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Exploring Morphological Population Variability: Host Plant and Habitat Dependency in the Protected Moth *Gortyna borelii* (Lepidoptera, Noctuidae)

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Abstract: In this paper, we discuss the evolutionary implications of the correlation between different species of *Peucedanum* plants and the distribution of *Gortyna borelii* moth populations in Romania. We highlight geographic separation and isolation among these populations due to anthropogenic landscape fragmentation, which hinders genetic exchange. A geometric morphometric analysis was utilized to visualize and compare the morphometric variations in relation to the environmental variables, particularly the host plant. Additionally, the distribution of *G. borelii* populations across Europe and in Romania that are correlated with the host plant was analyzed. The significant morphological and morphometric differences between the analyzed populations support our working hypothesis, according to which the use of different *Peucedanum* species by the larvae of *G. borelii* leads to an intraspecific diversification correlated with the host plant species. The newly discovered population of *G. borelii* in Romania holds substantial conservation importance, necessitating protection measures, including demarcating habitat areas and raising awareness among stakeholders. *G. borelii* is a protected species at the European level (Habitats Directive 92/43/EEC, Appendices II and IV), considered endangered due to the isolation of its populations and anthropogenic pressures exerted through agricultural practices. Understanding the impact of agricultural practices on their habitat is crucial for effective management strategies. Overall, this study sheds light on the complex interplay between ecological adaptation, host plant specialization, and speciation dynamics in phytophagous insects, emphasizing the importance of conservation efforts to preserve *G. borelii* populations and their habitats.

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1. Introduction

Lepidoptera represents the greatest diversification of herbivorous insects, including many species of borers, leafminers, gall-formers, and inquilines [1]. Endophagy arose early in the evolution of Lepidoptera species and may have promoted their later dispersal [1,2]. The evolutionary history and ecological strategies of Lepidoptera highlight the importance of understanding their diverse roles within ecosystems and their ability to adapt to various environmental conditions.

The macroevolutionary patterns driving this diversification, alongside the roles of chemical ecology and natural selection on populations within and between different community types, have been extensively explored [3].

The diversification pattern in Lepidoptera and other insects has often been explained by host plant specialization [4–6]. Ecological adaptation and specialization encompass various factors such as competition, predation, parasitism, and habitat adaptability, all intricately tied to resource distribution and abundance.

An exemplary instance illustrating such ultra-specialization within isolated populations, where diversification is driven by ecological adaptation, is observed in *Gortyna borelii* Pierret, 1837. This species serves as a compelling subject for morphological and morphometric studies. With its geographically isolated populations and adaptation to different host plants within the *Peucedanum* genus, this species presents as an intriguing subject for further morphological and morphometric investigations. Such studies hold significant potential for illuminating the early stages of intraspecific diversification and incipient speciation.

The fisher’s estuarian moth, *Gortyna borelii*, (Figure 1A,B) is a Noctuidae (Tribus Apameini) protected in the EU (Habitats Directive 92/43/EEC, Appendices II and IV), and its population is currently declining in Europe. In the Red List of Romania, *G. borelii* has been assessed as NT at the national level and VU in some regions [7].

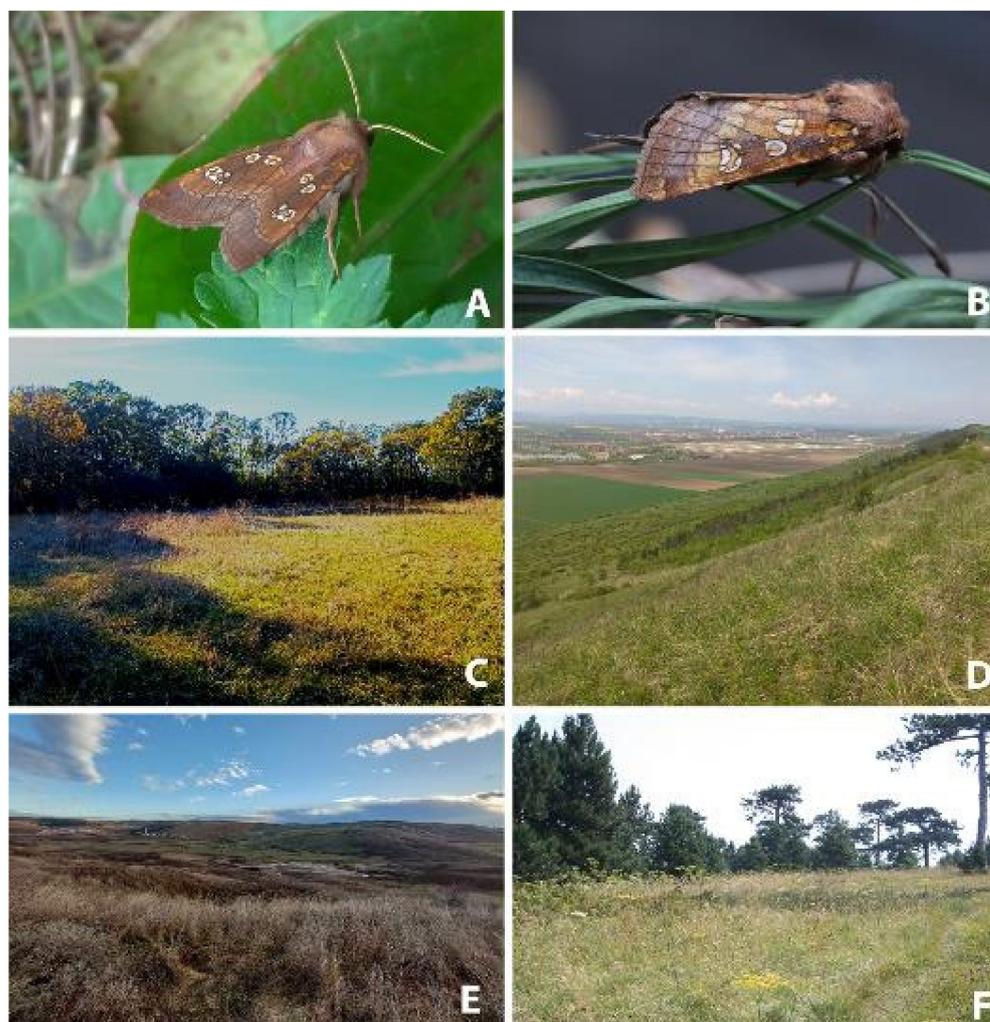


Figure 1. (A) *Gortyna borelii* from Vișoara; (B) *Gortyna borelii* from newly discovered site near Aphida; (C) the species’ habitat in Cefa; (D) the species’ habitat in Vișoara; (E) the species’ habitat in Apahida; (F) the species’ habitat in the Domogled Mountain.

The species is found in several smaller, more or less isolated areas in Spain, France, Great Britain, Germany, Italy, Slovenia, Croatia, Serbia, Hungary, Romania, Bulgaria, Ukraine, and Russia (north of the Caucasus) [8–10].

The biology and living conditions of *G. borelii* have been described more or less accurately in several publications [8,10–25]. *G. borelii* is considered oligophagous on *Peucedanum* sp. [8,10], but it is recorded as locally monophagous [22].

Since molecular data indicate an approximately 29-million-year-old origin for the Apameini tribe and an evolution correlated with the massive development of the *Poaceae* family [26], it can be assumed that endophagous species diverged from this group through adaptive radiation more than 25 million years ago.

Oviposition usually takes place on dried grasses, between the stem and the leaf that is close to it [17,24,27]. The eggs, which are flat in shape, are laid in rows resembling strings, with the female employing her outstretched ovipositor for distribution [17,24,25]. After hatching, the newly emerged caterpillars must traverse several meters to reach their food source [17,24,25]. The preimaginal stages and biology of the species were first comprehensively documented by König [12,13] in southwest Romania.

The selection of oviposition sites and the subsequent development of larvae on various host plants play pivotal roles in determining the survival rates of *G. borelii* [28–30]. These factors greatly influence the species' ability to thrive and reproduce successfully in different ecological contexts.

In Lepidoptera, the transition to endophagy, internal feeding, and potentially the exploitation of unoccupied feeding niches likely played a crucial role in the success of early taxa [31]. Endophagous species have been shown to access superior food sources through internal feeding [32–34]. Additionally, residing within plant tissues may confer other advantages, such as protection from pathogens and predators, although this hypothesis is sometimes debated [35]. Nevertheless, endophagous insects enjoy several benefits, including reduced competition, protection against natural enemies [36,37], decreased risk of desiccation due to a microenvironment with physiological advantages, and access to a higher quality diet [38]. These factors collectively contribute to the ecological success and evolutionary adaptability of endophagous Lepidoptera species.

Adaptability to host plants stands out as one of the most influential evolutionary forces driving ecological speciation in phytophagous insects [39,40]. Recent advancements have led to the identification of adaptive insect genes potentially responsible for host plant adaptation [41–43]. These genes encode various proteins, including chemosensory proteins for plant detection, oral secretion proteins to counter plant defenses, digestive enzymes for plant molecule breakdown, and detoxification proteins to counteract plant secondary metabolites [42]. Notably, these genes often exhibit accelerated adaptive evolutionary rates in phytophagous insects [44,45]. Prior studies have also demonstrated speciation processes with gene flow driven by ecologically divergent selection associated with the use of new host plants [41,46,47]. For instance, genomic differentiation has been observed between the maize strain and the rice strain in *Spodoptera frugiperda* (Noctuidae) [48]. These findings underscore the complex interplay between ecological adaptation, host plant specialization, and speciation dynamics in phytophagous insects.

The process of allopatric speciation, in which species split into different strains that become reproductively isolated and evolutionarily independent, is relatively well known and documented [49,50]. Host specialization is a well-documented process that leads to intraspecific diversity, sympatric isolation, and speciation, especially in phytophagous insects [51–58].

The evolution of host specificity in Lepidoptera species is probably strongly influenced by plant volatile organic matter [4,59].

In evolutionary terms, the first endophagous insects probably had selective advantages, as they were less likely to be killed by predators, parasitoids, and pathogens, which may have favored the evolution of endophagy [60,61]. Endophagous insects avoid ingesting plant defense chemicals and/or structures, which are usually concentrated in the cuticle

and epidermis [62]. Evading plant defenses and feeding on the most nutrient-rich plant parts resulted in a higher feeding efficiency and performance of endophages compared to ectophages [34,35]. Conquering new foraging niches and food resources in a limited foraging space led to better nutrition. Insects are able to manipulate plants to concentrate nutrients and reduce plant defenses in their food source, leading to higher insect performances [34,63]

In many parts of Europe, *G. borelii* faces significant threats and is classified as endangered or threatened with extinction. Regionally, it is not uncommon for populations to become extinct or lost entirely, rendering it one of the most endangered noctuid species in Europe. This precarious status underscores the urgent need for conservation efforts to safeguard the species and its habitats.

The primary threat to *G. borelii* is the decline of its food source, largely attributed to habitat destruction. Many of the sites in the Banat region that were documented by F. König to the 1970s have been lost to human intervention, particularly through desiccation efforts. As a result, the remaining populations are dwindling in size and becoming increasingly isolated, exacerbating the species' vulnerability to extinction.

In the current study, our objective is to investigate the morphometric variations among individuals of *G. borelii* originating from populations that utilize different *Peucedanum* species as host plants. We aim to highlight the evolutionary significance of the correlation between various *Peucedanum* species and the distribution patterns of *G. borelii* populations. Additionally, we emphasize the discovery of a new population of *G. borelii*, which holds considerable importance for the species' conservation efforts in Romania. Through our research, we seek to contribute valuable insights into the ecological and evolutionary dynamics of this endangered noctuid species.

2. Materials and Methods

2.1. Habitat Description

In Romania, *G. borelii* inhabits three distinct habitat types. The first and most widespread habitat consists of alluvial river plains, where the food plant *Peucedanum officinale* thrives in a range of conditions, from wet to dry environments occasionally subject to flooding. These habitats encompass meadows and tall forb communities, particularly during the spring season. This habitat type corresponds to populations found in southwest, west, and northwest Romania, including the historical provinces of Banat, Crisana, and Satu Mare (Figure 1C).

Another habitat where *G. borelii* is found is on dry and semi-dry slopes within the Transylvanian hills. Here, the species has adapted to utilize *Peucedanum ruthenicum* (syn. *tauricum*) as its host plant. These slopes are characterized by xerophilous fringes, which are located on steep dry slopes and abandoned vine terraces, forming what is commonly referred to as a "steppe heath" habitat. The plant communities in this habitat type include *Pruno spinosae-Crataegetum* and *Prunetum tenellae*, with characteristic species such as *Prunus spinosa*, *Crataegus monogyna*, and *Prunus tenella* (*Amygdalus nana*). This habitat typically experiences an average annual rainfall of less than 500 mm/year. The specific area corresponding to this habitat type is Viisoara, designated as the Natura 2000 site ROSCI0040 (Figure 1D).

The third habitat type, which unfortunately remains relatively understudied, is characterized by rupicolous grasslands situated on the limestone plateau of the Domogled Mountain in Băile Herculane at altitudes ranging from 700 to 1000 m (Figure 1F). This habitat features a dry, rocky terrain with a sub-Mediterranean climate. The caterpillar host plant in this environment can only be *P. longifolium* [13,18], as *P. officinale*, the common host plant in other habitats, is absent in this area. A further exploration of this habitat type could yield valuable insights into the ecological preferences and adaptations of *G. borelii* populations.

The spots identified in eastern and southeastern Romania with records of *G. borelii* by Baranyi et al. [9] are incorrect. Contrary to those claims, *G. borelii* has never been reported in this particular region of the country [7,64]. Clarification regarding the accuracies of

distribution records is crucial for maintaining the integrity of scientific knowledge regarding the species' range.

2.2. Plant Measurement

We conducted measurements of *Peucedanum* stem thicknesses in three distinct locations—Apahida, Viişoara, and Cefa (Crişana)—where the presence of *G. borelii* is documented (Figure 1C–E). To determine the average thickness of *Peucedanum* stems, measurements were taken 5 cm above the ground level using a caliper. A total of 50 plants were measured at each location. The mean values were calculated using the ANOVA test to analyze the data and assess potential variations in the stem thickness among the different locations.

2.3. Distribution Analysis of *G. borelii* Populations Correlated with the *Peucedanum* Species

Following the same methodology and using information from [9,10], we delimited the remaining *G. borelii* populations in Europe based on the different *Peucedanum* species on which they live.

We analysed the distribution of *G. borelii* populations in Romania correlated with the different *Peucedanum* species on which the larvae of these populations live, three specific types of habitats are highlighted.

2.4. Morphometric Analyses

The specimens of *G. borelii* that are displayed and preserved in the Rakosy and Sitar collections were photographed with a Canon EOS 70D camera using a Canon 100 mm macro lens (Figure 2).

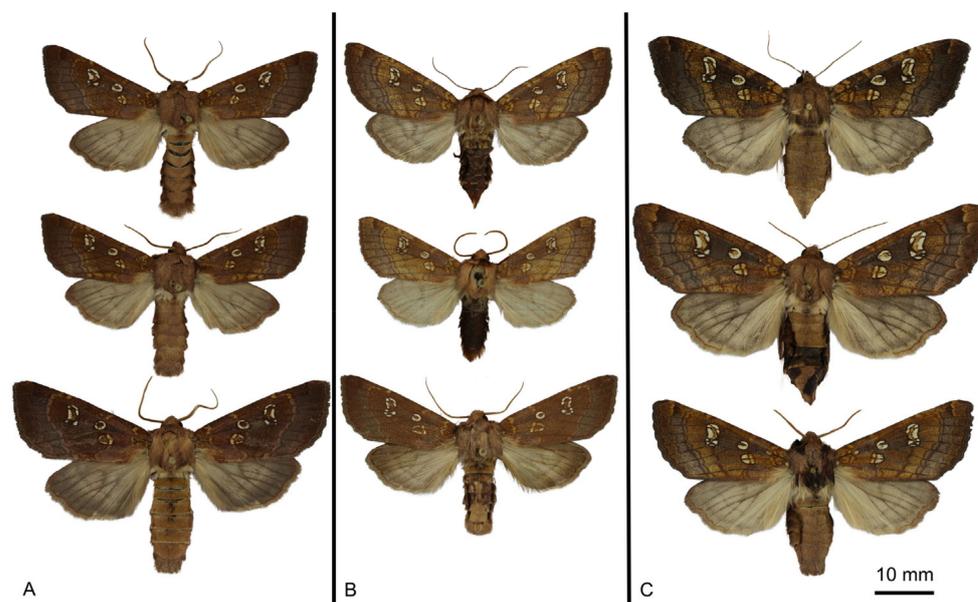


Figure 2. Specimens of *G. borelii* from study sites: (A) Apahida, (B) Viişoara, and (C) Cefa (Crişana).

The digital photographs were converted to the TPS format using the software TPSUtil, 1.4 version, which allows them to be processed in a system of coordinates. Landmarks [65] were placed with the program TPSDig2 (<http://life.bio.sunysb.edu/morph/soft-utility.html>, accessed on 5 January 2024); the placement was at the base of the wing and on the intersection of wing veins with the wing edge (Figure 3). A Principal Component Analysis was used to show a general direction of variation within a group by using the Principal Components that account for most of the variation: in this case, PC1 and PC2. The differences among populations was tested using a Canonical Variance Analysis (CVA), and the statistical differences were calculated using a Permutation Test, as our values might not follow a normal distribution, and this test can reach a conclusion without assuming

any distribution [66]. The Procrustes fit, PCA, CVA and Permutation Test were performed using the program MorphoJ (https://morphometrics.uk/MorphoJ_page.html, accessed on 5 January 2024).



Figure 3. Landmarks selected for geometric morphometrics and linear measurements.

The following abbreviations were used: AP = Apahinda, VI = Vișoara, and CR = Cefa (Banat).

3. Results

3.1. Study Sites with New Population Identified in Romania

The population in Cefa (Bihor), like the population in Banat, uses *P. officinale* as a host plant. The species' habitat is located in a clearing in the northern part of the Rădvani forest. The habitat is a flat meadow surrounded by an oak forest, where *P. officinale* plants abound. The Rădvani forest is part of the Cefa Natural Park and covers an area of approximately 3 hectares. This forest is a wetland area of great importance for birdlife, providing feeding and nesting conditions for a significant number of bird species that are protected at the European level (Figure 1C).

The population of Vișoara, whose caterpillars live on *P. ruthenicum* (syn. *tauricum*), is located in a protected area ("The Hill of Butterflies") that has been integrated into the Natura 2000 site "Coasta Lunii" (ROSCI0040). The steep dry slopes and the host plant are endangered by the former afforestation with Scots pine (*Pinus silvestris*) and common ash (*Frasinus excelsior*). The mild level of sheep grazing that sometimes takes place here does not actually do any harm as long as the sheep are not driven out from October to May (Figure 1D).

The newly discovered site next to Cluj is located at the edge of a former saline lake, not far from Apahida. On the northern slope of the hill, there is a strong population of *P. officinale*. In the valley area, there is a salt steppe with *Limonium gmelinii*, *Aster tripolium*, and other halobiont or halotolerant plant species. From May to August, the noctuid *Discestra dianthi hungarica* Wagner, 1930 flies here in large numbers (Figure 1E).

3.2. Host Plant Analyses

The average thickness of the host plant depending on the location is presented in Table 1.

Table 1. The average thickness of the host plant depending on the location (ANOVA test, $p < 0.0001$).

| | Min. | Median | Max. | Average |
|----------|------|--------|------|---------|
| Apahida | 5 | 10 | 17 | 10.23 |
| Viisoara | 2.5 | 3.75 | 13 | 4.28 |
| Cefa | 6 | 9 | 14 | 9.33 |

3.3. Distribution Analysis of *G. borelii* Populations Correlated with the *Peucedanum* Species

We delimited the *G. borelii* populations in Europe based on the different *Peucedanum* species on which they live (Figure 4A). We have thus obtained an interesting geographic pattern by which the trophic forms of *G. borelii* are also differentiated geographically. Thus, the populations in central France feed on *Peucedanum gallicum*; those in northeastern Spain, southern/eastern France, and northern Italy on *P. officinale*; and those in Corsica on *P. paniculatum*. The populations in the United Kingdom and Germany feed on *P. officinale*, as well as in Hungary, northeastern Croatia, northern Serbia, southwestern, western, and northwestern Romania, Poland, and Ukraine. We do not know the hostplant from the records for Bulgaria, Crimea, and Russia.

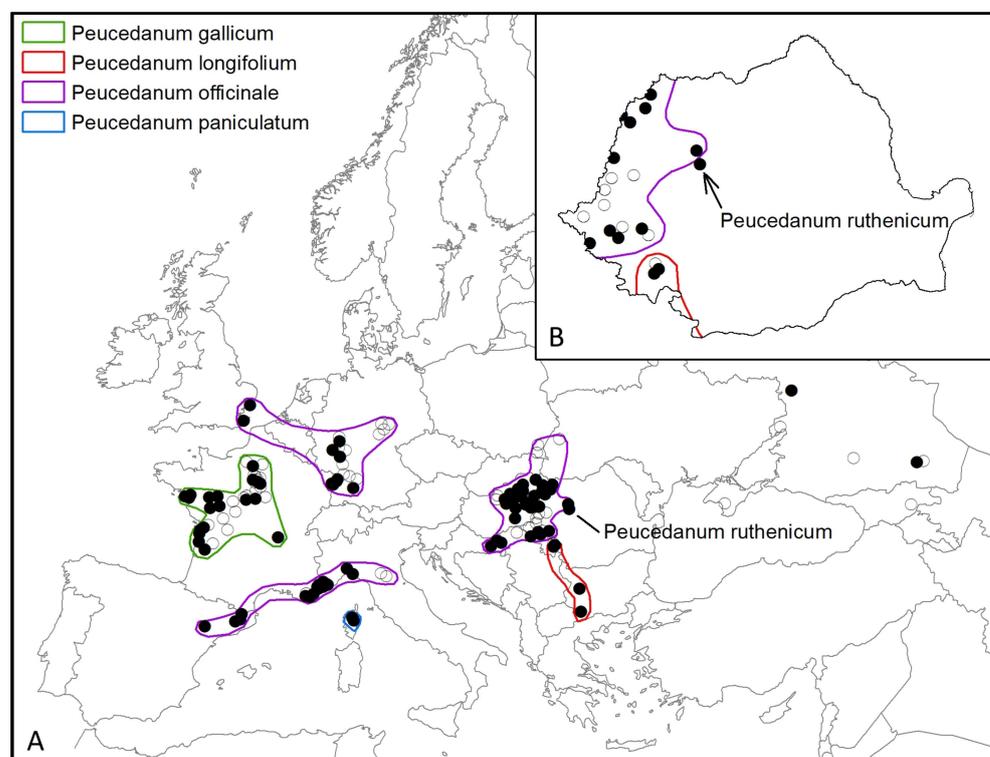


Figure 4. (A) Distribution of *Gortyna borelii* in Europe (adapted from [10,67], modified and corrected), indicating *Peucedanum* species specific to the larvae in various geographical regions. Circles represent records prior to 1980, while black dots represent records after 1980; (B) records of *Gortyna borelii* from Romania are provided, along with indications of *Peucedanum* species on which its larvae feed in different geographical areas.

Distribution Analysis of *G. borelii* Populations in Romania Correlated with the Different *Peucedanum* Species

The analysis of the distribution of *G. borelii* populations in Romania correlated with the different species of *Peucedanum* reveals three particular situations, which highlight three specific types of habitats (Figure 4B):

- The habitat for *G. borelii* whose larvae feed on *P. officinale* is characterized by clay loam soils, which are often slightly salty, wet, or even very wet in the spring and dry

in the summer. This type of habitat corresponds to the populations in the west and north-west of the country, also extending into Hungary. Here, we also include the Transylvanian habitat near Apahida.

- The much drier, moisture-deficient habitat on the foothills near Campia Turzii (Vișoara) is where the *G. borelii* population lives on *P. ruthenicum* (syn. *tauricum*). Individuals of this population are much smaller in size compared to individuals of populations feeding on *P. officinale*.
- The calcareous habitat on Mount Domogled (Băile Herculane) is where the population of *G. borelii* feeds on *P. longifolium*. Although *P. rochelianum* is also present on Mount Domogled, we have no information confirming its use by *G. borelii* larvae.

3.4. Morphometric Analysis

A total of 87 specimens of *G. borelii* were analyzed, for which the forewings were measured. Both the left wing and the right wing were measured. Damaged specimens that did not allow for the placement of landmarks were removed. This resulted in a total of 166 valid measurements.

By using the linear measurements of the wings, we could calculate the average length and width of the wings (Table 2).

Table 2. Mean wing length and width for all three populations.

| Location | Average Wing Length | Average Wing Width |
|----------|---------------------|--------------------|
| Apahida | 24.03958333 | 12.66208333 |
| Vișoara | 20.70883721 | 10.75348837 |
| Cefa | 24.90826923 | 13.27403846 |

For the geometric morphometrics analysis, we used the Procrustes fit, which gave us the mean point of each landmark and showed the overall spread of the landmarks from each specimen (Figure 5) Next, we used a Principal Component Analysis (PCA) to determine the general direction of variation using the PCs that cumulatively covered most of the variance (Table 3) (Figures 6–8).

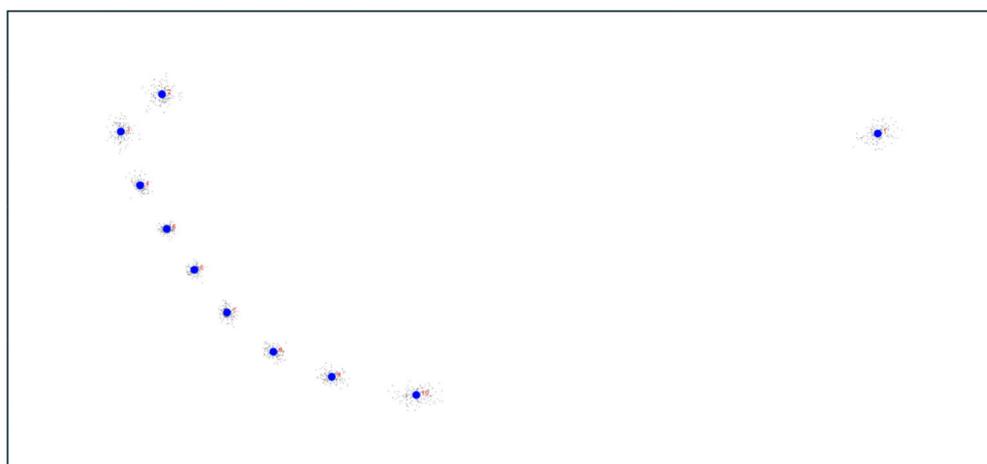


Figure 5. Graphic representation of Procrustes fit results.

Table 3. Variance covered using Principal Component 1 and Principal Component 2.

| PC | % Variance | Cumulative % |
|----|------------|--------------|
| 1 | 44.355 | 44.355 |
| 2 | 19.81 | 64.165 |

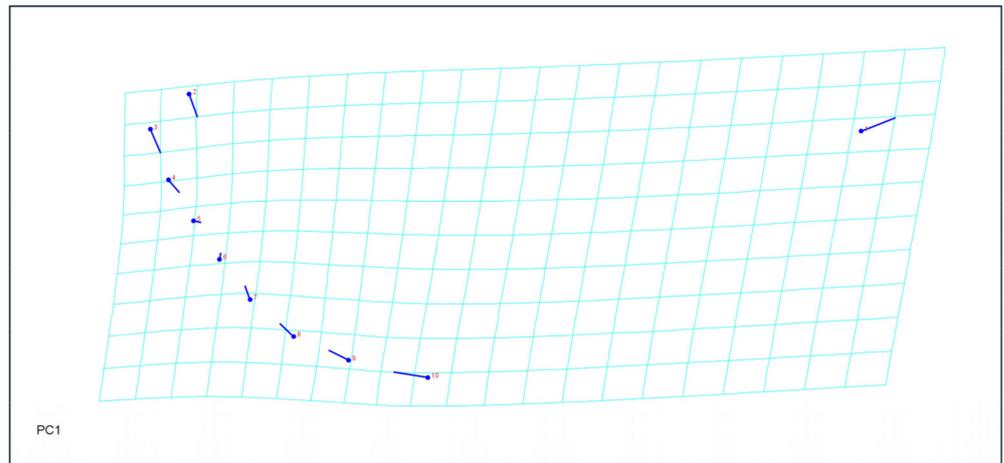


Figure 6. Graphic representation of Principal Component 1 for each landmark.

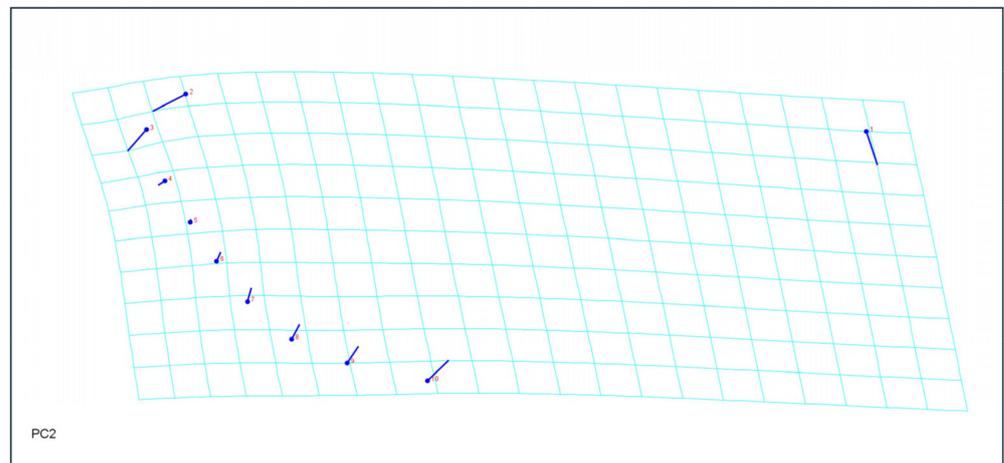


Figure 7. Graphic representation of Principal Component 2 for each landmark.

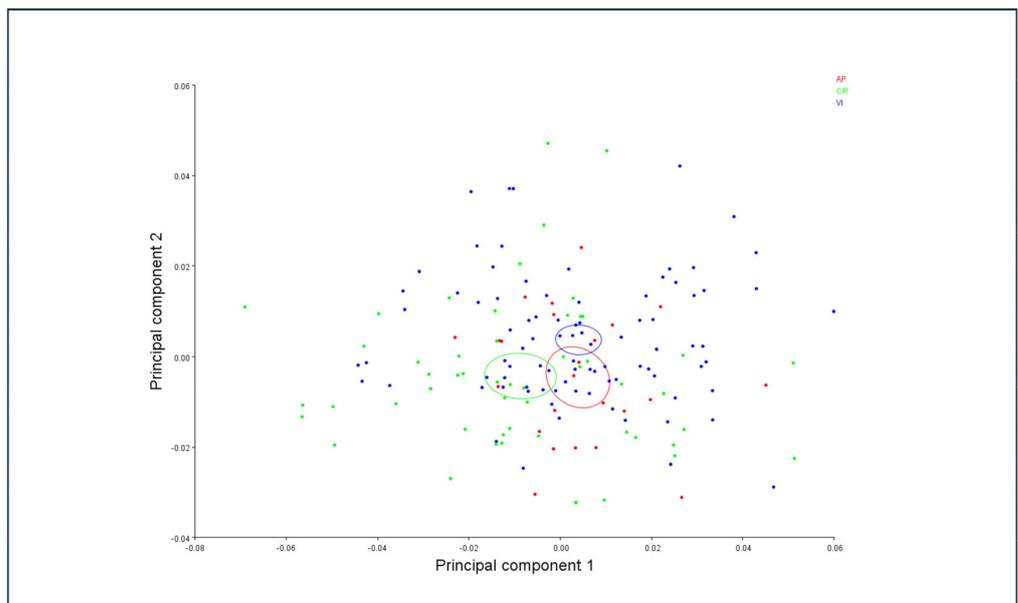


Figure 8. PCA1 and PC2 for all individuals in the study, with Confidence Ellipses for means at a 90% probability. Red-Apahida, green-Cefa, and blue-Viișoara.

We followed with a permutation test, using 10,000 permutation rounds for Procrustes distances among groups; all results were statistically significant (Table 4). Finally, we performed a Canonical Variance Analysis to illustrate the shape differences between the populations (Figure 9).

Table 4. *p*-values from permutation tests.

| | AP | CR |
|----|--------|--------|
| CR | 0.0266 | |
| VI | 0.0158 | 0.0004 |

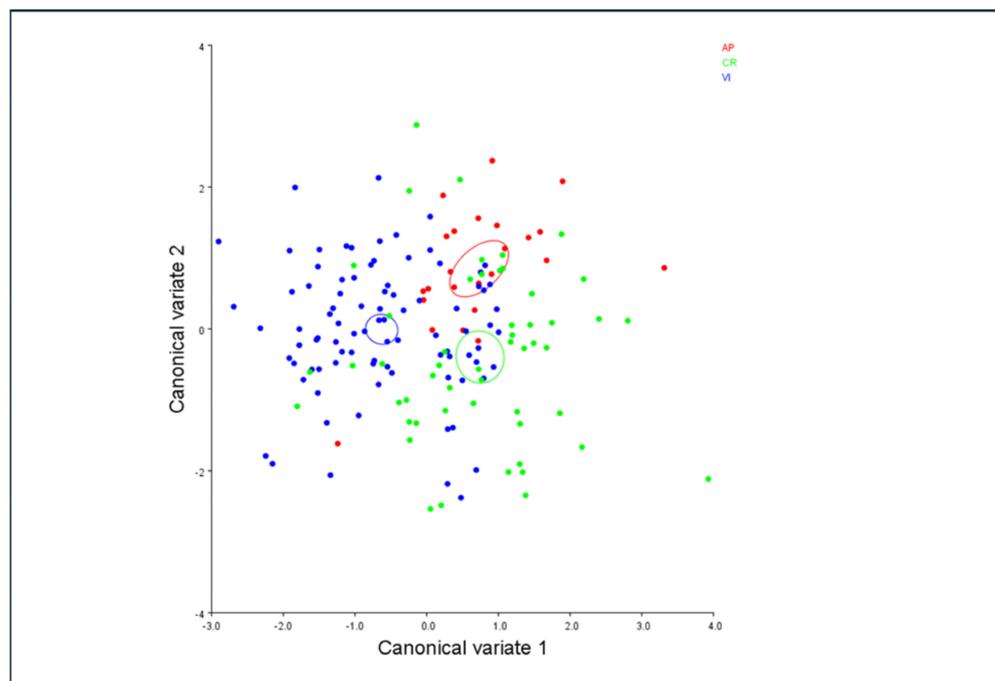


Figure 9. Canonical Variance Analysis for all individuals in the analysis, with Confidence Ellipses for means at a 90% probability. Red-Apahida, green-Cefa, and blue-Viișoara.

4. Discussion

4.1. Correlation between the Different Species of *Peucedanum* and the Distribution of *G. borelii* Populations, with Implications in Intraspecific Diversification

The diversification of the phytophagous insects' host plants is closely correlated with intraspecific diversity. Thus, adaptation to new plant species used as host plants in the larval stage determines the specialized relationships between partners of different sexes within the species. Consequently, there is a reduction in the gene flow, leading to intraspecific diversification correlated with the host plant species [68–71].

This can lead to speculation about the tendency for reproductive isolation. Reproductive isolation through reduced gene flow, together with geographic isolation, leads to the emergence of adaptive radiation, characterized by the diversification of species through the transition from one host plant to another. This is a well-known and extensively documented speciation process, particularly among phytophagous insects [51–53,71–73].

Furthermore, genomic differentiation occurs early in the intraspecific diversification process and may even expedite this process [74]. The situation of *G. borelii* populations may be analogous to that of the butterflies *Zerynthia polyxena* and *Z. cassandra*, which feed on different species of *Aristolochia* [28,75].

At the European level, specificity for a particular species of *Peucedanum* is observed depending on the geographic region. For instance, *G. borelii* populations in central and

northern France utilize *P. gallicum* as their host plant, forming a distinct cluster. Populations in Corsica form a separate group and use *P. paniculatum* as their host plant (Figure 4A).

The populations utilizing *P. officinale* as their host plant group into three distinct clusters: populations from the United Kingdom form one cluster together with those from Germany, and a second cluster is formed by populations from northwestern Spain, southern France, and northern Italy. The populations from central and western Transylvania (Romania) and the Pannonian Plain (Hungary) form the third cluster.

The Bulgarian populations, alongside those from southwestern Romania, utilize *P. longifolium* as their host plant. This species is adapted to calcareous soils with low humidity.

A third species of *Peucedanum* used as a host plant by *G. borelii* in Romania is *P. ruthenicum*. This third species is also adapted to well-drained, dry habitats, on clayey–sandy soil. Due to their ecological preferences, the sizes of *P. ruthenicum* plants are evidently smaller than those of *P. officinale* (Table 1).

G. borelii populations adapted to the three *Peucedanum* species exhibit clear geographic separation and isolation in Romania (Figure 4B). Despite the relatively short distance of approximately 35 km between the populations of Apahida and Viișoara, the anthropogenic fragmentation of the landscape over the past 400–500 years has hindered genetic exchange between these trophically differentiated populations. As a result, under the present conditions, it is unlikely that these populations can interbreed or exchange genetic information.

The incipient intraspecific diversification through host races has been documented and demonstrated in Lepidoptera species through both classical and recent studies [50,72,76,77]. The notion that adaptation to the host plant can play a decisive and repeatable role in the early stages of speciation was demonstrated by [39] using stick insects. Host-specific differentiation may lead to divergence in the adaptation to complex morphological and behavioral traits.

4.2. Morphological and Morphometric Differences in Relation to the Host Plant

The use of geometric and traditional morphometric measurements has proven successful in many studies of wing shape variation among Lepidoptera species over the years [78–84], and these methods were also applied in our study.

The morphological and morphometric analyses of the wing dimensions and shape in *G. borelii* show significant differences among the three populations of *G. borelii* analyzed (Table 2) (Figures 6–8).

A cluster analysis of the morphological distances revealed that the wing shape varies statistically significantly within populations feeding on different *Peucedanum* species. The visualization of the canonical variate analysis scatterplot did not demonstrate complete separation among plant species for the *G. borelii* populations. However, the canonical variable explained 90% of the total variance.

These differences are strongly influenced by the host plant (*P. tauricum*) available in Viișoara. The reduced dimensions and significantly smaller stem thickness in *P. tauricum* compared to *P. officinale* (Table 1) have constrained the population of *G. borelii* to adapt by significantly reducing their wingspan. The size differences between the two plant species are closely correlated with the environmental conditions, ecological processes, and selective pressures [85].

The 400–500 years of isolation of the population from Viișoara are also reflected in the modifications observed in the wing shape, as evidenced by the permutation tests for the Procrustes and illustrated through Canonical Variance Analysis (Figure 9).

It remains to be seen whether genetic analyses for the three ecological forms of *G. borelii*, adapted to three different *Peucedanum* species, will reveal incipient but clear intraspecific diversification, and subsequently, incipient speciation processes.

The evidence of these initial phases of intraspecific differentiation and incipient speciation holds significant importance, offering the prospect of deeper exploration using molecular analyses. Publishing these detailed and valuable observations is essential for future studies.

4.3. The Newly Discovered Population of *G. borelii* and Its Importance for the Conservation of the Species

The newly discovered population of *G. borelii* from Apahida is of significant importance for the conservation of the species in Romania (Figure 1E). The hill with *P. officinale* and the salt steppe belong to the Natura 2000 site Suatu–Cojocna–Crairât (ROSCI0238) and should therefore be protected. *G. borelii* is not included in the standard list of this Natura 2000 site [86]. Therefore, there are no specific protection measures in the site management plan. The grassland is partly used as a meadow and partly as a pasture for sheep grazing. Agricultural land is expanding year after year to the detriment of *P. officinale* areas. No *P. officinale* suitable for the caterpillars was found in the pasture. The small meadows are mown once a year in July. A second cut takes place irregularly at the end of August–beginning of September. Uneven areas are left unmown, which favors the preservation of the caterpillar host plant, and thus, the moth.

The conservation measures required to preserve this newfound population include the following:

To mitigate the threats faced by *G. borelii* and its habitat, several conservation measures can be implemented. One strategy involves demarcating areas with *P. officinale* and imposing restrictions on certain agricultural activities, such as grazing, which can result in the partial or complete destruction of these plants. Although not directly consumed by animals, grazing can still negatively impact the habitat through the trampling of plants. Additionally, findings from mowing experiments, such as those conducted by [22], suggest that cutting annually in either August or November can detrimentally affect the moth abundance.

Raising awareness within the local community is another crucial aspect of species conservation. Educating stakeholders about the importance of preserving *G. borelii* and its habitat can lead to greater support for conservation efforts and encourage responsible land management practices.

Furthermore, investigating the impacts of common agricultural practices in Romania, such as cleaning meadows by burning, on *Peucedanum* plants is essential. While it is possible that the endogenous life of *G. borelii* larvae provides some protection against fire, further research is needed to fully understand this aspect and to develop appropriate management strategies that balance conservation goals with agricultural needs.

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