4th International Forest Entomology and Pathology Symposium (ENFITO 2022)

12-14 May, 2022 Trabzon, TURKEY

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Full Text Book

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4th International Forest Entomology and Pathology Symposium

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Contents

FULL TEXTS

Monitoring of Forest Pest Insect Through Remote Sensing Time Series Analysis: Example of Tahtaköprü Province

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Abstract

Several biotic and abiotic factors threaten forest health in Turkey that has around 22.9 million ha of forest area. Insect pests are the main destructive biological threats for Turkish forests. Pine, beech and spruce forests stand out as forests under the threat of insect epidemics. In addition, boxwood and chestnut trees are also forest trees in danger of insect epidemics. Bark beetles (*Dendroctonus micans, Ips spp.*), pine processionary moth (*Thaumetopoea pityocampa*), chestnut gall vasp (*Dryocosmus kuriphilus*) and the box tree moth (*Cydalima perspectalis*) are the most serious forest pests in Turkey in the last decade. Integrated Pest Management (IPM) strategies with the ecological aspects are the main perspective to improve pest control strategies against forest pests. First step for this is to monitor the damage level of forest pests over time. The advanced techniques like remote sensing has become important tools for forest health monitoring. Moreover, with rapid development of technology, remote sensing applications introduces new approaches for monitoring and determining the damage levels of forest pests. In the early stage of damage, stressed tree leaves do not cause any colour change in the visible spectrum. Therefore, early detection of damage becomes difficult. In this study, it is aimed to detect and monitor forest pests early by performing time series analysis of plant indices and monitoring the spectral changes in the Google Earth Engine (GEE) platform. For this purpose, Tahtakopru (Inegol) location was chosen as the study area. The epidemic (2019), pre-epidemic (2018) and post-epidemic (2020) summer and autumn periods were monitored for beech trees infected by the red-tailed beech caterpillar (*Calliteara pudibunda*). For monitoring, time series analysis and Random Forest (RF) classification were performed using Sentinel-2 satellite data and 9 different plant indices: NDVI, SAVI, TVI, RVI, NPCRI, EVI, GNDVI, NDWI, RDI. As a result of the analysis, it was determined that the insect epidemic started in October 2018. When the classification results were compared, it was seen that the best result belonged to the 2019 summer-autumn period with an overall accuracy of 86.16% and a kappa value of 0.7864. When the 2018-2020 period was followed, it was determined that the overall accuracy value was 80.58% and the kappa value was 0.70. Finally, the change analysis was made on the GEE for the time of the epidemic and after, and the amount of damage caused by the insect epidemic was determined as 373 hectares.

Keywords: *Forest Monitoring, Time Series Analysis, Pest Insect, Remote Sensing, Google Earth Engine*

Introduction

A forest is a land ecosystem formed by trees, shrubs, herbaceous plants, fungi, microorganisms, insects, living and non-living things. This ecosystem has ecological, economic, sociological and political contributions to the world.

Forests are a source of clean oxygen, balance precipitation and climate changes, protect the fauna and flora in them, and help prevent air pollution and natural disasters. In addition to these, forests are used to meet the need for fuel, paper and furniture production, etc. is the main source of raw materials.

The forest areas, which constitute approximately 29% of our country with its rich biodiversity, tend to decrease day by day. One of the main reasons for this is harmful insects. Due to the high reproductive rate of insects, it is known that the damage caused by spreading to a whole forest in a short time is much more than the damage caused by fires.

According to the report prepared by the Foresters Association of Turkey, insects, fungi and other living things damaged an area of 121,790 hectares in total between 2015 and 2017 in Turkey, and as a result of this damage, 595,195 m3 of wood had to be cut in a three-year period. The change of the damaged area and the cut amount according to the years is shown in Figure 1. In this last three-year period, both the forest area affected by biotic pests and the amount of damaged wood have increased continuously.

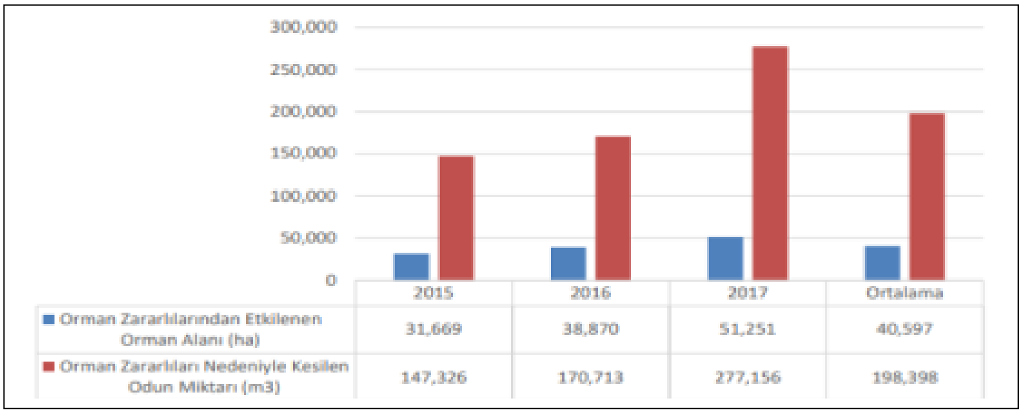


Fig. 1: Forest and tree wealth affected by insect and other biotic pests (TOD,2019)(Url-1)

Remote sensing is a science that aims to obtain information without physical contact with the earth, objects, aircraft and satellites. Remote sensing techniques provide fast, up-to-date, low-cost and highly accurate data.

The role of remote sensing methods in the fight against forest pests is so great that it cannot be ignored. By viewing forest areas with satellite data, forest types can be determined in a short time, damage and disease can be detected, even prevented, and forest health can be monitored. Maps are produced by detecting healthy and unhealthy areas in forest areas by methods such as spectral reflections, plant indexes, aerial photographs and drones, and time series analysis. With the help of these maps, the damage caused by insect species can be monitored and necessary precautions can be taken.

In this study, NDVI (Normalized Difference Vegetation Index), SAVI(Soil Adjust Vegetation Index), TVI(Transformed Vegetation Index), RVI(Ratio Vegetation Index), NPCRI (Normalized Pigment Chlorophyl Index), EVI(Enhanced Vegetation Index), GNDVI(By using the Green Normalized Difference Vegetation Index), NDWI (Normalized Difference Water Index), RDI (Ratio Drought Index) plant indices, forest pests were monitored by time series analysis and the amount of damage was determined by change analysis. Finally, random forest classification algorithm was used to check the accuracy of the study.

Material and Methods

Study Area

Tahtaköprü location on the border of Bursa-İnegöl and Kütahya-Domaniç was chosen as the study area (Figure 2.). The reason for choosing the area is that it is rich in beech trees and is affected by the red-tailed beech caterpillar (Calliteara pudibunda).

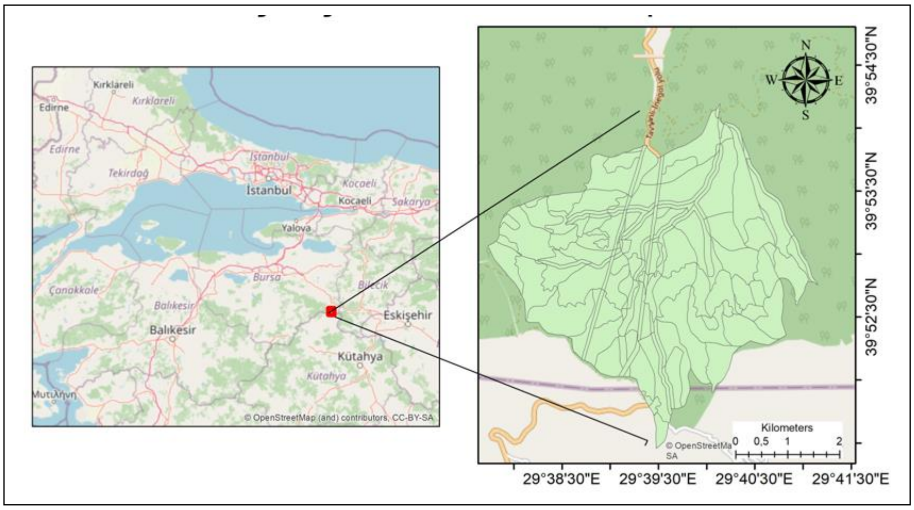


Fig. 2: Study area

Forest Pests

Insects are known to be the most harmful animal species in forests due to their high flight speed, rapid reproduction ability and ability to adapt quickly to their environment. In this study, monitoring of the red-tailed beech caterpillar (Calliteara Pudibunda), which causes damage to this tree species and also affects the study area, was carried out because the determined study area is rich in beech trees.

The red-tailed beech caterpillar (Calliteara Pudibunda) is a type of moth that only eats leaves and causes damage. It does not cause any drying on the tree trunk and therefore does not affect tree growth. Finally, it is known to cause damage during the autumn months. The picture of the red-tailed beech caterpillar (Calliteara Pudibunda) is given in Figure 3.

Fig. 3: Red-tailed beech caterpillar (*Calliteara Pudibunda*) (Url-2)

Vegetation Indexes

In the study, plant indices were used to monitor forest pests and forest health. Plant indices are values obtained by analyzing the spectra emitted from plants according to the band used and reducing them to a single value. Through these values, an idea about plant characteristics can be obtained and forest health and pests can be monitored.

The plant indices and formulas used in this study are given in Table 1.

Table 1: Vegetation indexes and formulas

Vegetation Indexes	Formulas
NDVI (Normalized Difference Vegetation Index)	(NIR-RED) / (NIR+RED)
SAVI (Soil-adjusted Vegetation Index)	((NIR-RED)/(NIR+RED+L))* (1 + L)
TVI (Transformed Vegetation Index)	$\sqrt{}$NDVI + 0.5
RVI (Ratio Vegetation Index)	RED / NIR
NPCRI (Normalized Pigment Chlorophyl Ratio Index)	(RED-BLUE) /(RED + BLUE)
EVI (Enhanced vegetation index)	(2.5* ((NIR - RED) / (NIR + 6 * RED −7.5* BLUE + 1))
GNDVI (Green Normalized Difference Vegetation Index)	(GREEN- RED) / (GREEN+ RED)
NDWI (Normalized Difference Water Index)	(NIR-SWIR) / (NIR+ SWIR)
RDI (Ratio Drought Index)	(SWIR / NIR)

Times Series Analysis

Time series are graphs obtained by ordering the data of an event according to time (Ozer et al., 2013). Through these graphs, past event monitoring and future event predictions can be made. Time series analysis, which is used in many fields such as mathematics, statistics and econometrics, is also widely used in the field of remote sensing.

In this study, the monitoring of forest pests was carried out by making time series analysis of plant indices. Sarıkaya et al.(2019; 2021) revealed in their study that the red-tailed beech caterpillar (Calliteara Pudibunda) caused an epidemic in October 2018 and 2019. Based on these studies, the period from June 2018 to October 2020 was determined as the period for monitoring the red-tailed beech caterpillar

(Calliteara Pudibunda). Plant indices were also calculated based on this date range and time series analyzes were performed.

Google Earth Engine (GEE)

GEE is an open source cloud platform and offers many conveniences to users. Examples of these conveniences are the coding panel, the possibility of using ready-made code, the rich data set of many satellites, and the data of a wide date range.

Within the scope of the study, calculations of plant indices and time series analyzes of these plant indices were carried out on the GEE platform. During the processing of the data, the use of some ready-made codes is included as well as the coding.

Sentinel-2A

Sentinel satellite data with wide spectrum and high resolution, which is also available on the GEE platform, was used for analyzes and calculations. The Sentinel satellite has two formats, Level-1C and Level-2A. Level-2A format was chosen to be used in the study.

Sentinel-2A satellite data was used from the GEE platform and data for the 2018 June-2020 October period were used. Primarily, snow, cloud and shadow masks were applied to these data. Then, the median of these images was taken monthly and converted into a single image. Plant index calculations and time series analyzes were performed on these images.

Change Detection

Analysis that aims to detect the changes between two satellite images of the same place is called change analysis (Url-3). With these analyzes, changes in land cover, illegal structures, deforestation and many more can be monitored.

In this study, change analysis was performed to determine the amount of damage caused by forest pests. For this purpose, a random forest classification algorithm was used and the satellite image was divided into 5 classes as diseased, healthy, road, electrical and residential. As a result of this classification, which was carried out on the images of October 2019 and 2020, the amount of diseased area was determined by taking the difference between the green area of 2020 and the green area of 2019.

Results

In order to better analyze the time series of plant indices, all plant indices were collected in a single graphic (Fig.4).

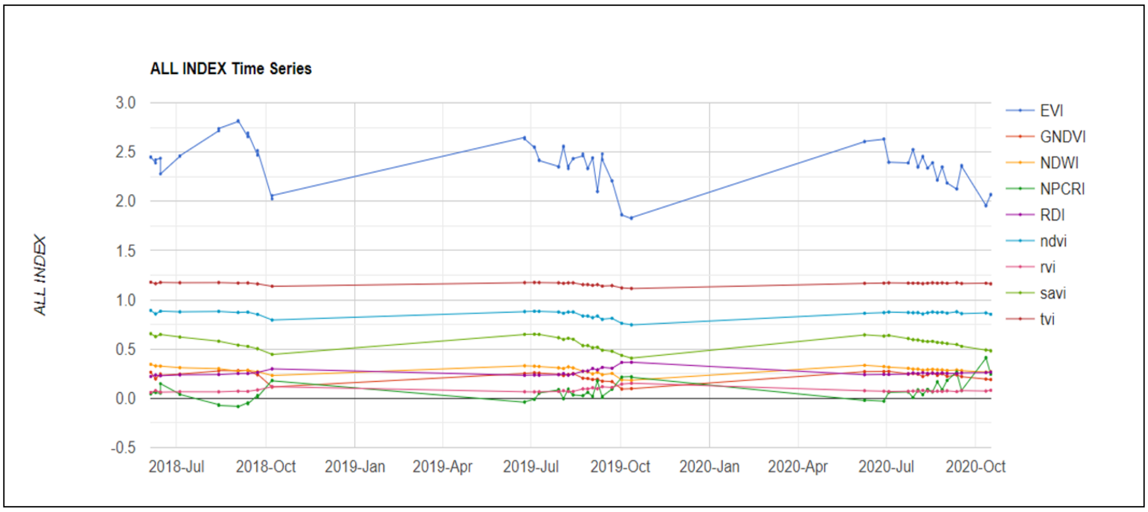


Fig. 4: Bitki indekslerine ait zaman serisi grafiği

When the graph is examined, the changes in October draw attention and these changes are shown in Fig.5.

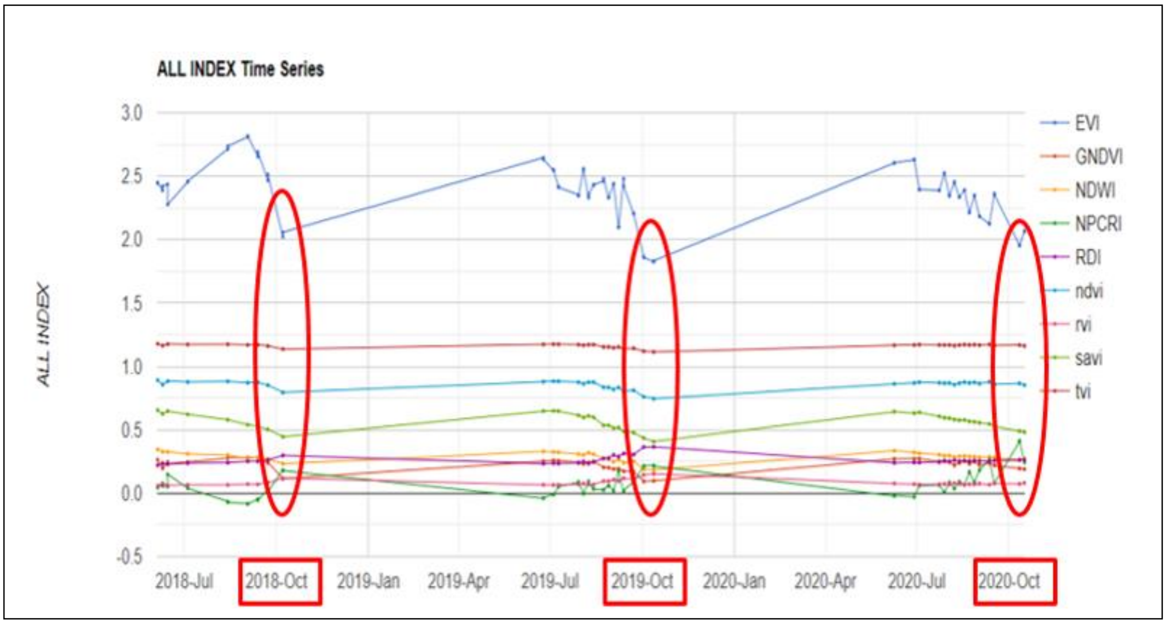


Fig. 5: Ekim ayındaki dikkat çeken değişimler

When the satellite images in October, which has more changes compared to the change in other months, are examined, it is seen that the epidemic started in October 2018, the epidemic peaked in October

2019, and the epidemic began to disappear in October 2020. Satellite images of these dates are given in Fig.6.

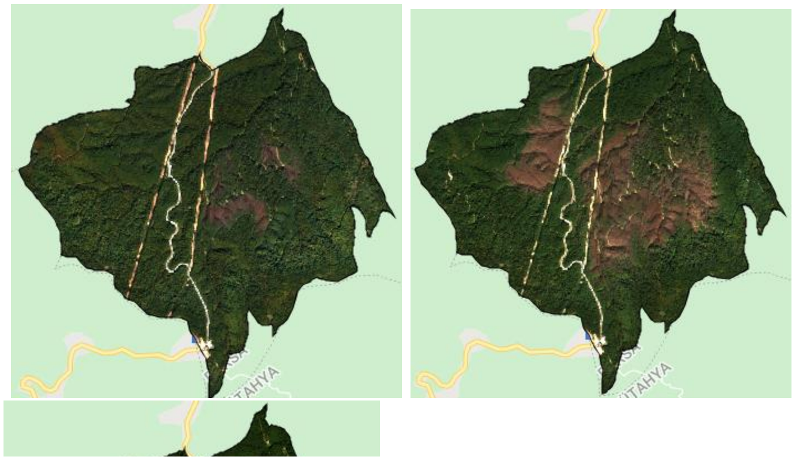
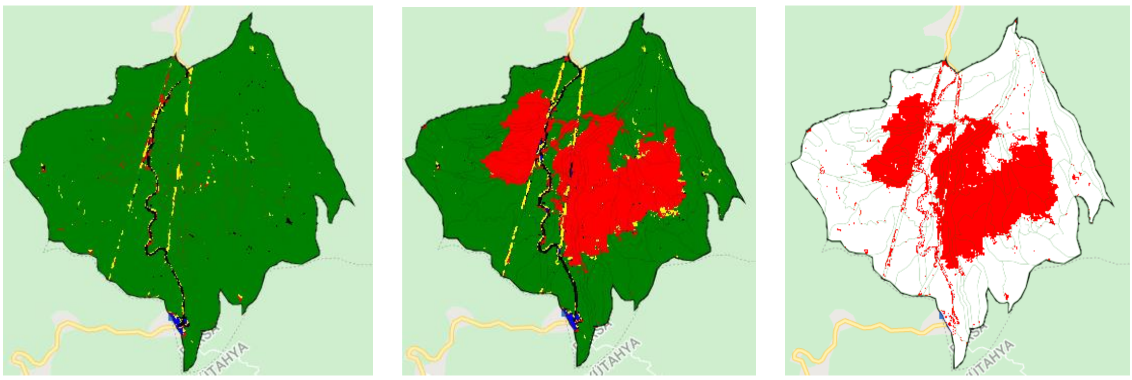


Fig. 6: 2018, 2019, 2020 Sentinel-2A satellite data for October

When the satellite images were examined, it was seen that the red-tailed beech caterpillar (Calliteara Pudibunda) caused serious damage to the eye. In order to determine the amount of damage, a change analysis was made on the satellite data of 2019 and 2020. As a result of the analysis, the amount of green space for 2019 was 373 hectares, the amount of green space for 2020 was 856 hectares, and the amount of damage was determined as 483 hectares depending on the difference between these two (Fig.7).



(a) 856 ha

(b) 373 ha

(c) 483 ha

Fig. 7: (a)Post epidemic-2020 (b) Epidemic (2019) (c) Change detection

Finally, a random forest classification algorithm was used to check the accuracy of the study, and the overall accuracy for the summer-autumn period of 2019 was 86.16%, and the kappa value was 0.7864. When the 2018-2020 period was followed, it was determined that the overall accuracy value was 80.58% and the kappa value was 0.70.

Discussion

This study showed that the use of remote sensing techniques is a very useful method in monitoring forest pests and their health. In addition to this method, the fact that the study was carried out in GEE also provided a fast, up-to-date and low-cost use. Being able to detect and monitor before, during and after the epidemic with time series analyzes of plant indices is an important benefit in the fight against pests.

Conclusion

The use of remote sensing methods in forestry should be expanded. The use of remote sensing methods in the monitoring and control of pests offers fast, low-cost and environmentally friendly solutions compared to mechanical, chemical and biotechnical control methods used in pest control.

With the rich data set of the Google Earth Engine interface used in the study, there was no shortage of data in the study. Therefore, it would be beneficial to use GEE in collaborations in the field of forestry and remote sensing.

With time series analysis, short-term monitoring can be done as well as long-term monitoring. In the study, 3-year time series analysis of plant indices was carried out. A more comprehensive study can be carried out by expanding this time interval and associating it with environmental and climatic events.

It is aimed that the study will be a pioneer for other studies in this field.

Acknowledgements

I would like to thank my advisor, Esra TUNC GORMUS, who supported and contributed to my studies.

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Url-2 https://en.wikipedia.org/wiki/Calliteara_pudibunda

Url-3 https://www.haritaciyiz.com/degisimanalizi

Saproxylic Elateridae (Coleoptera) Species in Inner Western Anatolian Region of Turkey

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Abstract

The main aim of this study is to exhibit the saproxylic Elateridae fauna of the Inner Western Anatolian region of Turkey (Afyonkarahisar, North of Denizli, Kütahya, and Uşak provinces). This study has been carried out in the scope of the Tübitak project titled “Researches on the Family Elateridae (Coleoptera) in Inner Western Anatolian Section of Turkey”. In the scope of this study, specimens were collected from decaying trees (*Pinus brutia*, *Salix* spp., *Populus* spp., and several fruit trees), and pheromone traps in 2019 and 2021. A number of collected specimens, collecting months, collecting altitudes, and temperatures of collecting localities of species were recorded and evaluated. Photographs of collecting methods were taken during field studies. Collected specimens are preserved as dried samples in the collections, examined morphologically and their species were determined. As a result of morphological examinations, 17 species were diagnosed from the genera *Agrypnus*, *Ampedus*, *Calais*, *Cardiophorus*, *Ischnodes*, *Lacon*, *Melanotus*, and *Prosternon*. Photographs of species were taken both in field studies and in the laboratory. Some ecological properties and zoogeographical distributions of these species are given, compare, and discussed.

Keywords: *Elateridae, saproxylic species, fauna, Inner Western Anatolian region.*

Introduction

The family Elateridae is one of the biggest families of the order Coleoptera, called “click-beetles” because of their clicking mechanism or called as “wireworms” because of larval morphology. It is the ninth biggest family (Insecta: Coleoptera: Elateroidea) (Lawrence, 1982). It has almost 10.000 species in the World (Lawrence 1982; Booth *et al.* 1990, Lodos 1998, Demirsoy 1999, Laibner 2000). Turkish biodiversity is rich in Elaterids including seven subfamilies, 65 genera, and 493 species (Kabalak and Sert, 2021). Adults are usually found on flowers or vegetation, beneath tree bark or stones, and in decaying woods, saprophagous, phytophagous, or predators. Larvae are found in a variety of habitats including soil, debris, and rotting wood (Lawrence et al., 2000). The larvae of many species are destructive agricultural pests, which feed on newly planted seeds and the roots of various plants, such as beans, cotton, potatoes, corn, beet, carrot, onion, alfalfa, clover, various fruits, and cereals (Kabalak and Özbek, 2018). Many species of the family Elateridae are saproxylic and live in decaying trees. There are important studies by different researchers on saproxylic Elateridae species and other insect groups in Turkey and the World (Avgın *et al.* 2014, Brunet and Isacsson 2010, da Silva et al. 2006, Kabalak *et al.* 2013, Platia et al. 2014, Platia et al. 2018, Sama *et al.* 2011).

The main purpose of this study is to exhibit saproxylic Elateridae species in the Inner Western Anatolia region (Figure 1).

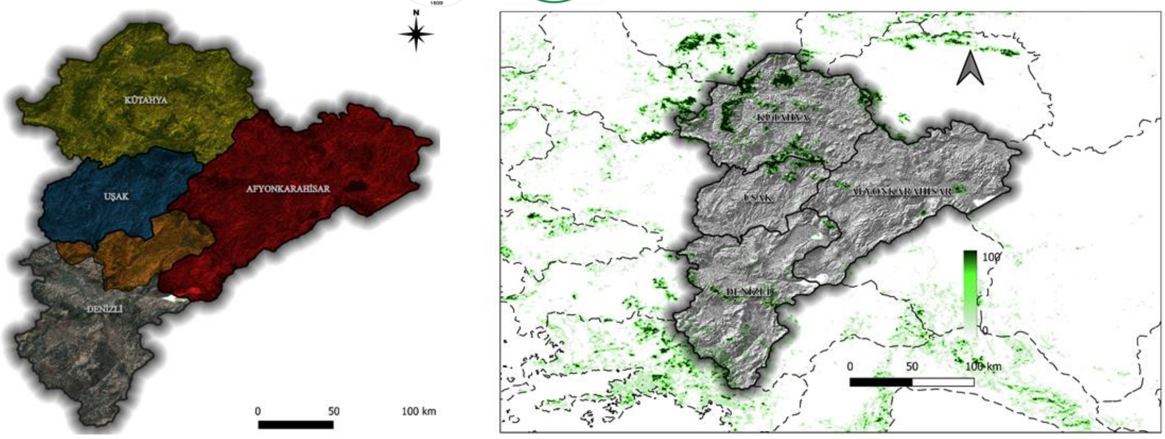

Fig. 1: Maps of the study area and coniferous forest of the research area and its surroundings.

Material and Methods

This study has three steps: collecting specimens by field studies (Figure 2), species diagnosis, and evaluation of results. Specimens were collected from decaying trees (*Pinus brutia*, *Salix* spp., *Populus* spp., *Quercus* spp., and several fruit trees) by using an aspirator, and pheromone traps between March to October 2019 and 2021. Photographs of collecting methods were taken during field studies. Collected specimens are preserved as dried samples in the collections, examined morphologically and their species were determined.

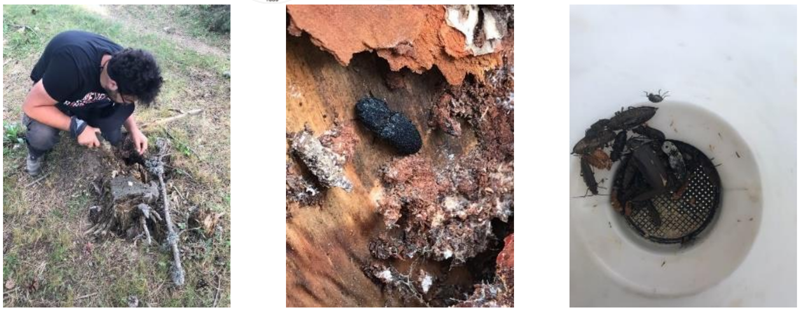

Fig. 2: Collecting from decaying trees by an aspirator and pheromone traps in field study.

Results

As a result of morphological examinations, 17 species were diagnosed from the genera *Agrypnus*, *Ampedus*, *Calais*, *Cardiophorus*, *Ischnodes*, *Lacon*, *Melanotus*, and *Prosternon* (Figures 3A-R and Table 1). Photographs of species were taken both in field studies and in the laboratory. Zoogeographical distributions of these species are given, compare, and discussed.

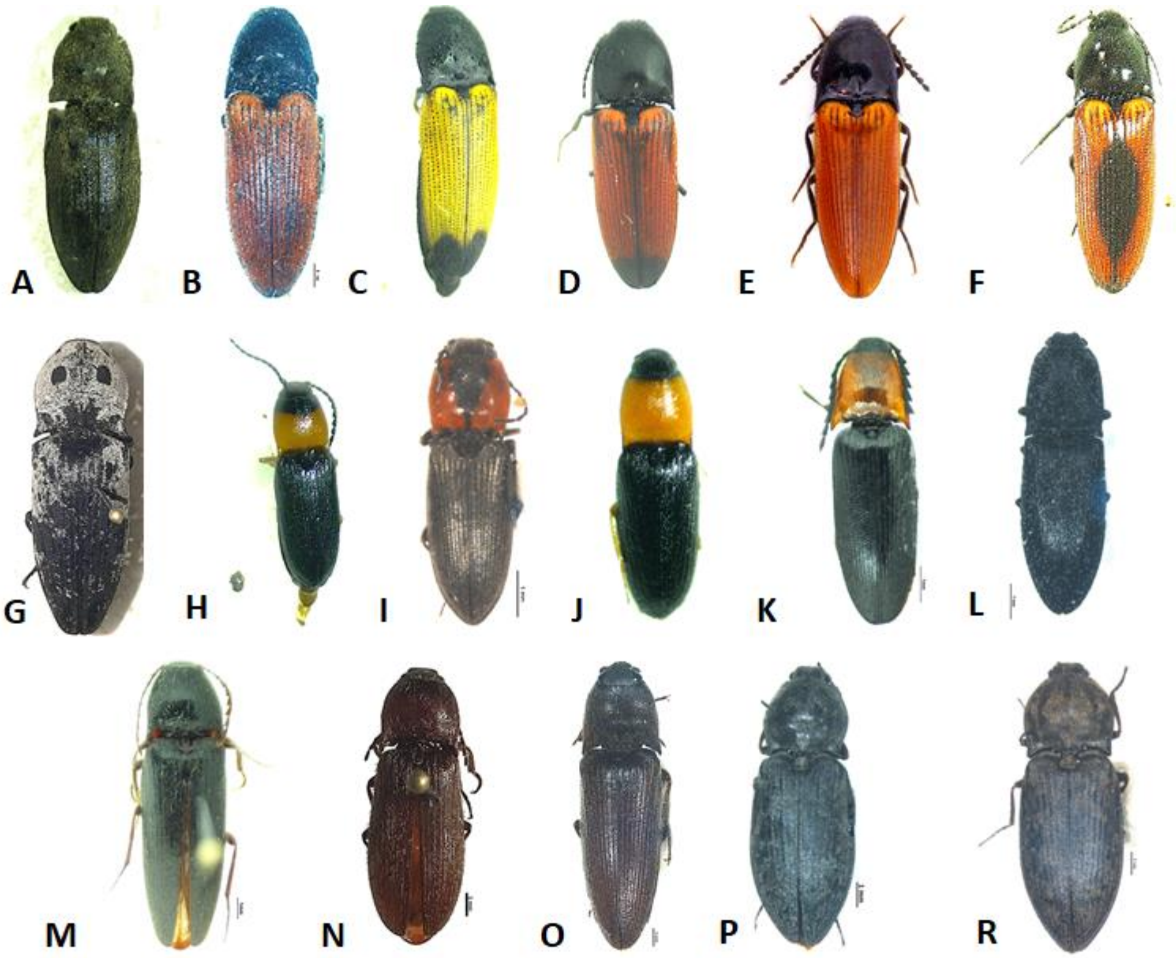

Fig 3: Habitus photographs of determined species. **A.** *Agrypnus murinus*, **B.** *Ampedus cinnaberinus*, **C.** *A. elegantulus*, **D.** *A. elongatulus*, **E.** *A. sanguineus*, **F.** *A. sanguinolentus*, **G.** *Calais parreysii*, **H.** *Cardiophorus anticus*, **I.** *C. discicollis*, **J.** *C. miniaticollis*, **K.** *Ischnodes sanguinicollis*, **L.** *Lacon punctatus*, **M.** *Melanotus crassicollis*, **N.** *M. fraseri*, **O.** *M. fusciceps*, **P.** *Prosternon syriacum*, **R.** *P. tessellatum*

Table 1: List of determined species and their subfamilies.

Subfamily	Determined Species
Agrypninae	*Agrypnus murinus* Ménétriés, 1832
Elaterinae	*Ampedus cinnaberinus* (Eschscholtz, 1829)
Elaterinae	*Ampedus elegantulus* (Schönher, 1817)
Elaterinae	*Ampedus elogantulus* (Fabricius, 1787)
Elaterinae	*Ampedus sanguineus* (Linnaeus, 1758)
Elaterinae	*Ampedus sanguinolentus* (Schrank, 1776)
Agrypninae	*Calais parreysii* (Steven, 1830)
Cardiophorinae	*Cardiophorus anticus* Erichson, 1840
Cardiophorinae	*Cardiophorus discicollis* (Herbst, 1806)
Cardiophorinae	*Cardiophorus miniaticollis* Candèze, 1860
Elaterinae	*Ischnodes sanguinicollis* (Panzer, 1793)
Agrypninae	*Lacon punctatus* (Herbst, 1779)
Elaterinae	*Melanotus crassiscollis* (Erichson, 1841)
Elaterinae	*Melanotus fraseri* Platia & Schimmel, 1993
Elaterinae	*Melanotus fusciceps* (Gyllenhal, 1817)
Denticollinae	*Prosternon syriacum* (Buysson, 1891)
Denticollinae	*Prosternon tessellatum* (Linnaeus, 1758)

Table 2: Distributions of detected species in Turkey and Palaearctic region. Geographic regions of Turkey: AR: Aegean Region, BSR: Blacksea Region, CAR: Central Anatolian region, EAR: Eastern Anatolian Region, MR: Marmara Region, MDR: Mediterranean Region. Subregions of Palaearctic Region: ETR: Endemic for Turkey, EU: Europe, FE: Far East, HOA: Holarctic, MA: Middle Asia, ME: Middle East, NA: North Africa, SB: Siberia (Cate 2007, Kabalak and Özbek 2018, Kabalak and Sert 2011, 2013, 2021, Sert and Kabalak 2011).

Species	Distribution in Turkey	Zoogeographical Distribution
Agrypnus murinus	BSR	HOA
Ampedus cinnaberinus	BSR, CAR, EAR	EU, MA, ME, SB, FE
A. elegantulus	BSR, CAR, AR	EU, ME
A. elongatulus	BSR	EU
A. sanguineus	BSR, EAR	EU, NA, MA, ME
A. sanguinolentus	CAR, BSR, AR	EU, NA, MA, SB, FE
Calais parreysii	CAR, AR, MR, MDR	EU, ME
Cardiophorus anticus	CAR, BSR, MDR	ETR
C. discicollis	CAR, BSR, AR, MDR	EU, MA, ME
C. miniaticollis	CAR, MDR	EU, ME
Ischnodes sanguinicollis	MDR, AR, EAR	EU, ME, FE
Lacon punctatus	BSR, CAR, AR, MDR, MR	EU, MA, ME

Melanotus crassicollis	AR	EU
M. fraseri	AR, CAR, MR	ME
M. fusciceps	CAR, MR, AR	EU, MA, ME
Prosternon syriacum	BSR, CAR, EAR, MDR	ME
P. tessellatum	BSR, CAR, MR, EAR	EU, MA, SB

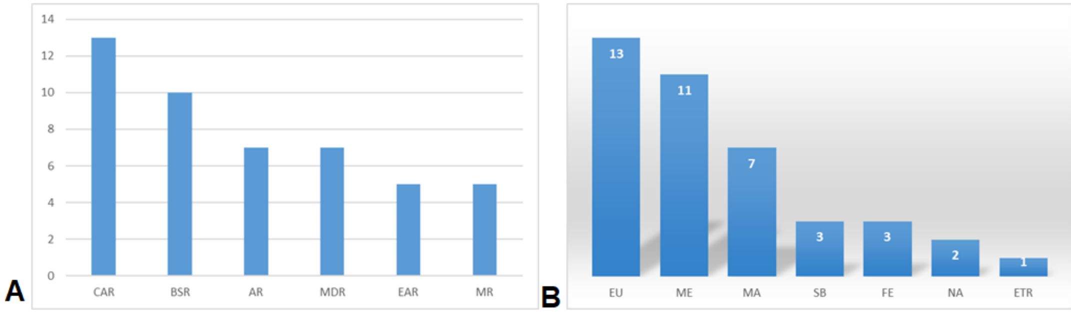

Fig. 4: Distributions of examined species. **A.** Distributions of examined species in Turkey, **B.** Zoogeographical distributions of examined species.

Discussion

We collected specimens from decaying trees (*Populus* spp., *Salix* spp., *Pinus* spp., *Quercus* spp.) and pheromone traps. We determined that 17 species were diagnosed from the genera *Agrypnus*, *Ampedus*, *Calais*, *Cardiophorus*, *Ischnodes*, *Lacon*, *Melanotus*, and *Prosternon*. Most of the determined species are shared with the Central Anatolian region in Turkey and Europe in the Palaearctic region (Table 2 and Figure 4). Important number of species were collected from decaying *Pinus* spp. (especially *P. brutia*) during field studies. We detected that the phenology of determined species (especially *Ampedus* spp., *Ischnodes sanguinicollis*, *Cardiophorus* spp.) is limited (between April to June) except for *Lacon punctatus*, which distributes in a large period. We could not detect a significant difference between the altitudes and temperatures of the localities where the determined species were collected. The research area could be accepted as rich in having saproxylic Elateridae species.

Conclusion

Saproxylic beetles are an important part of forest ecosystems, both in the food chain and in forest biodiversity. Our study has shown that especially many species of the family Elateridae has an important place among these insects.

Acknowledgements

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Niche Modelling Study on Six Elateridae (Coleoptera) Species in Turkey

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Abstract

The main purpose of this study is to make Ecological Niche Modeling (ENM) for *Athous haemorrhoidalis*, *Cardiophorus nigratissimus*, *Drasterius bimaculatus*, *Nothodes parvulus*, *Peripontius omissus* and *Peripontius terminatus* species within the scope of Tübitak project carried out in the Inner Western Anatolia region. ENM's for possible current and future distributional scenarios of examined species are created by Maxent Software. Possible suitable habitats in 2050 and 2070 for the species are calculated according to IPCC5 Climate scenarios. AUC value greater than 0.5 indicates that the model result is different from a random estimate. AUCs value is 0.65 for *Athous haemorrhoidalis*, 0.73 for *Cardiophorus nigratissimus*, 0.72 for *Drasterius bimaculatus*, 0.78 for *Nothodes parvulus*, 0.77 for *Peripontius omissus* and 0.85 for *Peripontius terminatus*. *Cardiophorus nigratissimus* is xerophilic species, *Athous haemorrhoidalis*, *Drasterius bimaculatus*, *Nothodes parvulus*, *Peripontius omissus*, and *Peripontius terminatus*, prefer humid habitats. As a result of ENM, we can state that suitable habitats of all examined species could decrease in future estimations.

Keywords: *Ecological Niche Modelling, Elateridae, Inner Western Anatolian region.*

Introduction

They are called as "click-beetles" because of their clicking mechanism or called as "wireworms" because of larval morphology. It is the ninth biggest family (Insecta: Coleoptera: Elateroidea) (Lawrence, 1982). It has almost 10.000 species in the World (Lawrence, 1982; Booth *et al.*, 1990; Lodos, 1998; Demirsoy, 1999; Laibner, 2000). Turkey is one of the important countries including 493 Elateridae species belonging to 65 genera and seven subfamilies (Gülperçin and Tezcan 2015; Platia 2017; Sert and Kabalak 2017; Gülperçin *et al.* 2018; Kabalak and Özbek 2018; Platia *et al.* 2018, Platia *et al.* 2020). This rich fauna could be evaluated as a vital biodiversity network representing an essential opportunity for monitoring the potential effects of climate change on living organisms of Turkey due to the diverse habitats of different taxa in this family. Elateridae specimens could be sampled from different habitats with different methods (Insect nets, aspirators, light traps, pitfall traps, pheromone traps) such as ground herbaceous plants of forests, herbaceous plants near streams, herbaceous plants near fields and roads, decaying trees, trees, and bushes, under stones and debris near streams and forests (Kabalak and Sert 2011; Sert and Kabalak 2011). Ecological niche modeling is a powerful tool that provides determining suitable habitats, distribution of species and mapping these habitats. In ENM, species known habitats and a wide range of environmental parameters are used. ENM can be used for understanding ecological requirements of species, distributions, biogeography and dispersal barriers and finding unknown populations. The main purpose of this study is to make Ecological Niche Modeling (ENM) for six Elateridae species (Figures 2a-f) having different distributional patterns (Table 1, Figure 1a-b) in the Inner western Anatolian region and the whole of Turkey.

Table 1: Distributions of examined species in geographical regions of Turkey and Sub-regions of Palearctic region.

Species	Distribution in Turkey	Zoogeographical Distribution
Athous haemorrhoidalis	BSR, CAR, EAR, AR, MR	EU, MA, ME
Cardiophorus nigratissimus	CAR, EAR, SEAR, AR, MDR, BSR	EU, MA, ME
Drasterius bimaculatus	BSR, CAR, MR, EAR, SEAR, AR, MDR	EU, MA, ME, NA
Nothodes parvulus	BSR, CAR, MR, EAR, AR, SEAR, MDR	EU, ME, NA
Peripontius omissus	BSR, CAR, EAR, MDR, AR	ME
Peripontius terminatus	BSR, CAR, AR, MDR	EU

a

b

Fig. 1: Maps of geographical regions of Turkey (a) and the Palearctic region and its sub-regions (b).

Material and Methods

Specimen Data

Specimens of *Athous haemorrhoidalis*, *Cardiophorus nigratissimus*, *Drasterius bimaculatus*, *Nothodes parvulus*, *Peripontius omissus* and *Peripontius terminatus* (figures 1a-f) were collected by insect net, aspirator, japanese umbrella at 81 locations in Turkey's Inner Western Anatolian Region and literature data based on Central Anatolia, Western Blacksea, and Middle Blacksea regions (Table 1). Part of the samples was preserved in absolute ethanol and stored at -20 °C until analyses, while the rest were retained as dry samples in the Elateridae collection of Hacettepe University Molecular Systematic Entomology Laboratory. Identification of collected samples to the species level was done by available keys and by collection comparisons (Platia 1994; Kabalak 2010). Table 1 includes distributional data in

Turkey (Gülperçin and Tezcan 2010; Kabalak and Sert 2011, 2013; Sert and Kabalak 2011; Kabalak ve Özbek 2018) and throughout the World (Cate 2007).

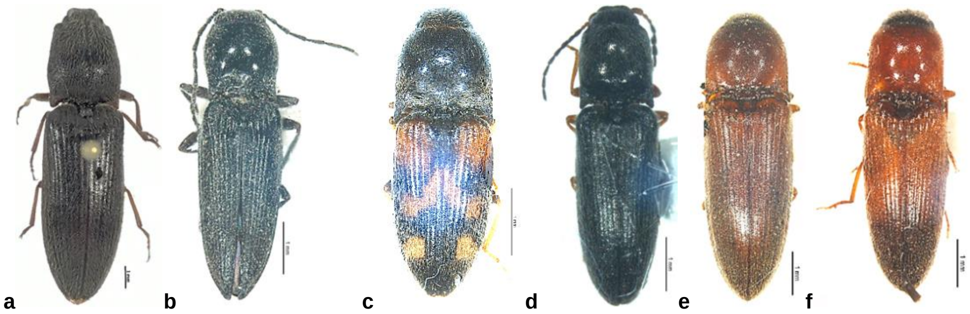


Fig. 2: Habitus photos of the examined species. **a.** *Athous haemorrhoidalis*, **b.** *Cardiophorus nigratissimus*, **c.** *Drasterius bimaculatus*, **d.** *Nothodes parvulus*, **e.** *Peripontius omissus*, **f.** *Peripontius terminatus*.

Ecological Niche Modeling

Within the scope of ENM, models for current, 2050, and 2070 years were created using MaxEnt 3.4.1 (Phillips *et al.* 2006; Elith *et al.* 2011) software. 4 RCPs (representative concentration pathways; RCP2.6, RCP4.5, RCP6, and RCP8.5') (Table 4) defined in the Intergovernmental Panel on Climate Change 5 (IPCC) were used to identify suitable future habitats for species distribution.19 bioclimatic variables (Table 3) used in the models were obtained from the Worldclim database (Hijmans *et al.* 2005; www.worldclim.org) at 30 arcsec (~1km) resolution. During the model preparation phase, geographic information system (GIS) operations were performed with ArcGIS 10.6 software. Presence data for *Athous haemorrhoidalis*, *Cardiophorus nigratissimus*, *Drasterius bimaculatus*, *Nothodes parvulus*, *Peripontius omissus*, and *Peripontius terminatus* were obtained from species identified from field studies, as well as in the Global Biodiversity Information Facility (GBIF) database (GBIF.org (2021)) and samples from literature. (Kabalak and Sert 2011; Kabalak and Sert 2013; Sert and Kabalak 2011; Kabalak and Sert 2021) (Table 2). ENMs were created using MaxEnt in the SDMtoolbox application and the spatial jackknife (Spatial jackknifing) option (Radosavljevic and Anderson, 2014). It is necessary to evaluate whether the generated ENMs differ from a random estimate. Area Under the Curve (AUC) was preferred for the validation of models (Fielding and Bell 1997). For ENM MaxEnt software is used (Elith *et al.* 2011; Phillips *et al.* 2004, 2006) in this study. Area Under the Curve (AUC) was preferred for the validation of models. AUC value greater than 0.5 indicates that the model result is different from a random estimate.

Table 2: Number of presence data of examined species and sources of examined data.

Species	Field study sampling	Number of locality from GBIF	Literature	Total
Athous haemorrhoidalis	12	1	16	29
Cardiophorus nigratissimus	12	2	12	26
Drasterius bimaculatus	23	6	18	47
Nothodes parvulus	12	1	6	19

Peripontius omissus	11	2	10	23
Peripontius terminatus	11	1	5	17

Table 3: List of bioclimatic variables and their explanations. Unused bioclimatic variables are marked with '*'.

Bioclimatic Variables	Explanations
BIO1	Annual Mean Temperature
BIO2	Mean Diurnal Range (Mean of monthly (max temp - min temp))
BIO3	Isothermality (BIO2/BIO7) (* 100)
BIO4	Temperature Seasonality (standard deviation *100)
BIO5	Max Temperature of Warmest Month
BIO6	Min Temperature of Coldest Month
BIO7	Temperature Annual Range (BIO5-BIO6)
BIO8	Mean Temperature of Wettest Quarter
BIO9	Mean Temperature of Driest Quarter
BIO10	Mean Temperature of Warmest Quarter
BIO11	Mean Temperature of Coldest Quarter
BIO12	Annual Precipitation
BIO13	Precipitation of Wettest Month
BIO14	Precipitation of Driest Month
BIO15	Precipitation Seasonality (Coefficient of Variation)
BIO16	Precipitation of Wettest Quarter
BIO17	Precipitation of Driest Quarter
BIO18	Precipitation of Warmest Quarter
BIO19	Precipitation of Coldest Quarter

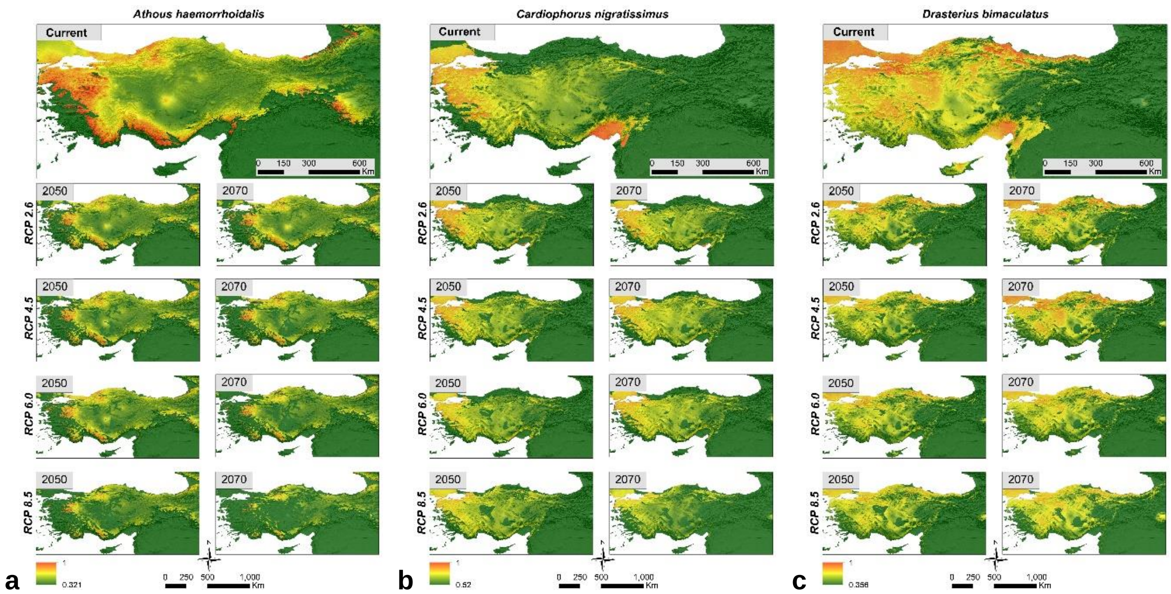
Table 4: AR5 global warming increase (°C) projections between 2046-2100.

	2046-2065	2081-2100
Scenario	Mean and likely range	Mean and likely range

RCP2.6	1.0 (0.4 to 1.6)	1.0 (0.3 to 1.7)
RCP4.5	1.4 (0.9 to 2.0)	1.8 (1.1 to 2.6)
RCP6.0	1.3 (0.8 to 1.8)	2.2 (1.4 to 3.1)
RCP8.5	2.0 (1.4 to 2.6)	3.7 (2.6 to 4.8)

Results and Discussion

Ecological Niche Modeling results of the current time for the species are consistent with the known distributions of the species. For all examined species the AUC value is higher than 0.5. Using IPCC 5 climate scenarios, possible future distributions of species for 2050 and 2070 are estimated using ENM. The results obtained are important in understanding how the examined species in Anatolia will react to climate change (Figures 3a-f). This result increases the importance of the conservation of these kinds of habitats.



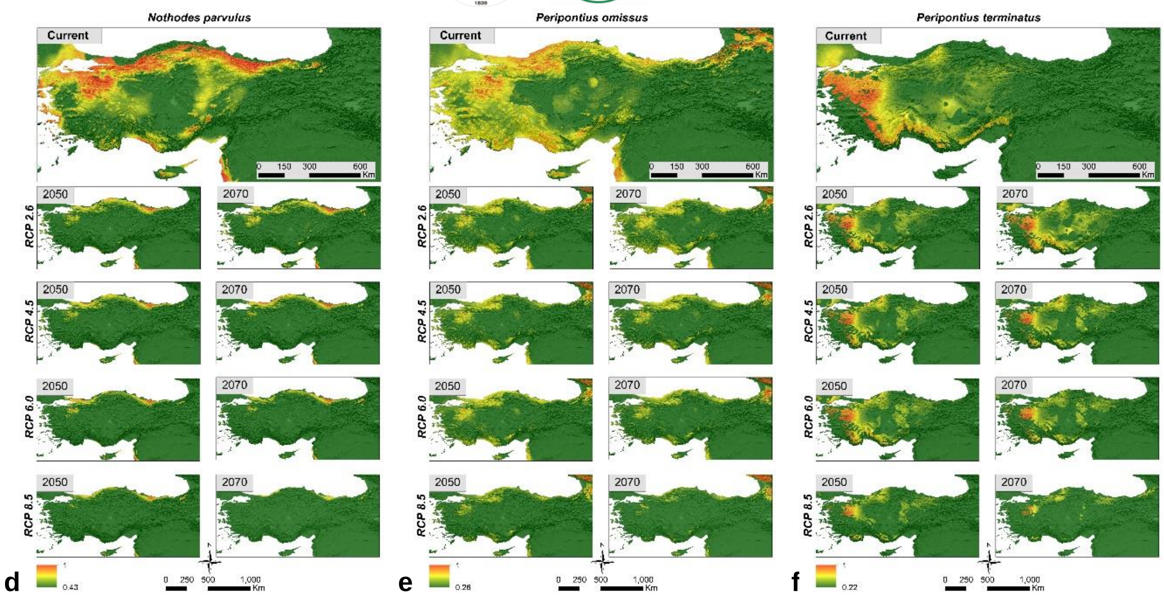


Fig. 3: Ecological niche modeling maps of examined species. a. *Athous haemorrhoidalis*, b. *Cardiophorus nigratissimus*, **c.** *Drasterius bimaculatus*, **d.** *Nothodes parvulus*, **e.** *Peripontius omissus*, **f.** *Peripontius terminatus*.

Conclusion

As a result of field study observations and mainly Ecological Niche Modeling analysis, we can state that suitable habitats of all examined species could decrease in future estimations. These results indicate that habitat-based protections are very important for the protection of these insects, which are one of the important parts of our biodiversity.

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An overview of Staphylinidae (Coleoptera) and Fungi Interactions and Scientific Studies in Turkey

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Abstract

The aim of this study is to examine the biological relationships of the Staphylinidae family, which is one of the families with the most species in the Coleoptera order, and fungi, and to evaluate the studies on this subject in Turkey and to reveal the deficiencies and the studies that need to be done.

Keywords: *Staphylinidae, Fungi, Mycophagy, Predation, Forest*

Introduction

Relationships between insects and fungi, both hostile and mutual, play a key role in natural communities. (Chen et al., 2014; Blackwell 2000; Pirozynski and Malloch 1988). Insects and fungi have a long history of association in common habitats. Fungal feeding or mycophagy is quite common in beetles (Coleoptera) and appears to be a primitive feeding habit that precedes feeding in plant tissues (Cai et al., 2016). Typical antagonistic interactions include insect use of fungi as food without spore propagation and fungal parasitic exploitation by insects (Chen et al., 2014; Fäldt et al. 1999; Guevara et al. 2000; Hedlund et al. 1995), while typical reciprocal interactions involve external transfer (or facilitation of fungal cross-fertilization) by insects of fungal spores in exchange for food (Chen et al., 2014; Bultman et al. 1998; Roy 1993; Schiestl et al. 2006). Another type of interaction of particular interest here is the dispersal of fungal spores, which are swallowed by various insect species as they eat their fruiting bodies bodies (Bultman et al. 1995; Tuno 1998, 1999).

Insects are the dominant group of forest invertebrates, and forest litter inhabitants play important roles in decomposition processes (Seastedt, 1984). One of the most abundant and specialized litter-dwelling insect groups is the rove beetles (Coleoptera: Staphylinidae).

The Staphylinidae family is the most species-rich and ecologically diverse insect family (Parker, 2017). According to the studies of Grebennikov and Newton (2009), the Scydmaenidae family is a subfamily of the Staphylinidae family and with 55.440 identified species, it is one of the largest families of the Coleoptera order and the animal kingdom. Irmler et al. (2018) stated that staphylinids constitute one of the largest insect families with enormous heterogeneity, containing more than 63,657 species known worldwide. Due to their worldwide distribution, ecological importance, behavioral and ecomorphological diversity, Staphylinids are nowadays becoming an insect group that is increasingly being investigated in the fields of evolution and ecology. They are also widely used as bioindicators of environmental conditions in applied sciences such as forest research and conservation. Staphylinids are found in almost all ecosystems of the Earth, from the Arctic to the humid tropics, and from marine habitats to high alpine ecosystems. Although their morphology appears fairly uniform with short elytra, their bodies are extremely flexible, making them susceptible to living in a wide variety of microhabitats. Staphylinids are insects that can feed on many different foods. A few groups feed on fungi (Irmler et al., 2018).

Relationships with fungi played an important role in the evolution of Staphylinidae. These relationships occur in the form of predation on mycophage or other fungi living organisms (Lipkow, 1997). Staphylinids may also use fungi as breeding and mating sites or may be attracted by parasitic fungi. Therefore, such interactions have contributed significantly to this degree of diversification of this insect group (Newton, 1984).

Rove beetles are useful indicators of forest degradation and recovery because they are susceptible to environmental degradation, vary in species and trophic roles, and are easily sampled (Bohac, 1990, 1999; Pohl et al., 2007, 2008; Klimaszewski et al., 2013; Work et al., 2013). Rove beetles occupy numerous microhabitats in forest ecosystems where they occur together with fungi (Stefani et al. 2016).

Relationships with fungi played an important role in the evolution of Staphylinidae. Interactions with fungi occur as mycophagy or predation on other fungi-dwelling organisms in each of the four subfamily groups. Mycophagous/fungivorous species are found in the following subfamilies: Micropeplinae, Neophoninae, Habrocerinae, Aleocharinae (e.g. *Gyrophaena* Mannerheim, *Phanerota* Casey, *Eumicrota* Casey, *Placusa* Erichson, *Homalota* Mannerheim, *Stictalia* Casey, *Pseudatheta* Cameron, *Pagla* Blackwelder, *Polylobus* Solier), In some studies *Autalia* Leach, *Atheta* Thomson, *Silusa* Erichson, *Liogluta* Thomson, *Aleochara* Gravenhorst, *Oxypoda* Mannerheim, are the other genera belonging of the Aleocharinae (Assing, 2009, 2011; Sert et al., 2013; 2021). Tachyporinae (e.g. *Sepedophilus* Gistel), Scaphidiinae (e.g. *Scaphisoma* Leach, *Cyparium* Erichson), Oxyporinae (*Oxyporus* Fabricius). The following subfamilies include species with at least facultative mycophagy: Glypholomatinae, Omaliinae, Proteininae, Dasycerinae, Trichophyinae, Osoriinae. (Lipkow, 1997).

Rove beetles are a diverse group that exhibit a wide variety of trophic relationships and occupy numerous microhabitats in forest ecosystems. Many Aleocharina and Staphylininae such as *Aleochara*, *Philonthus*, *Platydracus* and *Staphylinus* species are voracious predators of other arthropods such as fly larvae (Klimaszewsk et al. 2013, Klimaszewski 1984, Smetana, 1995). At least some species of Scaphidiinae, Osoriinae, Tachyporinae and Aleocharinae (Gyrophaenina) eat the flesh or spores of fungal sporocarps (Seevers 1951, Ashe 1984, Newton 1984).

Material and Methods

In this study, all studies (available) on the relationship between Staphylinidae and its fungi in the world and in Turkey were reviewed and the results were presented.

Results

When the studies on the relationship between Staphylinidae and fungi in the world are examined, it is seen that important studies have been carried out.

Hanley and Goodrich (1995) studied Oxyporinae (Staphylinidae) mycophagy and the host relationship five patterns of host selection within the Oxyporinae are proposed.

Lipkow (1997) studied with *Oxyporus* species that inhabit in mushrooms and they examined on the nutrition, reproduction, selection of mushrooms, and avoidence of competition by *Oxyporus* species.

Betz et al. (2003), aim to survey the morphological diversity of the mouthparts in the guild of staphylinoid spore-feeders (and pollen-feeders as a comparable feeding type). And the result of the study is the enlarged systematic and ecological diversity in leiodids and, in particular, staphylinids is well reflected by an increase in the trophic morphological diversity in the order from (1) Ptiliidae, (2) Leiodidae, towards (3) Staphylinidae.

The study of Lipkow and Betz (2005), summarize the diversity of relationships between beetles and fungi for several subfamilies and elucidates possible adaptations of their mouthparts to mycophagy (especially sporophagy). Additional aspects of this study reveal the types and strengths of the relationships between staphylinids and fungi and consider the characteristics of larval development, parental care and behaviour of fungus-dwelling staphylinids.

Klimaszewski et al. (2013), analyze Staphylinids gut contents. They identify the gut contents with using microscopic and molecular (DNA) methods. When the results of the study are reviewed, both dissection and molecular analysis of guts strongly suggest that rove beetles in this study may feed primarily on yeasts.

Stefani et al., (2016) examined fungal community composition in the gut of rove beetles (Coleoptera: Staphylinidae) from the Canadian boreal forest The goal of this study was to investigate the fungal community composition in the gut of Staphylinidae from boreal forest in order to better understand the diversity and the complexity of fungus-insect relationships.

Cai et al., (2017) they reported diverse gilled mushrooms (Agaricales) and mycophagous rove beetles (Staphylinidae) from mid-Cretaceous Burmese amber, the latter belonging to Oxyporinae. The results of the study have shown that the mouthparts of early oxyporines, including enlarged mandibles and greatly enlarged apical labial palpomeres with dense specialized sensory organs, match those of modern taxa and suggest that they had a mushroom feeding biology. Diverse and morphologically specialized oxyporines from the Early Cretaceous suggests the existence of diverse Agaricomycetes and a specialized trophic interaction and ecological community structure by this early date.

Cai et al., (2016) reported a remarkable genus and species, *Vetuproteinus cretaceus* belonging to a newtribe (Vetuproteinini) of the extant rove beetle subfamily Proteininae (Staphylinidae) in Mid-Cretaceous Burmese amber. They reported that, this staphylinid was a feeder on the fungi.

There is currently no study conducted in Turkey regarding this important relationship between staphylinids and fungi. When the studies carried out in Turkey are examined, it has not been possible to go beyond the faunistic studies. When we look at the studies conducted in Turkey, Assing (2007) stated that one of the fungi (mushroom species not specified) is one species from the genus *Autalia*, 10 species from the genus *Atheta*; Assing (2009) One species from *Anthophagus* and *Silusa* genera; Assing (2011), a species in the genus *Omalium*; has detected. Abacigil et al. (2013) reported that samples were collected from mushrooms from Kaz Mountains. Sert et al. (2013) identified a species from the genus *Liogluta* and a new species from the genus *Gyrophaena* (*Gyrophaena cagatay* Sert et al. 2013) from Mount Hasan. Sert et al. (2021) identified two species in the genus *Aleochara*, nine species in the genus *Atheta*, one species in the genus *Liogluta*, two species in the genus *Autalia*, one species in the genus *Falagria*, six species in the genus *Gyrophaena*, one species in the genus *Silusa*, and one species in the genus *Oxypoda*. Apart from these studies, there is no study that examines the relationship between fungi and Staphylinidae in detail, both faunistic, systematically and ecologically.

Conclusion

Compared to studies conducted in the world, studies conducted in Turkey show that there is no study on the relationships between Staphylinidae and fungi. All of the studies carried out remained as faunistic studies. For this reason, a comprehensive project related to Staphylinids and fungi has been prepared in the Marmara Region, which has been selected as the pilot region. This project will be submitted to TÜBİTAK. In case this planned project is realized, an important step will be taken to fill the gap in such an important issue in our country. In the future, this project is planned to be expanded to include other regions of Turkey, and to clearly demonstrate the Staphylinidae-Fungi relationship of the whole of Turkey.

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