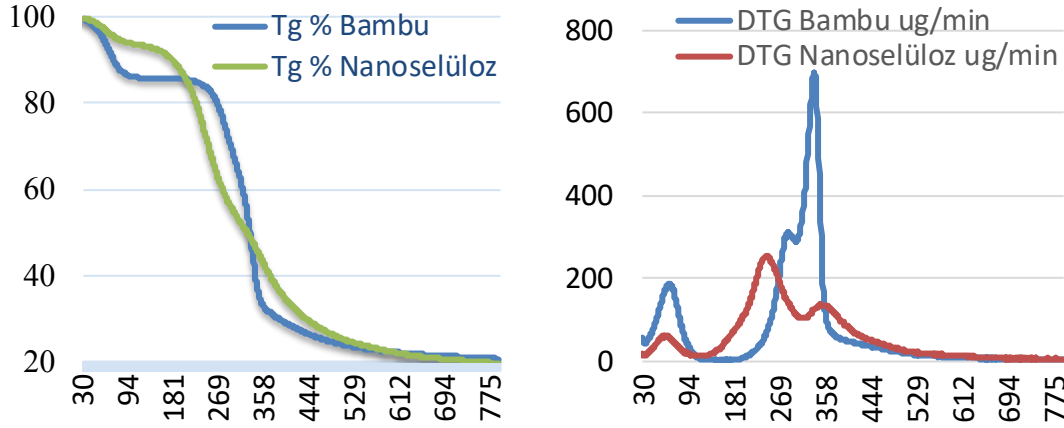
FTIR Analizi

Bambu ve bambudan elde edilen CNC’un kimyasal yapısı ve değişimleri FTIR spektroskopisiyle araştırılmıştır. FT-IR spektrumları için universal ATR aksesuarı olan Brooker marka cihaz kullanılmıştır. Ölçümler 4000 - 400 cm⁻¹ dalga boyları arasında 4 cm⁻¹ çözünürlükte yapılmıştır.

BULGULAR ve TARTIŞMA

TGA-DTG ait Bulgular

Şekil 8’de işlem görmemiş bambu ve bambudan elde edilen nanokristalin selülozun termal bozunma sonucu ağırlık kaybı-sıcaklık grafiği gösterilmiştir. 100°C’ye kadar olan ağırlık kayıplarının yapıya bağlı olmayan suyun uzaklaşması olarak yorumlanmaktadır. Bundan sonraki ağırlık kayıpları ise piroliz sonucu gerçekleşmektedir. Bambu 250°C-350°C bölgesinde bozunurken, selüloz nanolifleri 200°C-400°C gibi geniş bir bölgede bozunmakta olup, degradasyonun iki basamakta gerçekleştiği görülmektedir. Nanoselülozların düşük bozunma sıcaklığı bambuya kıyasla küçük lif boyutlarındaki geniş spesifik yüzey alanı olarak yorumlanabilir (Sofla ve ark. 2016). Sülfürik asit ile üretilen CNF’in termal analizde onset sıcaklığı 200°C’lerde olup bambuya göre ve diğer asit ve yöntemlerle üretilen CNF’lere göre düşüktür (Sofla ve ark. 2016). Bunun sebebinin sülfürik asit ile muamele esnasında yapıya bağlanan sülfat gruplarının, sıcaklıkla birlikte kopması ve genel yapının termal stabilitesini düşürmesi olarak açıklamak mümkündür (Roman ve Winter 2004). Sıcaklıkla yapıdan ayrılan sülfat grupları, ortamdaki asitliği ve reaktiviteyi arttırarak selülozun depolymerizasyonunu hem bazı hidroksil gruplarını bozmasıyla ya da katalizör etkisiyle hızlandırmakta olduğu düşünülmektedir.



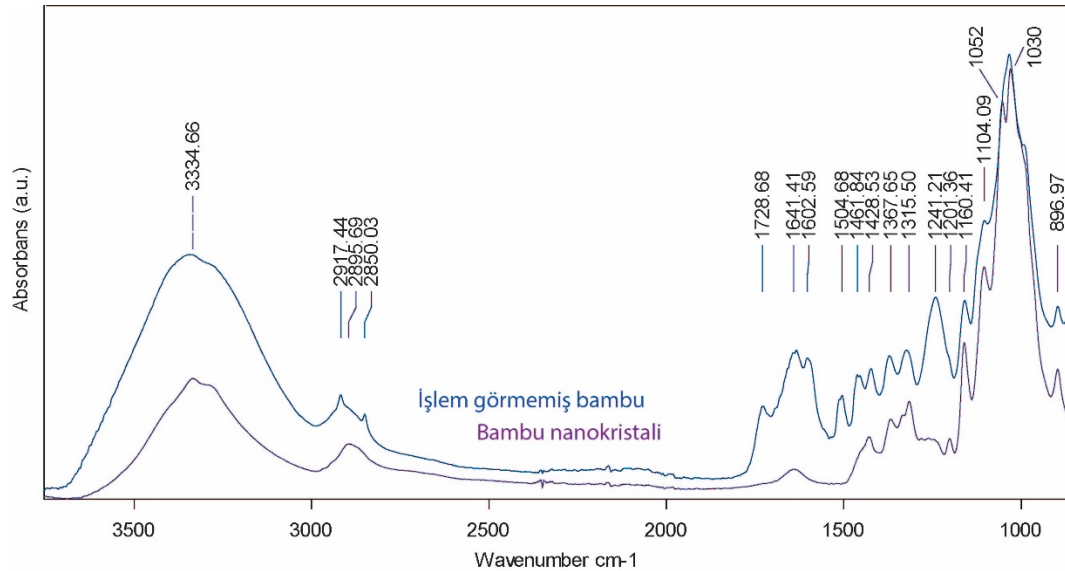
Şekil 8. İşlem görmemiş bambu ve CNC'un TGA ve DTG grafikleri

FTIR Spektroskopisine ait Bulgular

Şekil 9'da işlem görmemiş bambu ve selüloz nanofibrillerin FTIR spektrasi gösterilmiştir. İki örnek de 3200-3500 cm^{-1} band aralığında çoğunlukla selüloz moleküldeki hidroksil gruplarına ait O-H gerilim titreşimi görülmektedir. 2850-2950 cm^{-1} band aralığı da C-H ve C-H₂ gerilim titreşimleri olarak bilinmektedir. İşlem görmemiş bambu temel olarak 1600 cm^{-1} ve 1730-1740 cm^{-1} bölgelerinde hemiselüloz ve lignin komponentlerinden kaynaklanan titreşimlere sahiptir. İşlem görmemiş bambudaki 1728 cm^{-1} bandını oluşturan C-O titreşimi, hemiselüloz ve pektindeki asetil ve üronik ester gruplarından ve lignindeki p-kümerik asitlerideki ester bağlantılarında görülmektedir (Li ve ark. 2014). Bu

bandın CNF'de tamamen kaybolduğu ortaya çıkmaktadır. Ayrıca işlem görmemiş bambudaki 1604 cm^{-1} lignin aromatik gruplarındaki C-C düzlem için simetrik gerilme titreşimi olarak bilinmekte olup, CNF örneğinde kaybolmuştur (Kumar ve ark. 2012). Bu bandların CNF'de kaybolmaları lignin ve hemiselülüzün özellikle kimyasal ekstraksiyon sürecinde uzaklaşması sebebiyle olmuştur.

Selüloz miktarının yüzde olarak arttığını da band yoğunluklarından anlamak mümkündür, özellikle 897 cm^{-1} bandının yoğunluğunun arttığı gözlenmektedir. Bu band selüloz molekülünde glikoz birimleri arasındaki glikozidik bağa ait titreşimden kaynaklanmaktadır.

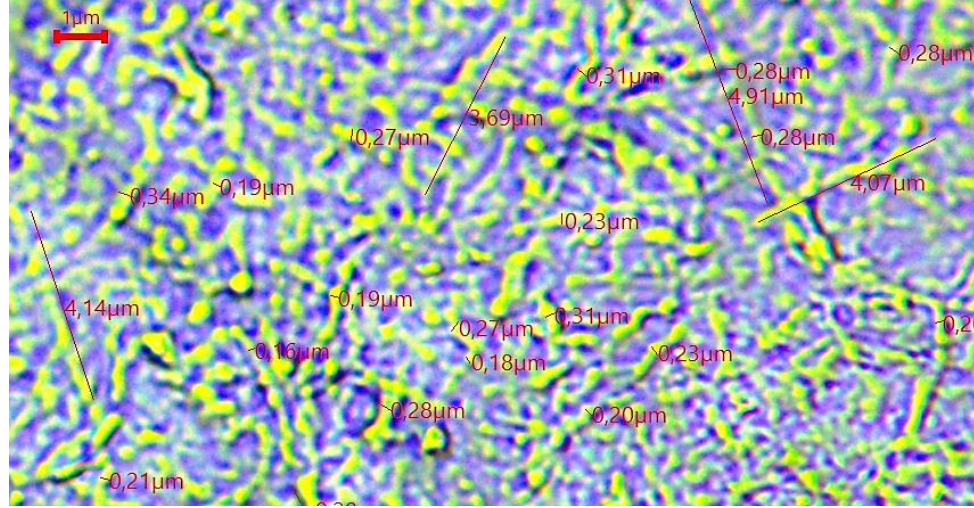


Şekil 9. İşlem görmemiş bambu ve bambu nanofiberlerin FTIR spektroskopisi

Işık Mikroskobuna ait Bulgular

Şekil 10'da selüloz nanofibrillerin ışık mikroskobu altında görüntüsü verilmektedir. 1 µm ölçekle verilen resimde görüntü alınabilen birçok lifin çapının ortalama 200 nm olduğu, boylarının ise farklılık göstermekle birlikte 3 µm'den fazla olduğu anlaşılmaktadır. Ancak farklı

bölgelerde başka bölgelerde 2-3 µm çapında 20-30 µm uzunluğunda makrofibrillerin de olduğu görülmüştür. Parçacık boyutlarını kesin olarak belirlemek ve dağılımını ortaya çıkarmak için parçacık boyutu analizi yaptırmak gerektiği görülmüştür.



Şekil 10. Selüloz nanofibrillerin ışık mikroskobu altındaki görüntüsü (40x objektif -1µm ölçek)

SONUÇLAR

Bu çalışmayla literatürde ilk defa *Forgesia nitida* bambu türünden sülfürik asitle hidroliz yöntemiyle selüloz nanofibrillerin üretilmiştir. Üretilen nanofibril selüloz termal olarak, kimyasal olarak ve yapısal olarak incelenmiştir. Yapılan analizler sonucunda termal ve kimyasal bulguların literatürle uyumlu bir şekilde olduğu. Termal çıktılara bakıldığında, nanoselüloz hazırlama sürecinde kullanılan sülfürik asit sebebiyle, selüloza bağlanan sülfat gruplarının termal bozunmayı bir miktar hızlandığı anlaşılmaktadır. FTIR sonuçlarına göre lignin ve hemiselülozun, selüloz yapısından tamamen uzaklaştığı görülmüştür. Morfolojik analizlere göre de nanofibril çapının ışık mikroskobuyla fark edilebilen ölçekte 190 nm'lere kadar düştüğü görülmüştür. Ancak birçok makrofiberinde gözlemlendiği selüloz ortamında, sonuç olarak yöntemde homojenizasyonu artıracak şekilde iyileştirmeler yapılması gerektiği, ilave olarak asit hidroliz süresinin arttırılmasının gerekli olduğu anlaşılmıştır.

TEŞEKKÜR

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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 sporocarp 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 bun. 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 et 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 m²/ha. Similarly, Martínez-Peña et al. (2012a) reported that wet and warm autumns and stands with basal area around 40 m²/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).

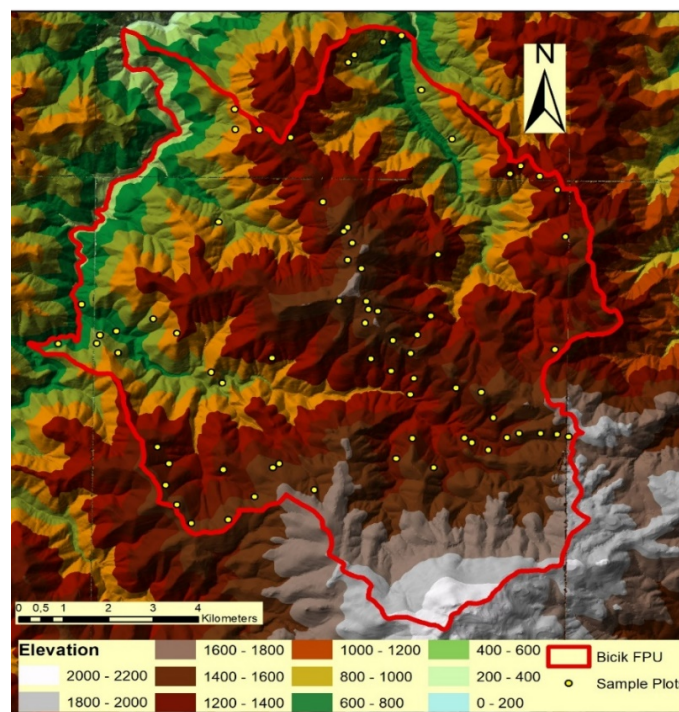


Figure 1. The spatial layout of the study area

Sampling design

Seventy-five permanent sample plots were established based on random sampling design. The sampling plots covered an area of 100 m² 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 ($p \leq 0.05$) 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 Kruskal 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 difference of 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, Kruskal-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. Kruskal-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 significant 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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