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Research Article

# Biodiversity of noctuid moths (Lepidoptera: Noctuidae) in the Ark Protected Area, East Iran

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**Abstract.** Determination of the insect biodiversity in protected areas is very important for effective conservation and ecosystem management. The present study was carried out to investigate distribution and diversity of noctuid moths in mountainous and plain regions in the Ark Protected Area, eastern Iran, on the sites with very diverse altitudinal gradients and different environmental conditions. Samplings were carried out during spring and summer of 2023 and 2024. Three pairs of sampling sites were chosen from areas composed of plains and mountains in Ark Protected Area in the province of Khorasan-e Jonoubi, Iran. Semi-monthly samplings were carried out at selected sites using light traps. Biodiversity was analyzed using non-parametric and parametric methods. A total of 1948 specimens belonging to 56 species of noctuid moths were caught in the study areas. *Dysmilichia bicyclica* (Staudinger, 1888) comprising 20.7% of the fauna proved to be the most dominant noctuid species of the area. Analysis of species dominance categories reveals that most noctuid species (66.1%) have subrare dominance in this region. Results indicate that biodiversity indices differed significantly between plain and mountainous areas. Mountainous regions were more species-rich (Menhinick index: 1.86 and 1.68) and abundant while plains were more species-even (Buzas and Gibson index: 0.75 and 0.65) and dominated by some species. Differences in both species richness, evenness, and dominance, between plains and mountains, underline the need for habitat-specified conservation actions to preserve moth communities. Also, our findings point out the crucial implementation of conservation in this area, as it is a habitat for many subrare moth species.

**Keywords:** Altitudinal gradients, Consevation, Khorasan-e Jonoubi, Species Richness, Topography

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## Introduction

Nowadays, the protection of rare and endemic species is increasingly emphasized, as their survival is highly sensitive to ongoing climate and environmental changes. Variations in their populations often serve as key indicators of broader ecological shifts, highlighting the need for targeted conservation efforts (Laurila-Pant *et al.*, 2015; Noori *et al.*, 2023). Human-driven extinctions of various life forms occur at a rate 100 to 200 times higher than the natural background extinction rate (Angermeier & Karr, 2019). Biodiversity decline due to the impact of human actions can cause terrible consequences such as loss of ecosystem services, decreased ecosystem resilience and threats to food security (Sala *et al.*, 2000). Preventing the reduction of biodiversity is increasingly becoming one of the important goals of environmental management (Laurila-Pant *et al.*, 2015; Angermeier & Karr, 2019). Insects are most diverse and abundant group of organisms which play crucial roles in any ecosystem (Gullan &

Cranston, 2014). Consequently, the study of insect biodiversity is important specially if environmental management is aimed at a protected area.

The Ark Protected Area, located in the east of Iran, due to the high diversity in habitat factors, including topography, which includes both mountainous and plain areas, provides a good opportunity to study insect biodiversity and the impact of various biotope factors on it. Because of the differences in vegetation, climate, and altitude between these two types of places, there are many microniches that can serve as home for a variety of insects, including those in the Lepidoptera order (Meléndez-Jaramillo *et al.*, 2021). Some previous studies have demonstrated the high diversity of these communities and the significant differences between mountainous and plain areas on a global (e.g., Tenorio *et al.*, 2023) and regional (e.g. Wang *et al.*, 2010) scales. In fact, mountains, in comparison to other geological landforms, harbour exceptional levels of biodiversity even when are characterized by relatively smaller areas (Körner *et al.*, 2017; Rahbek *et al.*, 2019).

Altitude is among the major topographical drivers of insect assemblage, and along the elevation gradient, a species diversity sometimes shows complicated patterns such as a decreasing trend, mid-elevation peaks, and plateau effects. Such patterns may be influenced by climate change, the species-area relationship, ecotones, biotic interactions, and historical factors (Popović *et al.*, 2021; Rajaei *et al.*, 2023a; Noori *et al.*, 2024a). The Lepidoptera are among the orders most sensitive to environmental variation. Many works reported diversity and structural changes along altitudinal gradients for assemblages of Lepidoptera. Altitudinal gradients in species richness are described by geometrical constraints due to the shape of distributional areas, aspects, and transitions of habitats. This is reiterated in field studies by Colwell *et al.* (2016), Fernandes *et al.* (2016) and Vieira *et al.* (2022). Noctuid moths (Lepidoptera: Noctuidae) are one of the most diverse and economically important insect families. With more than 12,000 described species across approximately 1,150 genera, they are found in all zoogeographical regions worldwide (Keegan *et al.*, 2021).

The Noctuidae of Iran was firstly studied by some pioneer Entomologist and Lepidopterologist like Jean Édouard Ménétries which collected and studied this family along with other families of Lepidoptera in 19$^{th}$ century (Rajaei *et al.*, 2023c). Continuing their studies, later Lepidopterologists published several monographs that contain a wealth of information about the Noctuidae family in Iran. For instance, a worthy reference for faunistic research on this family in the country was provided by Hacker (1990) and Ebert & Hacker (2002). Additional taxonomic and faunistic information on this family in Iran was later provided by the Witt Catalogue and Fibigeriana book series (e.g. Ronkay *et al.* 2008, 2017; Lödl *et al.*, 2013, 20159), alongside Iranian researches such as Rabieh *et al.* (2014) and Shahreyari-Nejad *et al.* (2020). The wealthy publication of Rajaei and Karsholt in 2023 is the latest great work on Lepidoptera of Iran including all the reported Noctuidae species and their distributional information. Although, research on insect biodiversity within protected areas in Iran and along elevational gradients is limited. One notable exception is the study by Hajizadeh *et al.* (2022), which, for the first time, documented changes in moth diversity patterns in relation to environmental gradients, such as vegetation characteristics, in the Hyrcanian forests of northern Iran. This study provides important insights into how environmental factors influence the moth communities in this unique ecosystem (Hajizadeh *et al.*, 2022).

This study examines the biodiversity of Noctuid moths (Lepidoptera: Noctuidae) across both mountainous and plain regions of the Ark Protected Area. Additionally, it evaluates the abundance distribution models within the Noctuidae community in the region. By investigating biodiversity indices such as species richness, species dominance, species evenness and diversity, this research aims to determine how different characteristics of the biotope in a protected area can affect the biodiversity in that area. The results of this research can be used for the next steps in order to effectively manage the ecosystem.

## Materials and methods

### Study area

The Ark Protected Area is situated in Khorasan-e Jonoubi province in eastern Iran (Fig. 1), with an area of 23,571 hectares bounded by geographic coordinates between 583700 E to 585500 E longitude and 324700 N to 330500 N latitude. Maximum elevation of the region was 2,481 meters while its minimum elevation was 1,303 meters.

This territory was declared as a protected area under the official decree No. 270 dated 19/01/2006 by the High Council for Environmental Protection.

Topographically, this area is almost a mountainous, rocky region with some plains southward. Climatically, this region is mainly an arid and semi-arid land with a number of natural features such as mountains, hills, springs, rivers, and qanats.

Some of the main plant species of this area belong to the *Artemisia* genus, while strong shrubs in higher elevations include *Pistacia* and *Amygdalus* species. Other common plant species are *Cuminum cyminum* L. (Cumin), *Ferula assa-foetida* L. (Asafoetida), *Marrubium vulgare* L. (White Horehound), *Hyssopus officinalis* L. (Hyssop), *Satureja hortensis* L. (Summer Savory), *Achillea millefolium* L. (Common Yarrow), *Thymus vulgaris* L. (Common Thyme), *Ebenus cretica* L. (Cretan Ebony), *Ficus carica* L. (Fig trees), *Astragalus* spp. (Milkvetch), *Tamarix* spp. (Athel Tamarisk), *Salix* spp. (Willows), *Cousinia* spp. (Cousinia), *Alhagi persarum* Boiss. & Buhse (Camelthorn), *Ephedra* spp. (Mormon-tea) (Aliabadi, 1403).

## Sampling

Sampling was conducted twice a month during the spring and summer seasons of 2023 and 2024 in the Ark Protected Area (Fig. 1). Because the majority of moths diversity and density are concentrated in the spring and summer periods; samplings during these seasons were undertaken in a bid to get the best chance of recording the most activity of most species. Temporal changes in environmental factors, such as temperature, humidity, and resource availability, significantly influence Lepidoptera assemblages, where the majority of the species have high activity levels and reproductive cycles during warmer months. Thus, the alignment of samplings within these seasons strengthens the representativeness of data procured and allows the richness of biodiversity to be evaluated better (Meléndez-Jaramillo *et al.*, 2021). Following a field survey of the area, the presence of two distinct geographical conditions—plain and mountainous—was identified. In regard to this geographical influencing factor on the biodiversity of the noctuid moths within this region, three pairs of sampling sites that represent both plain and mountainous areas were selected. Sampling was undertaken at the six selected locations (Fig. 1; Table 1) in such a manner that the collections had the shortest interval. Comparing of the biodiversity indices were done between plain and mountainous locations in each site (1 with 2; 3 with 4; 5 with 6) (Table 1). In each location, sampling was conducted twice per month throughout the spring and summer seasons, resulting in a total of 24 sampling events per location over two years. The sampling locations within the mountainous region were chosen to correspond to the average altitude of each area, approximately, ensuring the minimization of altitude-related biases. Additionally, all sampling sites were uniformly oriented toward the north to control for potential directional influences on the study results. Specimens were collected in each location using one light trap including a 150 W generator-driven mercury-vapor (MV) lamp, which was placed inside a white tent approximately 1.8 meters high. All noctuid moths attracted to the light trap were collected, and all specimens were then transferred to the laboratory for counting and identification. Identifications were done using several literatures (e.g. Fibiger, 1990, 1997; Fibiger *et al.*, 2008; Fibiger & Hacker, 2007). The systematics and nomenclature are according to Lödl *et al.* (2012).

## Assessment of Species Diversity

To assess species diversity, non-parametric numerical indices were utilized, including:

1. Species Heterogeneity Indices: Shannon-Wiener Index and Simpson's Index;
2. Species Dominance Indices, including Simpson's Index and Berger-Parker Index.
3. Species Evenness Indices: Pielou's Index, Buzas and Gibson's Index.
4. Species Richness: Based on the number of species (s), Margalef Index, and Menhinick Index.

For comparing the aforementioned numerical indices, both non-parametric tests (Permutation Test and Hutchinson's t-test) and parametric methods (diversity ordering) were employed.

## Comparison of Numerical Indices of Species Diversity

When we have two samples from a population, we can calculate diversity indices for each. However, we cannot compare these index values using classical hypothesis tests (Silverman, 2018).

**Table 1.** Location characteristics (latitude, longitude and elevation) of the six sampling sites in the Ark Protected Area, Khorasan-e Jonoubi province, Iran.

| Sampling location | Latitude | Longitude | Elevation (m) | Location type |
|---|---|---|---|---|
| 1 | 58° 46′ 24″ | 32° 54′ 47″ | 1535 | plain |
| 2 | 58° 47′ 09″ | 32° 58′ 40″ | 1684 | mountain |
| 3 | 58° 42′ 43″ | 32° 59′ 59″ | 2010 | mountain |
| 4 | 58° 50′ 34″ | 32° 49′ 02″ | 1333 | plain |
| 5 | 58° 64′ 58″ | 32° 99′ 31″ | 1620 | mountain |
| 6 | 58° 39′ 24″ | 32° 56′ 34″ | 1435 | plain |

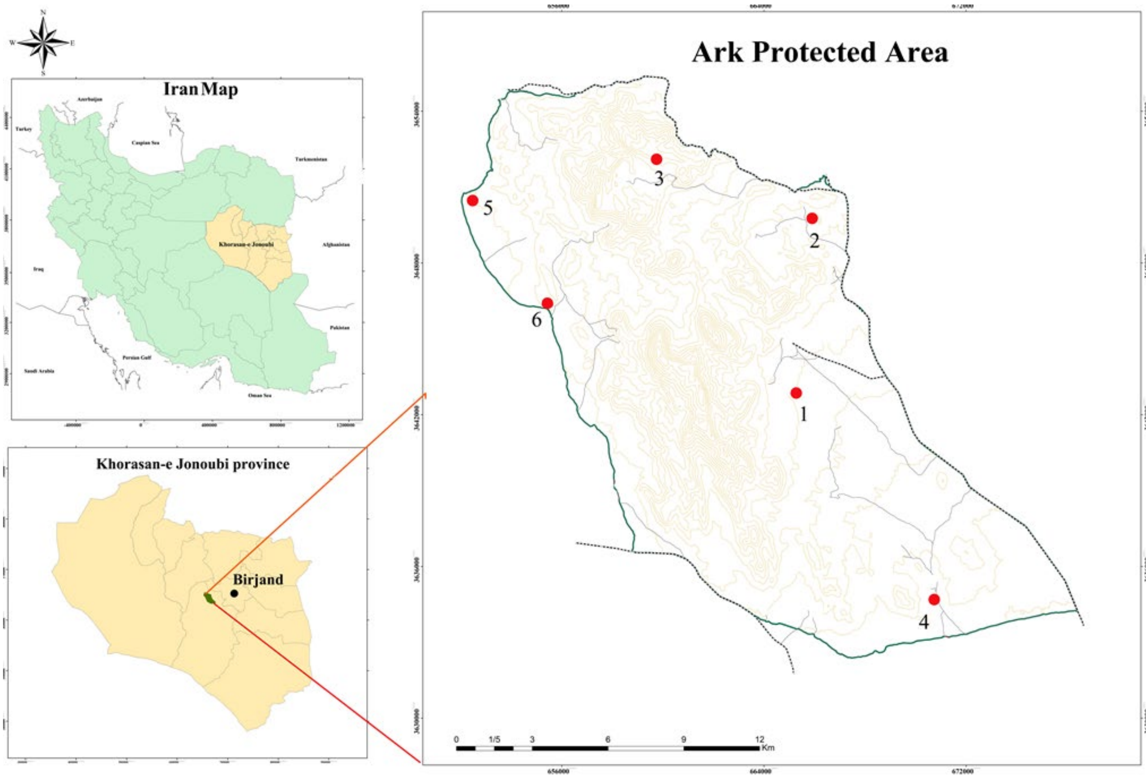


**Fig. 1**. Location of the Ark Protected Area in the Khorasan-e Jonoubi province, Iran and the sampling locations 1-6.

## Permutation Test

The permutation test is a type of non-parametric test. This test is used when dealing with the worst-case scenario in data analysis (Farine & Carter, 2022). In a permutation test, we do not have access to the distribution of the data, and the data sample sizes are often very small. The p-value in this test is calculated using the Monte Carlo method. In this study, diversity indices were compared using random permutations (9999 permutations). The criterion for determining the significance of the difference was a p-value of ≤ 0.05.

## Hutcheson's t-test

Hutcheson's t-test was developed as a method for comparing the diversity of two population samples using the Shannon diversity index (Hutcheson, 1970). The main formula for this test is similar in appearance to the classical Student's t-test formula.

$$t = \frac{H_a - H_b}{\sqrt{S_{H_a}^2 + S_{H_b}^2}}$$

In the formula H represents the Shannon diversity index for each of the two samples (subscripted a and b). The bottom of the formula refers to the variance of each of the samples.

### Calculation of Variance for the Shannon-Wiener Diversity Index

Calculating the variance and degrees of freedom for species diversity indices can be challenging. The key aspect of this formula is that it determines the variance of the Shannon index. The variance of Shannon diversity was calculated using the formula shown below (Etto *et al.*, 2012):

$$S_H^2 = \frac{\sum p \cdot (\ln p)^2 - (\sum p \cdot \ln p)^2}{N} + \frac{S-1}{2N^2}$$

Where S represents species richness, or the total number of species. N is the total number of individuals in the sample. p is the relative abundance (or proportion) of each species.

### Diversity ordering

One parametric method for measuring biodiversity is through the use of diversity ordering method. These curves, also known as community diversity profiles, are graphical representations that plot diversity values (D) against a scale parameter (α). D is the diversity measure at a given scale, whose value depends on the chosen diversity index (species richness, Shannon entropy, Simpson's index). α is a parameter that regulates the sensitivity of the diversity measure to species abundances-for example, α = 0, D equals species richness; α = 1, D equals Shannon entropy; and α = 2, D is similar to Simpson's index, which gives more importance to dominant species. This method covers a wider area of biodiversity by giving information about various ecological conditions. The diversity of communities is displayed as either separate or intersecting curves. Each resulting curve is referred to as a community diversity profile, which can be used to rank diversity as follows (Petrovskii, 2018):

Community A was considered more diverse than Community B if the profile of A was consistently higher than the profile of B. When curves for two communities intersect, this means that they cannot be ranked (Etto *et al.*, 2012). In this study, the Rényi diversity profile was used to compare species diversity (Rényi, 1961).

### Species-abundance distribution (SAD) models

In this study, for biodiversity assessment, apart from the numerical indices of biodiversity calculation, species-abundance distribution models were also used. The most common methods are using species richness - log abundance class (Preston) plots and abundance - species rank order (Whittaker) plots. In their meta-analysis, Ulrich *et al.* (2010) considered the use of abundance-species rank order (Whittaker) plots to evaluate the species abundance distribution of animal communities. Because many of the models predict very similar shapes, model distinction and testing become problematic (Ulrich *et al.*, 2010). Therefore, in this study abundance-species rank order (Whittaker) plots include: Null (brokenstick), preemption, Log-Normal, Zipf and Zipf-Mandelbrot models were used.

Also, the Akaike information criterion (AIC) was used to select the best model. AIC allows the ranking of the candidate models and might select the best model within the collection given the experimental data considered (Portet, 2020).

### Dominance structure

After calculating the abundance and frequency of insect species, to evaluate the dominance structure of insects, Heydemann's classification (Weigmann, 1973) was used. This classification has five degrees of dominance: eudominant (more than 30%), dominant (10–30%), subdominant (5–10%), rare (1–5%), and sub-rare species (less than 1%).

### Data analysis

All analyses were performed using R Statistical Software (Version 4.1.2, R Core Team, 2021, R Packages: diverse (Guevara *et al.*, 2016) and vegan (Oksanen *et al.*, 2019) and PAST (Version 4.09, Hammer-Muntz *et al.* (2001)).

## Results

A total of 1948 specimens from 56 species of noctuid moths were collected across the study sites (Table 2). The table provides details on the abundance, proportion and dominance of each collected species. Most abundant noctuid moth, *Dysmilichia bicyclica* (Staudinger, 1888) with the 20.7% of the fauna in this area followed by *Bryophila maeonis* (Lederer, 1865) and *Spodoptera exigua* (Hübner, 1808) constituting 11.3% and 7.9% of the fauna, respectively.

Table 2. Noctuidae species and the number of captured specimens, proportion and dominance degree in the Ark Protected Area, Iran.

| Species | Abundance | Proportion | Dominance degree |
|---|---|---|---|
| *Dysmilichia bicyclica* (Staudinger, 1888) | 404 | 20.74 | Dominant |
| *Bryophila maeonis* (Lederer, 1865) | 221 | 11.34 | Dominant |
| *Spodoptera exigua* (Hübner, 1808) | 154 | 7.91 | Subdominant |
| *Dichagyris grisescens* Staudinger, 1879 | 148 | 7.60 | Subdominant |
| *Bryophila idonea* Christoph, 1893 | 136 | 6.98 | Subdominant |
| *Bryophila tephrocharis* (Boursin, 1954) | 132 | 6.78 | Subdominant |
| *Euxoa transcaspica* Kozhanchikov 1928 | 125 | 6.42 | Subdominant |
| *Dichagyris melanuroides* Kozhanchikov, 1930 | 68 | 3.49 | Rare |
| *Dichagyris* sp.1 | 50 | 2.57 | Rare |
| *Trichoplusia ni* (Hübner, 1803) | 42 | 2.16 | Rare |
| *Dichagyris leucomelas* Brandt, 1941 | 36 | 1.85 | Rare |
| *Anarta trifolii* (Hüfnagel, 1766) | 36 | 1.85 | Rare |
| *Rhiza laciniosa* (Christoph, 1887) | 33 | 1.69 | Rare |
| *Dichagyris erubescens* (Staudinger, 1892) | 30 | 1.54 | Rare |
| *Dichagyris vallesiaca* (Boisduval, 1837) | 22 | 1.13 | Rare |
| *Heliothis nubigera* (Herrich-Schäffer, 1851) | 22 | 1.13 | Rare |
| *Helicoverpa armigera* (Hübner, 1808) | 21 | 1.08 | Rare |
| *Dichagyris forficula* (Eversmann, 1851) | 20 | 1.03 | Rare |
| *Chersotis curvispina* Boursin, 1961 | 19 | 0.98 | Rare |
| *Caradrian clavipalpis* Scopoli, 1763 | 16 | 0.82 | Subrare |
| *Bryophila raptricula* (Denis & Schiffermüller, 1775) | 14 | 0.72 | Subrare |
| *Euxoa homicida* (Staudinger, 1900) | 13 | 0.67 | Subrare |
| *Dichagyris* sp.2 | 12 | 0.62 | Subrare |
| *Cloantha hyperici* (Denis & Schiffermüller, 1775) | 12 | 0.62 | Subrare |
| *Aegle subflava* Erschoff, 1874 | 11 | 0.56 | Subrare |
| *Cryphia receptricula* (Hübner, 1803) | 10 | 0.51 | Subrare |
| *Euxoa lugubris* Brandt, 1941 | 8 | 0.41 | Subrare |
| *Dichagyris flammatra* (Denis & Schiffermüller, 1775) | 8 | 0.41 | Subrare |
| *Tyta luctuosa* (Denis & Schiffermüller, 1775) | 8 | 0.41 | Subrare |
| *Dichagyris* sp.3 | 8 | 0.41 | Subrare |
| *Caradrina inumbrata* (Staudinger 1900) | 8 | 0.41 | Subrare |
| *Autographa gamma* (Linnaeus, 1758) | 7 | 0.36 | Subrare |
| *Caradrian adriennea* Hacker and Gyulai, 2004 | 7 | 0.36 | Subrare |
| *Bryophila* sp.1 | 6 | 0.31 | Subrare |
| *Mythimna unipuncta* (Haworth, 1809) | 6 | 0.31 | Subrare |
| *Agrotis ipsilon* (Hüfnagel, 1766) | 6 | 0.31 | Subrare |
| *Euxoa conspicua* (Hübner, 1827) | 6 | 0.31 | Subrare |
| *Caradrina albina* Eversmann, 1848 | 6 | 0.31 | Subrare |
| *Acontia lucida* (Hufnagel, 1766) | 6 | 0.31 | Subrare |
| *Euxoa clauda* Püngeler, 1906 | 5 | 0.26 | Subrare |
| *Megalodes eximia* (Freyer,1845) | 5 | 0.26 | Subrare |
| *Rhyacia arenacea* (Hampson, 1907) | 4 | 0.21 | Subrare |
| *Cryphia* sp.1 | 4 | 0.21 | Subrare |
| *Leucania loreyi* (Duponchel, 1827) | 4 | 0.21 | Subrare |
| *Hadena montana* (Brandt, 1941) (e) | 4 | 0.21 | Subrare |
| *Euxoa* sp.1 | 4 | 0.21 | Subrare |
| *Hadena* sp.2 | 4 | 0.21 | Subrare |
| *Hecatera dysodea* (Denis & Schiffermüller, 1775) | 4 | 0.21 | Subrare |
| *Heliothis viriplaca* (Hufnagel, 1766) | 2 | 0.10 | Subrare |
| *Margelana versicolor* (Staudinger 1888) | 2 | 0.10 | Subrare |
| *Caradrina vicina* Staudinger, 1870 | 2 | 0.10 | Subrare |
| *Agrochola lychnidis* (Denis & Schiffermüller, 1775) | 2 | 0.10 | Subrare |
| *Mythimna l-album* (Linnaeus, 1767) | 2 | 0.10 | Subrare |
| *Caradrina bodenheimeri* Draudt, 1934 | 1 | 0.05 | Subrare |
| *Lacanobia oleracea* (Linnaeus, 1758) | 1 | 0.05 | Subrare |
| *Protoschinia scutosa* (Denis & Schiffermüller, 1775) | 1 | 0.05 | Subrare |

(e): species is endemic to Iran.

Analysis of the species dominance categories reveals that the most noctuid species (66.1%) have subrare dominance and dominant, subdominant, and rare species account for 3.6%, 8.9%, 21.4% of the species dominance, respectively. The Monte Carlo permutation tests revealed significant differences in biodiversity indices between the plain and mountainous regions across all three comparing sites, except for specific cases such as individual counts between comparing site 1 (locations 1 vs. 2) and certain indices at comparing site 2 (locations 3 vs. 4) and comparing site 3 (locations 5 vs. 6) (Fig. 2; Tables 3, 5, 7). At comparing site 1, all biodiversity indices, except dominance, were significantly higher in the plain region (Table 3), with Hutcheson's t-test confirming a significant difference in Shannon-Wiener diversity ($p \le 0.001$; Table 4). In contrast, comparing site 2 exhibited significant higher species richness, individual counts, Margalef's richness index, and Shannon-Wiener diversity in the mountainous region (Table 5). Also, significant differences in Shannon-Wiener diversity confirmed by Hutcheson's t-test ($p \le 0.001$; Table 6). At comparing site 3, individual counts and dominance indices were significantly higher in the plain region, whereas diversity and evenness indices were greater in the mountainous region (Table 7), but Hutcheson's t-test showed no significant difference in Shannon-Wiener diversity ($p = 0.15$; Table 8). Additionally, rank abundance distribution (RAD) curves indicated that the species abundance in both regions followed the geometric series model based on the lowest Akaike Information Criterion (AIC) values (Figs. 3-4).

Table 3. Results of Monte Carlo permutation tests (9999 permutations) used to test the effect of topography on the noctuid species diversity components (Richness, Dominance, Diversity and Evenness) in the Ark Protected Area, Khorasan-e Jonoubi province, Iran (comparing site 1).

| Component | Indices | Plain | Mountain | Perm p(eq) |
|---|---|---|---|---|
| Richness | Taxa S | 25 | 18 | 0.00** |
| | Menhinick | 2.26 | 1.61 | 0.00** |
| | Margalef | 4.99 | 3.52 | 0.00** |
| Dominance | Simpson D | 0.064 | 0.14 | 0.00** |
| | Berger-Parker D | 0.098 | 0.23 | 0.00** |
| Diversity | Shannon H | 2.94 | 2.32 | 0.00** |
| | Simpson I | 0.94 | 0.86 | 0.00** |
| Evenness | Pielou J | 0.91 | 0.80 | 0.00** |
| | Buzas and Gibson | 0.75 | 0.57 | 0.00** |

**pvalue≤0.01

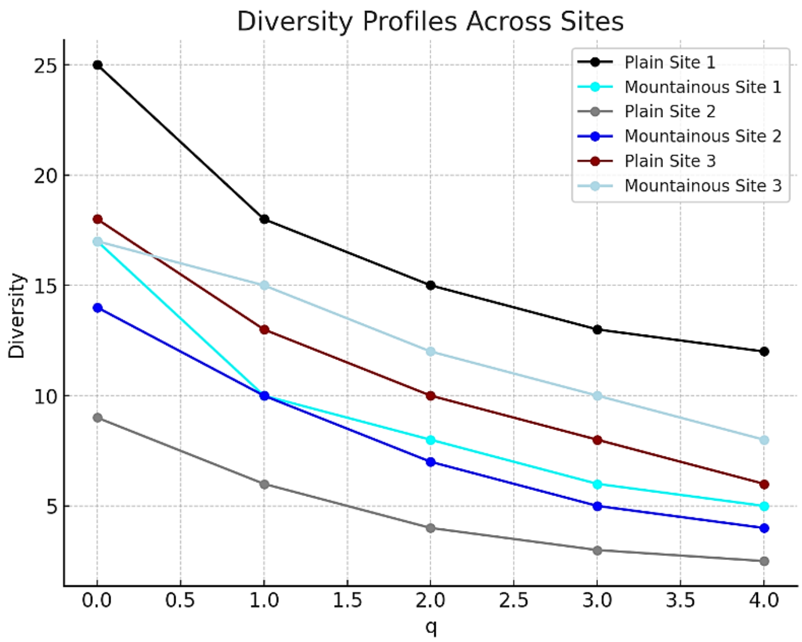


**Fig. 2.** Diversity profiles of three comparing sites using the Rényi series representing the noctuid moths for the plain and mountain area in the Ark Protected Area, Iran. Hill numbers of the order q (q = 0 species richness, q = 1 Shannon diversity, q = 2 Simpson diversity, and q = ∞ Berger and Parker index).

Table 4. Hutcheson's t-test (p= 0.05) between Shannon-Wiener diversity indices for noctuid moths in the Ark Protected Area, Khorasan-e Jonoubi province, Iran (comparing site 1).

| Management | Shannon index | | t | p. value |
|---|---|---|---|---|
| | H | Variance | | |
| Plain | 2.94 | 0.005 | 5.42 | 0.000** |
| Mountain | 2.32 | 0.0002 | | |

**pvalue≤0.01

Table 5. Results of Monte Carlo permutation tests (9999 permutations) used to test the effect of topography on the noctuid species diversity components (Richness, Dominance, Diversity and Evenness) in the Ark Protected Area, Khorasan-e Jonoubi province, Iran (comparing site 2).

| Component | Indices | Plain | Mountain | Perm p(eq) |
|---|---|---|---|---|
| Richness | Taxa S | 9 | 15 | 0.03* |
| | Menhinick | 1.44 | 1.86 | 0.25 |
| | Margalef | 2.18 | 3.35 | 0.03* |
| Dominance | Simpson D | 0.25 | 0.15 | 0.10 |
| | Berger-Parker D | 0.46 | 0.32 | 0.21 |
| Diversity | Shannon H | 1.77 | 2.26 | 0.05* |
| | Simpson I | 0.75 | 0.85 | 0.10 |
| Evenness | Pielou J | 0.81 | 0.83 | 0.68 |
| | Buzas and Gibson | 0.65 | 0.64 | 0.90 |

*pvalue≤0.05

Table 6. Hutcheson's t-test (p= 0.05) between Shannon-Wiener diversity indices for noctuid moths in the Ark Protected Area, Khorasan-e Jonoubi province, Iran (comparing site 2).

| Management | Shannon index | | t | p. value |
|---|---|---|---|---|
| | H | Variance | | |
| Plain | 1.77 | 0.015 | -2.40 | 0.02* |
| Mountain | 2.26 | 0.026 | | |

*pvalue≤0.05

Table 7. Results of Monte Carlo permutation tests (9999 permutations) used to test the effect of topography on the noctuid species diversity components (Richness, Dominance, Diversity and Evenness) in the Ark Protected Area, Khorasan-e Jonoubi province, Iran (comparing sites 3).

| Component | Indices | Plain | Mountain | Perm p(eq) |
|---|---|---|---|---|
| Richness | Taxa S | 18 | 17 | 0.79 |
| | Menhinick | 1.63 | 1.68 | 0.94 |
| | Margalef | 3.54 | 3.45 | 1.00 |
| Dominance | Simpson D | 0.13 | 0.09 | 0.00** |
| | Berger-Parker D | 0.27 | 0.16 | 0.01** |
| Diversity | Shannon H | 2.41 | 2.57 | 0.09 |
| | Simpson I | 0.87 | 0.91 | 0.00** |
| Evenness | Pielou J | 0.83 | 0.91 | 0.01** |
| | Buzas and Gibson | 0.62 | 0.77 | 0.01** |

**pvalue≤0.01

Table 8. Hutcheson's t-test (p= 0.05) between Shannon-Wiener diversity indices for noctuid moths in the Ark Protected Area, Khorasan-e Jonoubi province, Iran (comparing site 3).

| Management | Shannon index | | t | p. value |
|---|---|---|---|---|
| | H | Variance | | |
| Plain | 2.41 | 0.007 | -1.44 | 0.15 |
| Mountain | 2.57 | 0.005 | | |

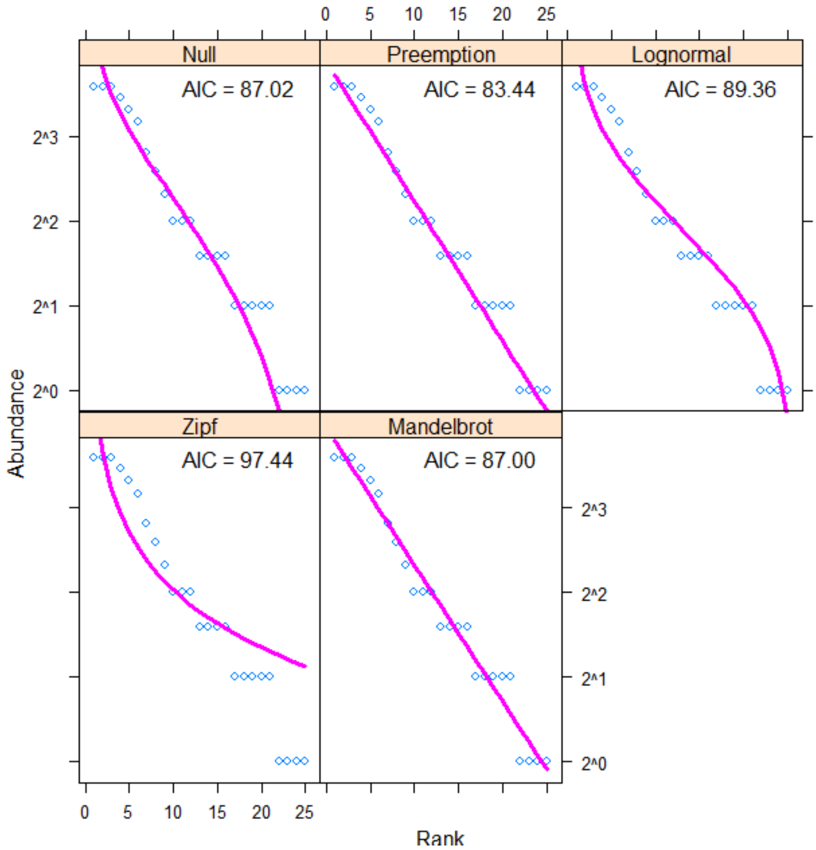


Fig. 3. The species abundance distribution (SAD) for plain and fit Null (brokenstick), preemption, log-Normal, Zipf and Zipf-Mandelbrot models of species abundance.

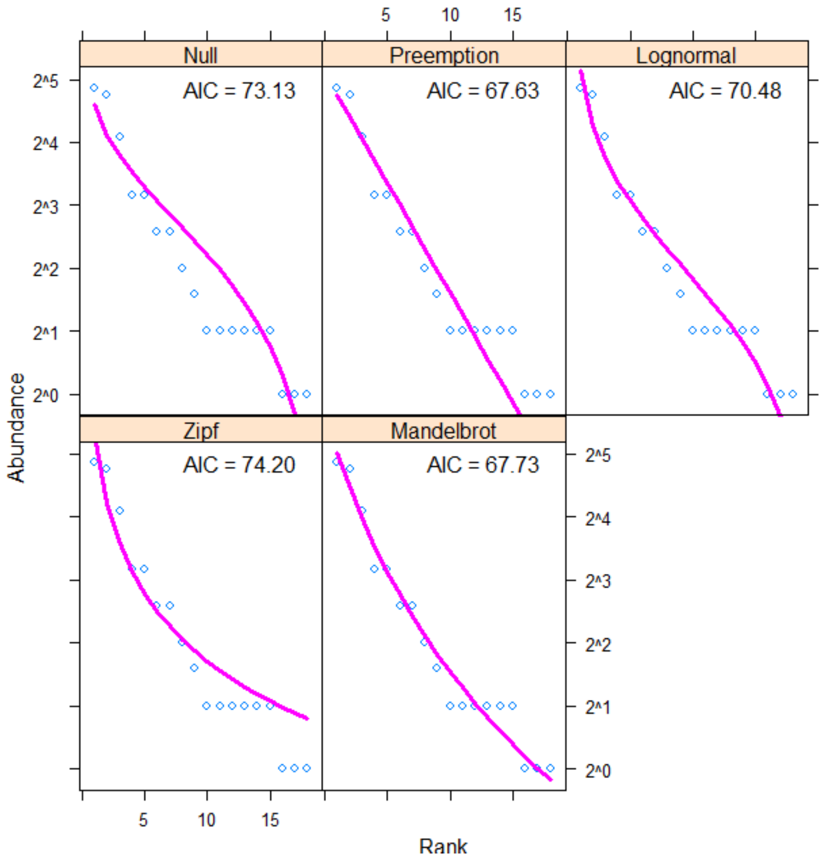


Fig. 4. The species abundance distribution (SAD) for mountain and fit Null (brokenstick), preemption, Log-Normal, Zipf and Zipf-Mandelbrot models of species abundance.

## Discussion

In total, 1,948 specimens belonging to 56 Noctuid species were collected. Species dominance greatly varied among the comparing sites. *D. bicyclica* was the most dominant species followed by two species *B. maeonis* and *S. exigua*. *D. bicyclica* is an Anatolian-Iranian moth species which inhabits both desert and mountainous habitats (Wiltshire, 1944). The biology of this moth species and its larval food plants are unknown.

According to Rajaei *et al.* (2023b), *Hadena montana* (Brandt, 1941) is the only endemic species identified among the Noctuidae collected in the Ark Protected Area (Table 2). This species was first described by Brandt (1941) from the Binaloud Mountains in Khorasan-e Razavi Province. However, no information is available regarding its host plant or other ecological characteristics, except for its peak occurrence at the Binaloud Mountains during late July (Brandt, 1941).

The dominance analysis revealed a community structure where most species fall under subrare categories. The result suggests that although a few species are highly prevalent, the majority of species maintain lower abundance levels, indicating a relatively high biodiversity with limited dominance by specific taxa. These findings point out the crucial implementation of conservation in this area, as it is a habitat for many subrare moth species.

Results of biodiversity indices tests also showed that diversity indices significantly differed between the plain and mountainous regions, hence indicating the topography influence on moth community structure. In general, species richness, abundance, and Margalef's richness index were higher in the mountainous regions, indicating that elevation may favor greater species richness and abundance. This aligns with ecological theories suggesting that mountainous areas, with their complex microclimates and habitat heterogeneity, support a broader range of ecological niches, leading to increased species richness and diversity (Seibold *et al.*, 2016; Wani *et al.*, 2023).

Interestingly, the plain regions exhibited higher values in most diversity and evenness indices, such as the Shannon-Wiener index and Simpson's index. This pattern may suggest that the plain regions support more evenly distributed populations, potentially due to more uniform environmental conditions and vegetation cover compared to the heterogeneous mountainous regions. This is further supported by the high values of evenness indices for the plains, as depicted by both Pielou's and Buzas and Gibson, since there is an even representation of species in relation to mountainous areas, which are likely dominated by just a few species (Tews *et al.*, 2004).

The observed patterns have a number of ecological implications. Firstly, greater richness and diversity in mountainous areas reflect that elevation and habitat complexity are an essential factor to support diverse moth communities. These findings were also in agreement with the other studies on Lepidoptera that have also observed similar biodiversity pattern along the elevational gradients (e.g. Spitzer *et al.*, 1997; Bennie *et al.*, 2008; Choi & Chun, 2009; Meléndez-Jaramillo *et al.*, 2021; Hajizadeh *et al.*, 2022; Vieira *et al.*, 2022). The higher evenness and lower dominance in the plain areas might reflect a fairer distribution of species and/or possibly smaller ecological pressures or competitive interactions. Second, the significant differences among comparing sites in all biodiversity indices underline the relevance of microhabitats and local conditions as determining factors of moth communities. These findings are in conformity with other studies on Lepidoptera showing analogous patterns of biodiversity along elevational gradients (e.g. Spitzer *et al.*, 1997; Bennie *et al.*, 2008; Choi & Chun, 2009; Meléndez-Jaramillo *et al.*, 2021; Hajizadeh *et al.*, 2022; Vieira *et al.*, 2022).

Higher evenness and dominance in plain areas might suggest a better balance in the distribution of species and probably fewer ecological pressures or competitive interactions. Also, the variations in biodiversity indices across comparing sites emphasize the importance of microhabitats and local environmental conditions in shaping moth communities. The Ark Protected Area's complex topography appears to support a rich assemblage of noctuid moths, with each comparing site exhibiting unique biodiversity characteristics. These results underline the importance of preserving diverse habitats within protected areas, as each habitat type is uniquely contributing to overall biodiversity.

In this study, SAD has been utilized as an ecological indicator to assess the impacts of disturbances (such as pollution and land-use change) on biotic communities (Matthews & Whittaker, 2015). The result of the present study showed that the species abundance of noctuid moths both in the plains and in the mountains follows the geometric model. The geometric model has proven to be effective for species-poor communities as well as resource-poor environments (Fattorini, 2005). This model is found in early successional stages or in species-poor (and often harsh) environments (Magurran & McGill, 2010) and resource-poor environments (Fattorini, 2005). It is also recommended for ecosystems that are affected by human interference or have a strong dominance of a few species (Graffelman, 2021). In these environments, dominant species preempt the largest portion of the limiting resource (Zak & Willig, 2004).

Since a method alone cannot provide a detailed evaluation of biodiversity, in the present study, to evaluate and compare the biodiversity components of noctuid moths, statistical methods (permutation test and Hutcheson t test), diversity ordering curves and the SAD models were used. The results were somewhat similar to each other and complemented each other.

The current research was conducted in three replications, and contradictory results were obtained regarding the effect of topography on the richness and diversity of species of noctuid moths. The reason for the contradiction in the results can be explained by the fact that it seems that in studies of biodiversity assessment in mountainous areas, it is difficult to separate the slope, elevation and rainfall from each other, and perhaps the changes in species richness and diversity are indirectly related to the slope and directly to the elevation, and it depends on the rainfall. In mountainous areas, slope direction, light intensity, received rainfall, topology, temperature and humidity are different (Yang *et al.*, 2014). Numerous studies have demonstrated that the distribution and diversity of insect species are influenced by a variety of complex biotic and abiotic factors (Klingauf, 1981; Cuevas-Reyes *et al.*, 2004; Hodkinson, 2005; Gao *et al.*, 2015; Moreira *et al.*, 2016; Rasmann *et al.*, 2013; Zhao *et al.*, 2023). These mainly encompass climatic factors (such as temperature and relative humidity), plant communities, soil characteristics, and elevation gradients (Zhao *et al.*, 2023). Temperature fluctuations are very high in dry and mountainous areas, insects, being ectothermic organisms, show significant reactions to climate change. Consequently, thermal fluctuations greatly impact their growth, reproduction, and survival (Rasmann *et al.*, 2013). Moreover, butterflies are mobile and their larval stages exhibit higher food specialization (Marini *et al.*, 2009), therefore, it is difficult to evaluate their species richness and diversity, which may produce contradictory results. Finally, it is recommended to achieve more accurate results, this kind of research should be done in different climatic regions and with more repetitions.

Results from our investigation into noctuid moth diversity in the Ark Protected Area are in line with general patterns in Lepidoptera and general biodiversity studies in Iran. In this line, earlier works have revealed that most species richness and endemism across the different taxa including Lepidoptera, believe to lie chiefly within middle and higher elevation of the mountain ranges of the Zagros and Alborz, Irano-Anatolian, and the Caucasus region of Iran's biodiversity hotspots (Noroozi *et al.*, 2018; Yusefi *et al.*, 2019; Noori *et al.*, 2024a). This agrees with our results because we recorded a higher richness and diversity in mountainous sites of the Ark Protected Area, reflecting the ecological complexity and habitat heterogeneity of such regions. Other previous studies also showed that endemism rates vary positively with elevation, a trend which this work reflects. The prevalence of *H. montana*, that is an endemic species to the Ark Protected Area, also confirms that Iranian Lepidoptera are much more elevated at mid to high elevations (Rajaei *et al.*, 2023a).

One of the important inferences from recent biodiversity studies is that many regions outside the so-called officially defined biodiversity hotspots also support high species diversity and endemism. These include mountainous areas inside the central desert basins, northern shores of the Persian Gulf, and southeastern Iran (Noroozi *et al.*, 2018; Noori *et al.*, 2021). Similarly, our study suggests that the Ark Protected Area, though not recognized as a core area of biodiversity hotspots, serves significantly in the conservation of noctuid moths and thus needs conservation attention beyond traditionally recognized areas.

These results are also in line with previous studies indicating that Protected Areas (PAs) of Iran are not well-placed for the protection of the most biodiverse parts of the country (Farashi & Shariati, 2017; Noroozi *et al.*, 2018, 2019; Noori *et al.*, 2021). Whereas there are 378 protected areas in Iran that cover around 11% of its land surface, it has been estimated that the protection status mainly relates to the central desert basins and not the mountainous areas with the highest species diversity (Noroozi *et al.*, 2019; Yusefi *et al.*, 2019; Noori *et al.*, 2024a). For example, the work of Noori *et al.* (2024b) indicated a number of the key mismatches between PAs coverage and species-rich areas in Lepidoptera. It included evident gaps in coverage within biodiversity hotspots of Irano-

Anatolia, increasingly exacerbated by ever-growing human pressures. Karimi & Jones (2020), for instance, showed how 22% of PAs in Iran face severe anthropogenic threats due to overgrazing, agriculture, and habitat degradation- more than half of those covered by biodiversity hotspots. While the Ark Protected Area does provide a home for rare and endemic species amongst noctuid moths that are highly diversified, our study definitely underlines the urgent need to revise current policy toward habitat-specific protection from broad-scale designation based on political or administrative reasons. According to the International Union for Conservation of Nature (IUCN), Ark is a category VI protected area wherein biodiversity conservation is integrated with the sustainable use of natural resources. Category VI is defined as an area whereby ecological preservation is combined with human activities in a manner that extraction of resources, traditional livelihoods, and conservation are maintained in a sustainable way. The Ark Protected Area provides a home for numerous flora and fauna species, thus helping in protecting the regional biodiversity. It will also contribute to the local livelihoods through sustainable activities such as controlled grazing, eco-tourism, and non-destructive harvesting of resources. Active management of the area demands active conservation in adaptation, frequent ecological monitoring, and community involvement in the maintenance of biodiversity integrity, along with the promotion of sustainable development (Dudley, 2008; Dudley *et al.*, 2010).

Furthermore, the long-lasting effects of climate change are foreseen to add to the threats of Iran's biodiversity in the near future. It has been modeled in Evans (2009); Lelieveld *et al.* (2012); Mansouri Daneshvar *et al.* (2019), and Noori *et al.* (2023) for increases in temperature and, more generally, drought with a focus on southern Iran. Since most Lepidoptera species are somewhat sensitive to changes in climatic conditions, their distribution and further survival would be driven by such changes. Future work shall be targeted at modeling changes of moth diversity given various climate futures for adapted conservational plans.

Our results also stress the general importance of order Lepidoptera as fundamental indicators of the biodiversity pattern in Iran. Studies have previously outlined that Lepidoptera faunas are among the better-known insects in Iran, with 4,812 species documented from 70 families, 19.7% of which are endemic (Rajaei *et al.*, 2023a). Still, there is a high number of knowledge gaps, especially in the microlepidoptera, and partial coverage, as in the case of the Ilam and Khorasan-e Jonubi provinces, has remained poorly investigated (Rajaei *et al.*, 2023a). Our study adds to the growing body of evidence that detailed distribution studies on moths and other insect groups represent an urgent need for a better understanding of biodiversity in Iran. On a related note, it has also been indicated that moth diversity follows habitat complexity while species richness normally follows the patterns of plant diversity due to the host-specificity of many Lepidoptera larvae. Other literature also referred to a very similar pattern when the families Geometridae and Tortricidae have expressed their maximum diversity in forested areas, whereas the family Noctuidae was more diversified in semi-arid and steppe environments (Rajaei *et al.*, 2023a).

The present study confirms and extends the earlier research on Lepidoptera biodiversity and wider patterns of species diversity in Iran. The greater richness of noctuid moths in mountainous parts of the Ark Protected Area is in complete agreement with the previous studies which emphasized such factors as elevation, habitat heterogeneity, and variation in microclimate as significant features determining species distribution. Although, these findings suggest that Iran can potentially make a significant contribution to conservation, the current network of protected areas is disproportionately low in coverage over the most species-rich and ecologically significant parts of the country; any improved conservation planning effort will require targeted conservation, further research into under-explored taxa, and embedding climate resilience in any future management.

This study illustrates the strong influence of topography on noctuid moth diversity within the Ark Protected Area. The differences in species richness, evenness, and dominance across plains and mountains underscore the necessity of adopting habitat-specific conservation strategies to protect these moth communities. Future studies could investigate the specific environmental variables driving these patterns, such as vegetation types, elevational gradients, and microclimate variations, to deepen our understanding of the ecological drivers of moth biodiversity in Iran's protected areas.

## Author's Contributions

**Mohammad Mahdi Rabieh**: Conceptualization; methodology; formal analysis; investigation; draft preparation; final review and edit; visualization; supervision; project administration and funding acquisition. **Moslem Rostampour**: Conceptualization; methodology; formal analysis; investigation; draft preparation; final review and edit; visualization.

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## Data Availability Statement

The specimens examined in this study are deposited in the first author's collection at the Department of Plant Protection, Faculty of Agriculture, University of Birjand, Birjand, Iran and are available by the curator upon request.

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## Ethics Approval

Insects were used in this study. All applicable international guidelines for the care and use of animals were followed. This article does not contain any studies with human participants performed by the author.

## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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# تنوع زیستی شب پره های خانواده Noctuidae در منطقه حفاظت شده آرک، شرق ایران

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**چکیده:** تعیین تنوع زیستی حشرات در مناطق حفاظت شده برای حفاظت موثر و مدیریت اکوسیستم بسیار مهم است. مطالعه حاضر به منظور بررسی پراکنش و تنوع شب پره های خانواده Noctuidae در مناطق کوهستانی و دشت منطقه حفاظت شده آرک در شرق ایران در ارتفاعات و محیطهای مختلف انجام شد. نمونه برداری در بهار و تابستان سال های ۱۴۰۲ و ۱۴۰۳ انجام شد. سه جفت محل نمونه برداری از مناطق دارای دشت و کوهستان در منطقه آرک در استان خراسان جنوبی انتخاب شد. نمونه برداری در مکان های انتخابی با استفاده از تله های نوری هر دوهفته یکبار انجام شد. داده‌های تنوع زیستی با روش‌های پارامتریک و ناپارامتریک تحلیل شد. در مجموع ۱۹۴۸ نمونه متعلق به ۵۶ گونه شب پره در مناطق مورد مطالعه جمع آوری شد.گونه *Dysmilichia bicyclica* (Staudinger) به میزان ۲۰/۷ درصد از فون شب پره‌های این خانواده را شامل شده و به عنوان غالب ترین گونه Noctuidae در منطقه تشخیص داده شد. تجزیه و تحلیل نوع غالبیت گونه‌ها نشان می‌دهد که بیشتر گونه‌های این خانواده (۶۶/۱ درصد) در این منطقه بسیار نادر (subrare) هستند. نتایج نشان می‌دهد که شاخص‌های تنوع زیستی بین مناطق دشت و کوهستانی تفاوت معنی داری دارد. مناطق کوهستانی دارای غنای گونه‌ای (شاخص Menhinick: ۱/۸۶ و ۱/۶۸) و فراوانی بیشتر بودند، در حالی که دشت‌ها دارای یکنواختی (شاخص Buzas & Gibson: ۰/۷۵، ۰/۶۵) بیشتر و غالبیت در برخی گونه‌ها بودند. تفاوت در غنای گونه ای، یکنواختی و غالبیت بین دشت و کوهستان بر نیاز به اقدامات حفاظتی خاص زیستگاه برای حفظ جوامع بالپولکداران تأکید می‌کند. همچنین، براساس یافته های این تحقیق، این منطقه زیستگاه گونه‌های شب پره بسیار نادر زیادی است و اجرای اقدامات حفاظتی در این منطقه اهمیت زیادی دارد.

**کلمات کلیدی:** توپوگرافی، حفاظت، خراسان جنوبی، شیب‌های ارتفاعی، غنای گونه‌ای

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