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Animal Biodiversity and Conservation 47.1 (2024)
DOI: 10.32800/abc.2024.47.0039

Research paper

Heterogeneity is key to supporting forest-dweller butterflies

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Handling Editor:
C. Stefanescu

Received: 29/08/2023
Cond. acceptance: 29/11/2023
Final acceptance: 25/03/2024
Published: 09/04/2024

Cite:
Ambarlı D, 2024. Heterogeneity is key to supporting forest-dweller butterflies. *Animal Biodiversity and Conservation* 47.1, 39-48. DOI: https://doi.org/10.32800/abc.2024.47.0039

ISSN: 1578-665 X
eISSN: 2014-928 X

Abstract

Heterogeneity is key to supporting forest-dweller butterflies. Worldwide, forests are considered biodiversity hotspots. Butterflies are among the surrogate species for forest biodiversity yet in many parts of the world, little is known about the presence or habitat use of forest-dweller butterflies. In this study we aimed to narrow the information gap by applying a time-effective butterfly survey in forests in northeast Türkiye that are surrounded by several prime butterfly areas. The target species were *Boloria euphrosyne*, *Coenonympha arcania*, *Erebia aethiops*, and *Satyrium ilicis*. The surveys provided 128 records of the species. Random forests models showed that the mean temperature of the warmest month, canopy cover of pine trees, tree size, and managed meadows in or at the edge of forests are important parameters for species occurrence. Nevertheless, the direction of the effects varied between species. Maintaining heterogeneity in forests in terms of the forest variables indicated above and promoting small-scale grassland management in forest openings and edges are important conservation measures for forest-dwelling butterflies. The relevance of the temperature suggests that climate change may have significant effects on the occurrence of forest butterflies.

Key words: Habitat use, Hay meadows, Forest structure, *Erebia aethiops*, *Satyrium ilicis*, *Coenonympha arcania*

Resumen

La heterogeneidad es fundamental para proteger a las mariposas que viven en los bosques. Los bosques representan puntos de gran biodiversidad en todo el mundo. Las mariposas son algunas de las especies indicadoras de la biodiversidad forestal, sin embargo, la presencia de mariposas en los bosques y el uso que hacen del hábitat no se conocen bien varias partes del mundo. La finalidad del presente estudio es subsanar la falta de información mediante un rápido estudio de las mariposas de los bosques del nordeste de Türkiye, rodeados de varias zonas con una gran riqueza de especies de mariposas. Las especies objeto del estudio fueron *Boloria euphrosyne*, *Coenonympha arcania*, *Erebia aethiops* y *Satyrium ilicis*. En el estudio se registraron 128 ejemplares de las especies. Los modelos de bosque aleatorios mostraron que la temperatura media del mes más cálido, la cubierta de dosel de los pinos, el tamaño de los árboles y las praderas gestionadas dentro o en los márgenes de los bosques son parámetros importantes para la presencia de las especies. Sin embargo, el sentido de los efectos varió según la especie. Para proteger a las mariposas que viven en los bosques, es fundamental mantener la heterogeneidad de las variables forestales indicadas antes y promover la gestión de pastizales a pequeña escala en los claros y los márgenes de los bosques. La importancia de la temperatura sugiere que el cambio climático puede tener efectos notables en la presencia de las mariposas forestales.

Palabras clave: Uso del hábitat, Praderas de gramíneas, Estructura forestal, *Erebia aethiops*, *Satyrium ilicis*, *Coenonympha arcania*

Introduction

Forest ecosystems are hotspots of biodiversity and ecosystem services that are essential for human life. In the Anthropocene, we are witnessing a tragic loss of animal diversity due to forest destruction (Brooks et al 2002) and a decline in ecosystem services associated with this biodiversity loss (Nadrowski et al 2010). Most temperate forests are managed with a production-oriented perspective which can lead to biodiversity loss (e.g., in Europe, Ceccherini et al 2020). Consequently, forestry has become a key sector for mainstreaming biodiversity conservation (Convention on Biodiversity Secretariat 2014). To design effective management strategies that promote biodiversity, it is crucial to understand the impact of forestry activities on rare or forest-dweller species, but such information is generally lacking.

Forest management affects insect communities by altering resource availability and abiotic conditions through changing vegetation cover, composition, and structure (Bergman 2001, Doerfler et al 2018, Penone et al 2019). Butterflies (Lepidoptera) are among the most sensitive taxa to land-use changes and management practices (Stefanescu et al 2005, Nilsson et al 2008). Forest-specialist butterflies are only found in open, sunny places such as sparse stands, small-scale clearings, grassy grounds and road margins where the sun reaches the ground, places for butterfly busking and warming and where nectar plants are found (Bubová et al 2015, Oro et al 2023, Van Swaay et al 2006). Forestry-related activities such as felling, afforestation of grasslands, abandonment, and change in management practices shape the distribution and abundance of forest butterflies, even threaten them and cause local extinctions in the long term (Baz and Garcia-Boyero 1995, Inoue 2003, Nilsson et al 2008, Van Swaay et al 2006). In shady European forests, abandonment of traditional forestry practices such as regular small-scale clearcuts, tree stand thinning, and forest grazing cause the closing of forest canopy and disappearance of butterflies in forests (Konvička and Kuras 1999, Kuras et al 2003, Kodandaramaiah et al 2012). Though knowledge of the effect of forestry on butterflies is widely available for European, American, and tropical forests, such knowledge is not available for several hotspots of the world.

Forests of the Mediterranean macroclimate, such as in Türkiye, generally offer drier conditions and a greater diversity of forest types and habitats than forests in central Europe. As a result, the habitat and larval food plant selection of butterflies may differ. Furthermore, Türkiye is the richest country in Europe in terms of butterfly fauna, with more than 380 species, 45 of which are endemic to the country (Karaçetin and Welch 2011). Hosting three biodiversity hotspots of the world, Türkiye has 65 prime butterfly areas, some of which are of European concern (Karaçetin et al 2011; Van Swaay and Warren 2003). However, there is a lack of baseline information about the occurrence and habitat preference of habitat-specialist butterfly species and the effects of land-use activities. It is essential to identify the forest habitats and management practices supporting forest-dweller butterflies under different environmental conditions and promote such habitats by carefully designed forestry practices. Here we focus on four forest-dweller butterfly species and present a time-effective field survey in forests in northeastern Türkiye. The specific objectives were: i) to fill knowledge gaps in the occurrence of target species, ii) to reveal the habitat and forest stand types in supporting their populations using Random Forest Modeling, and iii) to draw up recommendations on conservation and forest management practices in order to support populations of forest-dweller butterflies.

Material and methods

Study area

The study was conducted in north-eastern Türkiye, encompassing a total of 434,500 ha of land managed by the Gümüşhane Forest Management Directorate (fig. 1A). The area is situated between 39° 50' - 40° 30' N and 38° 50' - 39° 50' E. The elevation varies from 1,100 m to 2,700 m a.s.l. The topography is rugged, shaped by the Harşit River basin, Mts Gümüşhane, Kelkit River valley, and the northern slopes of Mt. Çimen. The climate of the province is classified as semi-humid according to Erinç's classification system (Turkish State Meteorological Service 2022). The annual mean precipitation at the city center (1,210 m a.s.l.) is 605 mm, and the mean temperatures for January and July are -1.7 °C and 20.2 °C, respectively (Turkish State Meteorological Service).

The forests within the study area are sub-euxine forests, i.e., sub-humid Black Sea forests, in northeastern Anatolia (Mayer and Aksoy 1998). Based on forest stand maps, approximately 19 % of the land cover is shrubland or forest (database of Nature Conservation Centre). Among these, oak and juniper mixed or pure shrublands make up 11 % of the land and are indicated as degraded stands in the forest stand maps. Scots pine (*Pinus sylvestris*), oriental fir (*Abies nordmanniana*), and oriental spruce (*Picea orientalis*) make up pure or mixed forests of 6 % of the land (fig. 1B). The remaining forests are mixed forests of other tree species (2 %). Non-forest land is predominantly occupied by croplands (56 %) and rangelands (25 %), which are categorized as forest soils in forest stand maps (fig. 1B). Based on the forestry plan valid for 2011, a total of 59,000 ha was allocated for wood production (ca. 71 % of the forests), with the majority focused on Scots pine forests. In terms of area, 9 % of the land was designated as protection forest.

The study area stands out for its remarkable biodiversity: almost half of Türkiye's butterflies are present in the study area, which covers less than 1 % of the territory (167 out of 380, 44 % based on the database of Nature Conservation Centre 2011). Four of Türkiye's prime butterfly areas (PBAs) are in the study area (Karaçetin et al 2011, see fig. 1). The prime butterfly areas are mountain passes with extremely rich butterfly fauna, including many rare species and target species of this study (Karaçetin et al 2011). They are at the intersection of different biogeographical regions of

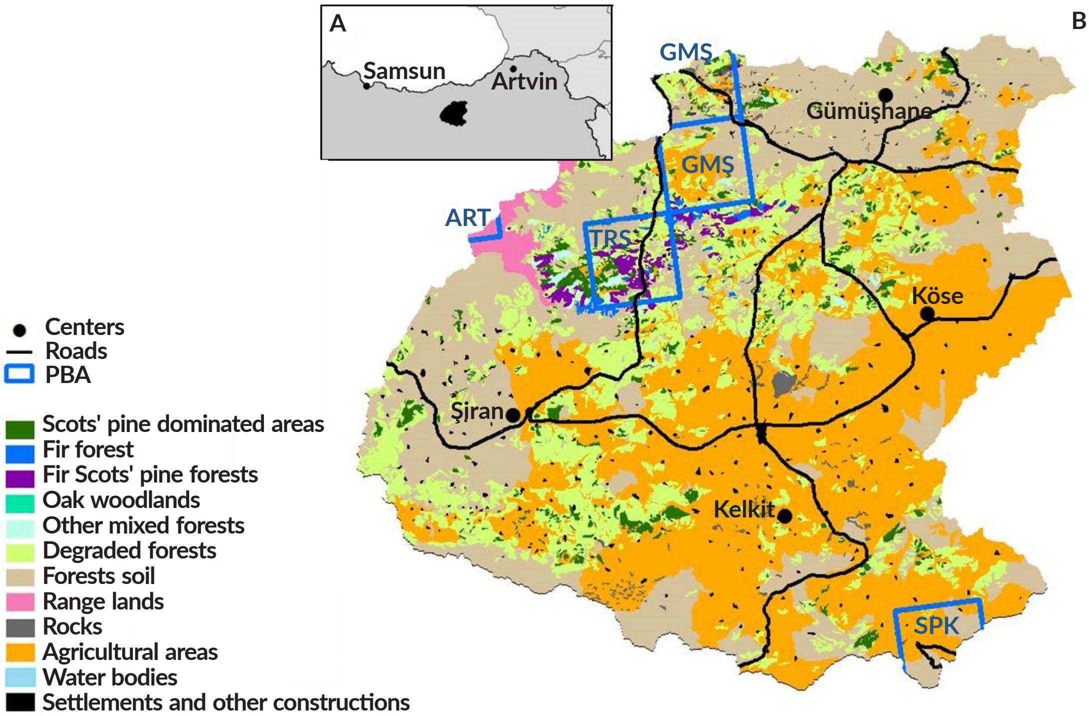

Fig. 1. Map of the study area, a total of 434,500 ha of land managed by the Gümüşhane Forest Management Directorate situated between 39° 50' - 40° 30' N and 38° 50' - 39° 50' E: A, location in Türkiye indicated with black shade; B, major forest and land cover types. Prime butterfly areas (Karaçetin et al 2011) are indicated in blue: ART, Artabel Gölleri (= lakes); GMŞ, Gümüşhane; TRS, Tersundağı Pass; SPK, Sipikör Pass. (Forest stand maps were obtained from Nature Conservation Centre).

Fig. 1. Mapa de la zona de estudio, un total de 434.500 ha de tierras gestionadas por la Dirección de Gestión Forestal Gümüşhane, situadas entre 39° 50' - 40° 30' N y 38° 50' - 39° 50' E: A, ubicación en Türkiye indicado con un sombreado negro; B, tipos principales de cubierta forestal y terrestre. Las zonas con una gran riqueza de especies de mariposas (Karaçetin et al 2011) se indican en azul: ART, Artabel Gölleri (= lagos); GMŞ, Gümüşhane; TRS, Tersundağı Pass; SPK, Sipikör Pass. (Los mapas de las formaciones forestales se obtuvieron del Centro de Conservación de la Naturaleza).

Türkiye (humid Black Sea forests, eastern Black Sea montane forests, and east Anatolian dry forests and steppes), and they provide a wide range of habitats along short gradients of altitude and climate as well as diverse topography. Those PBAs host 15 priority species for conservation, i.e., endemic or threatened, or both, such as *Aricia torulensis*, *Polyommatus tankeri*, *Erebia melancholica*, and *Polyommatus turcicus*.

Study species

This study was conducted as a part of the project titled The Integration of Biodiversity into Forest Management Planning in Gümüşhane conducted by the Nature Conservation Centre of Türkiye. Target butterfly species were selected using four criteria: i) high habitat-specificity in forest ecosystems, ii) strong potential for representing forest biodiversity, iii) likelihood of benefiting from straightforward conservation measures in forest management, and iv) high conservation priority such as endemic or threatened species (Nature Conservation Centre 2013). Target species were chosen from the region's 167 butterfly species in the Nature Conservation Centre's butterfly database (Nature Conservation Centre 2011) based on those criteria, with the nomenclature in line with Karaçetin and Welch (2011). As a result, four species were selected as target species: *Boloria euphrosyne*, *Coenonympha arcania*, *Erebia aethiops*, and *Satyrium ilicis*.

Boloria euphrosyne, pearl-bordered fritillary, is distributed in the Western Palearctic, from western Europe across Russia and north of Kazakhstan (Tolman and Lewington 1998). In Türkiye, the species is predominantly distributed in north Anatolia, across Bursa to Kars, with very few records from south Anatolia (Nature Conservation Centre 2011). Its habitats are woodland-associated in Europe: broad-leaved, coniferous, or mixed woodlands (Bailey et al 2002), woodland clearings including pine plantations, and open woodlands with brackens in the United Kingdom (Barnett and Warren 1995). In Türkiye, it has been recorded from meadows with violets in the deciduous and coniferous forests in Euxine (Black Sea) region (Hesselbarth et al 1995). It is generally univoltine, with one brood or generation per year, but additional broods are also possible in exceptional years. Various violet *Viola* spp. are recorded as the foodplant of its larvae. The species was identified as a forest flagship species for integrating biodiversity into forest management in Türkiye (Nature Conservation Centre 2011).

Coenonympha arcania, pearly heath, is another nymphalid butterfly with continuous distribution across most of Europe and the western lands of Asia, including parts of Türkiye, Russia, and Transcaucasica (Tolman and Lewington 1998, Kudrna 2002). The species prefers a higher number of different forest habitats than the grassy habitats (Van Swaay et al 2006). In Europe, it inhabits extensively managed dry grasslands with bushes, open warm woodlands, clear-cuttings, early stages of forest succession, mesophile grasslands near hedges, and forest edges (Binzenhofer et al 2005). In Türkiye, it is primarily found in north Anatolia, except for recent records from Hatay and historical records from Konya (Nature Conservation Centre 2011). It is a univoltine species, flying from May to the end of July. Its larval food plants include various grass species, *Festuca* spp., *Holcus lanatus*, *Brachypodium pinnatum*, and *Melica* spp. (Binzenhofer et al 2005). In Türkiye, the species use fresh and dry meadow vegetation and patchy woodlands in sparse deciduous and mixed forests (Hesselbarth et al 1995). It uses various habitats, such as deciduous and mixed open woodlands and grassy openings in scrubby hillsides (Baytaş 2007).

Erebia aethiops, Scotch argus, is a ringlet distributed from central and eastern Europe to western Siberia. In Türkiye, it occurs in northern provinces. It is a univoltine species whose larvae feed on grasses, including *Agrostis* spp. and *Poa* spp. (Baytaş 2007). Its habitats are listed as small, short- or tall-grassy, herbaceous meadows in dry or humid and open Euxinian fir, spruce, and pine forests; open shrubby slopes, forest paths, meadows streams in oaks, between 1,000 and 2,000 m a.s.l. (Hesselbarth et al 1995). The species was identified as a forest specialist in Europe (Van Swaay et al 2006). It is one of the species on the focus of climate change studies as it has been proven to have retracted by 80 kilometers in Britain since 1970 due to warming (Thomas et al 2006).

Satyrium ilicis, ilex hairstreak, is distributed from southern Europe and Belgium to western Asia. The species was identified as a forest specialist in Europe (Van Swaay et al 2006). It is defined as a light-demanding forest species in Germany (Hermann and Steiner 2000) and as a typical ecotone species inhabiting gradients from open (e.g., heathland, grassland) to closed vegetation (e.g., woodland) in Belgium but mostly shrubwoods (Maes et al 2014). It is abundant throughout Türkiye, living in open bushlands with oak trees from the sea coast to around 2,000 m a.s.l. (Hesselbarth et al 1995). A univoltine species flying from May to August, its larva feeds on *Quercus* species such as *Q. robur*, *Q. petraea*, and *Q. pubescens* (Hesselbarth et al 1995).

Butterfly surveys

A time- and cost-effective survey method was developed to determine the occurrence and habitat use of target butterflies in forests. A stratified random design was adopted to select survey sites, ensuring that each predominant forest type was represented in proportion to its percent cover, following the method outlined by Sutherland (2006). The sites were selected on the digital forest stand maps using ArcGIS 9.3.1 (ESRI Inc. 2009). The digital maps were obtained from the Nature Conservation Centre's database. A total of 41 sites were visited, 31 of which were surveyed under suitable weather conditions. Sampling took place between 15-22/06/2012, corresponding to the target butterflies' peak flight period.

A standard transect survey method was applied in each site. It was modified from the Pollard walk method which is commonly used to sample butterflies (Pollard 1977): during each survey, an hour was dedicated to walking and recording target butterfly species. The transects did not adhere to fixed distances or routes, but as a general guideline, they covered a distance of about 500 meters. The butterflies were identified using binoculars (Pentax Papilio 6.5 x 21, the minimum close focus 0.5 m) as target species are visually distinguishable with relative ease. Surveys were conducted each day between 8:30 am and 4:00 pm and only when weather conditions were suitable for a proper butterfly count, i.e., temperature above 17 °C and wind speed below five on the Beaufort scale. Exact coordinates of the site, date, time, species identity, abundance, altitude, topographic parameters, micro-habitat features, and land-use types were recorded in the field.

Explanatory variables

Several abiotic, forest-related, and land-use variables were recorded in the field or derived from desk studies. These variables are known to affect butterfly communities directly due to their physiological effects, or indirectly by changing the quality or quantity of the adult or larval food plants or habitats. The variables used in the analyses were as follows: solar radiation, mean temperature of the warmest period, canopy cover, average tree diameter, forest management type, canopy covers of Scots pine and firs, and local land-use type (see table 1). Among a long list of bioclimatic variables, two variables were chosen as explanatory factors: solar radiation from April to June and the mean temperature of the warmest month (WorldClim 2013). Solar radiation, a continuous variable, is the total radiant energy of each survey point. The data were obtained using the Points Solar Radiation tool in the ArcGIS 9.3.1 software (ESRI Inc. 2009). The calculation is based on the incoming radiant energy of the specific latitude and altitude on an elevation raster. The variable reflects the warmth of the site due to its exposure. It indicates the suitability of the microhabitat in terms of the thermal tolerance of the butterfly and is commonly used in butterfly habitat models (Binzenhöfer et al 2005, Freese et al 2006, Slamova et al 2013). The mean temperature of the warmest period, a continuous variable, is a proxy for the climatic conditions in summer, which affects conditions linked to butterfly physiology and activity, vegetation and food sources, and, therefore, habitat preference (Kevan and Baker 1983). Each survey site's datum was extracted from BIOCLIM layer BIO10 (Hijmans and Graham 2006). Annual and monthly climatic variables and altitude were not used in the analyses due to collinearity with the chosen variables mentioned above and type-II errors.

The dataset of forest-related variables was compiled using different sources (table 1). The canopy cover was recorded in the field, verified using Google Earth im-

Table 1. Summary of environmental, landscape and land use data collected for the survey sites: NA, "not applicable" for categorical data.

Tabla 1. *Resumen de los datos recopilados sobre el medio ambiente, el territorio y el uso de la tierra en los lugares del estudio: NA, "no aplicable" a los datos categóricos.*

Environmental parameters	Data type (unit)	Mean	SD	Data source
Topographic and climatic parameters				
Mean temperature of the warmest period (temperature)	Numerical (°C)	17.2	0.9	BIO10 climate layer
Solar radiation	Watt hours/m^2	581,604	125,970	Solar radiation tool of ArcGIS 9.3.1 software based on the digital elevation model
Forest characteristics				
Canopy cover	Numerical (%)	64.7	23.7	Digital forest stand maps
Tree diameter at 1.3 m	cm	19.7	11.2	Digital forest stand maps
Forest management type	Categorical (production, protection)	NA	NA	Digital forest stand maps
Scots pine cover	Numerical (%)	31.1	27.7	Field observation
Fir cover	Numerical (%)	4.3	12.6	Field observation
Local land use				
Land use type	Categorical (no different land use, grazing, hay cutting old cropland)	NA	NA	Field observation

ages (Google Inc. 2016), and reported in percentage. Data on tree size, i.e., diameter at 1.3 m, was obtained from forest stand maps and field observations. Forest management type was compiled from forest stand maps as production vs protection. Data on percent covers of Scots pine and fir were compiled in the field and complemented using data from digital stand maps. Local land-use types for grassy microhabitats were recorded during field observations in one of the following categories: none, grazing, hay-cutting, and old croplands.

Analysis

To understand the importance of explanatory variables on the occurrence of target butterflies, random forest models (RF) were applied. RF is a machine learning algorithm based on decision tree models (Breiman 2001). The decision tree is a predictive model that uses input data and generates a set of binary rules to reach a classification or regression. The dependent variable at the top (of an inverted tree) is divided into branches at the nodes based on the rules until a classification of samples is reached at the terminal node. RF generates random vectors to govern the growth of different trees (Breiman 1996). Then, an ensemble of many decision trees is made using averaging. It takes a different subset of data as training data and randomly selected variables each time, and uses results from each tree as votes for classification. As it is a nonparametric decision tree-based method, it is fast, reliable, and useful for incorporating several numeric and categorical data. It is not limited to the sample size, variable size, normality assumptions, overfitting, or outlier problems (Liaw and Wiener 2002).

Explanatory variables should not correlate strongly to avoid potential type II errors in the models. Correlation tests and the *corvif* function were used to check this condition. Correlations were calculated using nonparametric Spearman rank correlation analysis as the relationships between variables may not be linear, and the sample size was not large. Variables in strong correlations were not used together in the models (Spearman's rho > 0.7 significance at the level 0.05). In addition, variables with variable inflation factors higher than four were excluded from the analyses (Zuur et al 2009, see the section on explanatory variables). Those excluded were altitude, which is one of the main inputs used in generating the BIO10 layer, and percent oak cover, which was negatively correlated to the percent pine cover (r = -0.76). All analyses were performed in R version 3.4.3 (R Core Team 2022).

The RF models were built using the *randomForest* function in the randomForest package in R (Liaw and Wiener 2002) for two species with an adequate number of occurrences, i.e., *E. aethiops* and *S. ilicis*. A ratio of 0.7 was used to split test and training datasets. To control the number of parameters used, the number of variables selected in each split, i.e., *mtry* parameter,

Table 2. Results of random forest models in terms of variable importance: Decrease in mean Gini coefficients.

Tabla 2. Resultados de los modelos de bosque aleatorios en términos de la importancia de las variables. Disminución de la media de los coeficientes de Gini.

Explanatory variables	*S. ilicis* model	*E. aethiops* model
Temperature	1.7332	1.3677
Solar radiation	1.9206	1.4103
Canopy cover	1.0437	0.9972
Pine cover %	2.4876	1.9727
Fir cover %	0.3855	0.3567
Tree size	0.9779	1.4556
Forest management type	0.9845	1.1301
Land-use type	0.5576	1.4584
AUC-PR values	0.86	0.80

was set as four based on the number of independent variables and out-of-bag estimates of error rates which is calculated using *bestmtry* function. The area under the precision recall (PR) curve (AUC-PR) values were used to evaluate the performance of the models. It is an AUC metric that avoids unrealistically high AUC values in case of modeling a rare species or species with very large extents (Sofaer et al 2019). It is the area under the curve plotted using precision versus recall. Precision is the proportion of localities predicted as suitable that are actually occupied, and recall is the proportion of occupied localities predicted as suitable (i.e., the same as sensitivity) (Sillero et al 2021). The AUC values are interpreted as follows: an AUC value lower than 0.5 indicates a model with no discrimination, 0.7 to 0.8 is acceptable, 0.8 to 0.9 is excellent, and more than 0.9 indicates an outstanding model (Hosmer and Lemeshow 2000). The variable importance was reported in table 2 based on the mean decrease in Gini coefficient. Most important variables were focused on in the text, and the response to those variables was plotted using *plotmo* function in the *plotmo* package (Milborrow 2022).

Results

Occurrence of the target species and surveyed habitats

Of the 31 sites surveyed, 16 had more than 40% Scots pine cover. In eight sites, oak cover was higher than 40%. The remaining forests were either mixed in terms of forest trees or fir-dominated. From the point of management function, 18 of the sites were production forests, and six of them were protection forests. The remaining sites were classified in terms of function as either forest soil, agricultural areas, or places with poor conditions for forest growth where patches of short oak shrubs occur among grasslands. Those habitats were surrounded by macro-vegetation of forests or shrublands.

A total of 128 individuals of four target species were recorded. Two sites did not have any forest-dweller butterflies. Target butterflies except *B. euphrosyne* were recorded in the vicinity of locations of literature records from 1968 to 1993 as well as new locations (fig. 2). Only one individual of *B. euphrosyne* was recorded in a new site. The site was a meadow along a stream at the edge of a fir forest. A total of 35 individuals of *C. arcania*, which was known from three grids (10 km x 10 km UTM grids) in the study area, were recorded in 10 sites in nine grids, seven of which are new. A total of 40 individuals of *E. aethiops* was recorded from 13 sites in eight grids, four of which were new. A total of 52 individuals of *S. ilicis* were recorded on 20 sites in 16 grids, 12 of which were new for the species (fig. 2).

Habitat preferences

A) *Erebia aethiops*

The RF model yielded an acceptable prediction (AUC = 0.8) and showed that land-use type, pine cover, and tree size were the most important parameters (table 2). The species tends to occur at grassland patches in forests, primarily used for hay cutting or in forests without local land use. In addition, forests with moderate to large tree sizes (15-40 cm) and medium to high pine cover (higher than 20%) had a higher probability of hosting the species (fig. 3). Some of those forests had higher fir cover. Individuals were recorded in or on edges of open Scots pine or fir-dominated pure or mixed forests at the humid aspects of the mountains.

B) *Satyrium ilicis*

The RF model for the occurrence of *S. ilicis* was very good in terms of discrimination power (AUC-PR = 0.86). Based on the mean decrease in Gini coefficient; pine cover, solar radiation, and temperature of the warmest month were the most important parameters (table 2). The species was predicted to occur in forests with pine cover higher than 40%. In forests with low pine cover, the occurrence probability was predicted to be higher in places with low or very high solar radiation, not moderate radiation (fig. 3). The species occurs throughout the temperature range of the study sites. It prefers certain temperatures only in sites with very low solar radiation (fig. 3).

Discussion

In this study, I explored the occurrence and habitat use of four forest-dweller butterfly species in the sub-humid forests of Türkiye using a time-effective survey method. The surveys resulted in 25 new UTM-grid records from remote forest areas previously unexplored for butterflies, contributing to filling distribution gaps. The RF models showed that temperature, solar radiation, forest structure, composition, and small grassy habitats in forests are important for the occurrence of the target species. Hosting four prime butterfly areas of Türkiye, the richest in Europe, managing the forests of the study area to support target species in

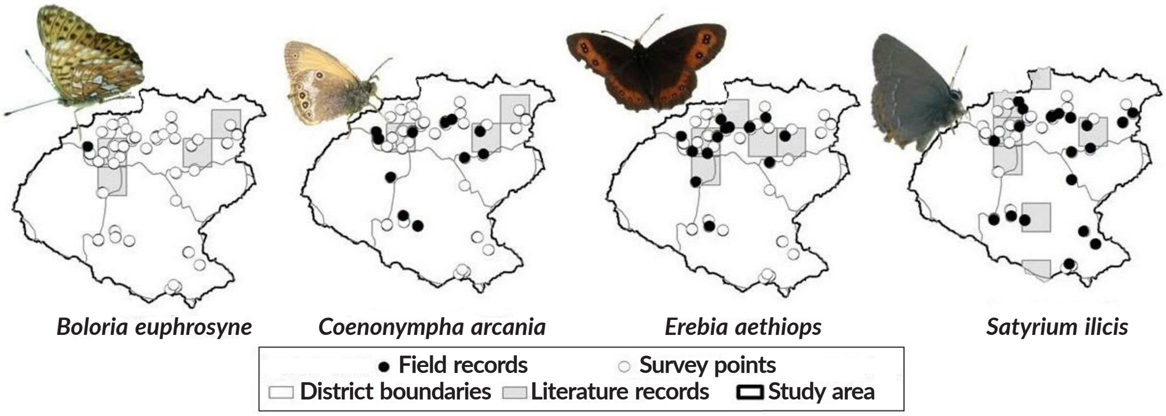

Fig. 2. Distribution maps of the target butterflies. White dots represent survey sites whereas black dots represent field records of the species. Due to the scale of the map, some dots are overlapping. Grey grids represent literature records (Nature Conservation Centre 2011) corresponding to 10 km x 10 km UTM grids and lines represent district boundaries.

Fig. 2. *Mapas de distribución de las mariposas objeto del estudio. Los puntos blancos representan los sitios del estudio, mientras que los puntos negros representan los registros de las especies sobre el terreno. Debido a la escala del mapa, algunos puntos quedan superpuestos. Las cuadrículas grises representan los registros que figuran en las publicaciones científicas (Centro de Conservación de la Naturaleza 2011) y corresponden a cuadrículas UTM de 10 x 10 km y las líneas representan los límites de los distritos.*

accordance with the results will also be beneficial for several other species inhabiting forest habitats, such as *Phengaris alcon*, a near-threatened species of the 27 European Union countries, recorded during field surveys (Van Swaay et al 2010).

The mean temperature of the warmest month in interaction with solar radiation was important for the occurrence of *S. ilicis*. The species was modeled to occur in the temperature range of the study area if the solar radiation was not too low. This finding is in accordance with the observations from Europe stating the species as high-light forest species occupying xerothermophilous habitats (Titeux et al 2009). Settele et al (2008) modeled the climatic risks on the species distribution in Europe and showed that the distribution responds to the annual temperature range. The distribution of its climatic niche will shrink by 19% by 2080 under the best climate and unlimited dispersal scenarios, and by 66% under the worst climatic conditions with no dispersal. The future climate of Europe will not be suitable for the species in several locations at the rear edge. Still, new locations in northern Europe will be suitable for colonization (Settele et al 2008). Occurring at lower latitudes compared to many European countries, populations in Türkiye can be considered vulnerable to climatic changes. Therefore, it is essential to conduct a detailed modeling study on the potential effects of climate change in Türkiye on the species and maintain its forest habitats to allow the viability of populations at suitable places in the future (Warren et al 2021).

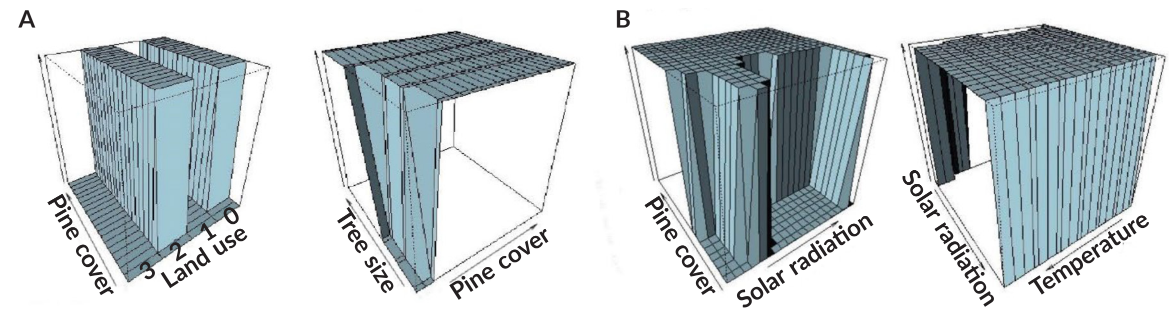

Fig. 3. Model responses to important explanatory variables selected based on the decrease in mean Gini coefficients: A, *Erebia aethiops;* B, *Satyrium ilicis.* Pine cover varied from 0% to 100%. Tree size varied between 0 and 45 cm as diameter at 1.3 m. Solar radiation varied between 450,000 and 750,000 watt hours/m^2. (Land-use categories are as follows: 0, no different local land use; 1, grazing; 2, hay cutting; 3, old cropland).

Fig. 3. *Respuestas de los modelos a variables explicativas importantes seleccionadas sobre la base de la disminución de la media de los coeficientes de Gini: A,* Erebia aethiops; *B,* Satyrium ilicis. *La cubierta de dosel de los pinos varió entre el 0% y el 100%. El tamaño de los árboles varió entre 0 y 45 cm de diámetro a 1,3 m. La radiación solar varió entre 450.000 y 750.000 vatios-hora/m^2. (Las categorías de uso de la tierra son las siguientes: 0, sin un uso diferente a escala local; 1, pastoreo; 2, corte de gramíneas; 3, tierras cultivables antiguas).*

Forest structure and composition were important factors for the occurrence of *S. ilicis* and *E. aethiops*. Percent cover of pine trees was important for both species. The probability of occurrence of *S. ilicis* was higher in forests with high pine cover. Oaks serve as larval foodplants, and the species is associated with oak woodlands and coppices (Fløjgaard et al 2018, Graser et al 2023). Therefore, a positive relationship between the occurrence and percent oak cover is expected. The oak cover was strongly negatively correlated to the percent cover of pine trees in the study sites (r = 0.78) and not used in the analysis due to collinearity. A positive relationship between occurrence and pine cover may seem contradictory, but in fact, in closed pine forests, the species was observed on oak shrubs, which females prefer for egg laying (Titeux et al 2009). The study forests, under the effect of the Mediterranean macroclimate, have oaks in the shrub layer even in closed Scots pine forests due to overall drier conditions than central European forests and mesic fir forests of the study sites. These can serve well as larval food plants. Pine cover should therefore be considered as a proxy for the presence of larval food plants in the shrub form. Promoting shrub layers of oaks within closed forests will support the presence of this species. From this point of view, shrub-dominated forest areas such as coppice oaklands should not be replaced with needle-leaved forests with no shrub layer (Kaya and Raynal 2001). Future studies on forest butterflies should take forest vertical structure into account. No strong effects of forest use on the occurrence of target species were found. The latter's possible explanation is the low variation in the forest use variable.

The occurrence of *E. aethiops* was also positively related with the cover of pine trees. Its occurrences were related to forests with larger tree sizes (15-40 cm) and forests with more than 20 % pine cover and grassy openings. Those findings are compatible with the 'species' habitat preference in Türkiye (Hesselbarth et al 1995). In addition to those facts, this study revealed that the species avoids forests with small trees. Canopy cover by large trees has a temperature buffering effect (De Lombaerde et al 2022). This preference is probably part of the hot-temperature avoidance mechanism, as the adults are known to fly in the shadow of trees (Kleckova and Klecka 2016). The result implies that promoting forests with large trees will be beneficial for the species.

The occurrences of *E. aethiops* and the only record of *B. euphrosyne* were related to small-sized grassy habitats. Those species and others use grasses as larval food plants (Schmitt 2003, Slamova et al 2013). Females of *E. aethiops* prefer grassy patches, and males prefer shady forest habitats (Slamova et al 2013). The literature records of *B. euphrosyne* from the study area (Nature Conservation Centre 2011) are from openings and meadows in the needle-leaved humid forests 1,500 m a.s.l. at mountain passes or slopes in the northern part of the area. Following the literature records, the species was recorded in a meadow along a stream at the edge of a fir forest. Disappearance of such habitats caused a decline in *B. euphrosyne* populations in Europe (Warren et al 2021). Maintenance of flower-rich meadows in or around needle-leaved forests will support populations of both *E. aethiops* and *B. euphrosyne*. Promoting small-scale hay cutting in forest openings would be a butterfly-friendly action in the forests.

This study showed that maintaining heterogeneity and diversity in forests in terms of tree size, forest layers, and forest openings will support target species. Such actions are critical for the biodiversity of the Black Sea forests, which are among European forests with good conditions (Maes et al 2023). These actions should prioritize prime butterfly areas of the study area by supporting traditional land-use practices and avoiding habitat-destroying activities.

The practicality of the study design helped to understand the occurrence patterns of two forest-dweller species. For the other two species, the dataset had limited value as a sample size of 31 combined with low presence would create either unstable results or models with low acceptance. A possible explanation of limited data for *B. euphrosyne* is a probable shift in the flight period of the univoltine butterfly for that year due to climatic variations. Furthermore, the occurrence of those populations needs assurance, as all of the literature records date back to before 1988. Those questions can be answered with intensive, repeated field surveys. From 2012 to 2023, only seven photos of the species were taken in Gümüşhane province, most of which were taken in mid-July at high altitudes compared to the study region (TRAKEL 2023). The lack of a high number of records may be connected to the rarity of the species or a low amount of observation efforts. Nevertheless, early- and late-summer repeated surveys at a larger number of sites would allow analyses with higher explanatory power. Between 1990 and 2018, including the survey period, there was a massive increase in the number of butterfly records around the world. Still, the trend was negative for Türkiye with several grids with intermediate to high-level data gaps (Girardello et al 2019). One reason behind this finding is the low number of researchers and enthusiasts around Türkiye and the absence of butterfly records of the enthusiasts in relevant databases. Promoting data collection by experienced observers or citizen scientists would contribute to similar studies on species with knowledge gaps. Such efforts will also help in understanding the status and distribution of rare species of the study area, such as the endangered *Aricia torulensis* (Karaçetin and Welch 2011).

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Acknowledgements
This study was a part of the project titled Integration of Biological Diversity into Forestry Management Plans in Demirköy Directorate of Forestry carried out by the Nature Conservation Centre. Digital maps were provided by the Centre. I thank Evrim Karaçetin for sharing her opinions on the selection of the species. I am grateful to Yakup Çakaroğulları for his support during the fieldwork. I am also thankful to the editor and the two reviewers for their constructive comments.

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