Diversity and distribution of genus *Amegilla* Friese, 1897 in Bosnia and Herzegovina (Hymenoptera: Apoidea)

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Abstract

In Bosnia and Herzegovina, the genus *Amegilla* Friese, 1897 is represented by four species. The known diversity of species of the genus *Amegilla* in Bosnia and Herzegovina was compared with current data on the diversity of bees in the Balkan Peninsula and Europe as a whole. Through extensive field research carried out in Bosnia and Herzegovina, the presence of the following *Amegilla* species was established: *Amegilla albigena* (Lepeletier, 1841), *Amegilla garrula* (Rossi, 1790), and *Amegilla quadrifasciata* (de Villers, 1789). Additionally, the species *Amegilla magnilabris* (Fedtschenko, 1875) was documented based on specimens stored in the Zoological Collection of the National Museum in Bosnia and Herzegovina. The *Amegilla* species are distributed in the Mediterranean and Pannonian regions. It's significant to mention that the distribution of *Amegilla* species in Bosnia and Herzegovina appears to be influenced by specific climatic and geographic factors. These species tend to be absent in the Dinaric region characterized by a continental climate, suggesting a preference for other ecological niches. Analyzing the distribution data further reveals the thermophilic nature of *Amegilla* species, primarily favoring open-type habitats. The research results highlight the significance of certain climatic variables in shaping their habitat suitability. For instance, the variable Bio 9, representing the mean temperature of the quarter with the least rainfall (the driest period), significantly influences the suitability of the habitat for *Amegilla albigena* (38.0%) and *Amegilla quadrifasciata* (16.1%).

Meanwhile, for *Amegilla garrula*, the variable Bio 1, representing the mean annual temperature, plays a pivotal role, accounting for 36.2% of its habitat suitability. These findings underscore the importance of understanding the intricate relationships between climatic factors and species distribution, shedding light on the ecological intricacies of *Amegilla* species in Bosnia and Herzegovina.

1. **Introduction**

The genus *Amegilla* Friese, 1897 belongs to the tribe Anthophorini, a group within the family Apidae that encompasses a vast diversity of bee species, totaling over 750 worldwide. Within this extensive genus, *Amegilla* comprises approximately 260 species distributed across various regions globally, with 36 of these species found in the West-Palaearctic region. *Amegilla* species, like their fellow Anthophorini members, are known as "digger bees" due to their distinctive nesting behavior, which involves excavating simple nests in dry ground. They are solitary bees, meaning they do not form colonies, and they are particularly well adapted to arid or sub-arid ecosystems, including matorrals, steppes, sub-deserts, and deserts. Only a small number of *Amegilla* species venture north of the 45th parallel where they are restricted to thermophilic habitats (Brooks, 1988).

In terms of their foraging habits, *Amegilla* bees primarily feed on flowers with long corollae, such as those from the Boraginaceae, Lamiaceae, Leguminosae, Scrophulariaceae, and Compositae families. They are also known for their impressive flying abilities, which enable them to move at high speeds. This agility makes them efficient pollinators, and it's important to note that their abundance and distribution may sometimes be underestimated due to their quick and agile nature. Due to their agility, their abundance and distribution may be underestimated. In Europe, the genus *Amegilla* is represented by 10 species, of which seven species are recorded in the Balkan Peninsula (Rasmont, 2014). In the bee fauna of Greece, the genus *Amegilla* is represented with a total of seven distinct species recorded. As we move northward, however, the number of *Amegilla* species gradually declines. In the neighboring faunas of Serbia and Croatia, the genus *Amegilla* is represented by five species each, indicating a slightly

lower diversity compared to Greece. Further to the west in Bosnia and Herzegovina, four species of *Amegilla* have been recorded, while in Slovenia, three species have been documented.

Within the western Balkan Peninsula, the genus *Amegilla* is notably represented by five species, all of which have been included in the bee checklists of Croatia (as recorded by Vogrin in 1918), Slovenia (as documented by Gogala in 2023), and Serbia (as noted by Mudri-Stojnić in 2021). These records serve as a valuable resource for understanding the distribution and diversity of *Amegilla* species in the region, contributing to our broader knowledge of bee populations and their ecological roles within these ecosystems. The primary aim of this paper is to offer a overview of the species belonging to the genus *Amegilla* found in Bosnia and Herzegovina. Additionally, the paper aims to conduct a detailed analysis of the distribution patterns of these species concerning the biogeographical regions within Bosnia and Herzegovina, as well as in neighboring countries. Data on the distribution of species of the genus *Amegilla* from western Balkan were used for ecological niche modeling. Using bioclimatic variables in raster form and the distribution of known geocoordinates of the site, a map of the predictive model was created to predict the distribution of species from the genus *Amegilla* within the raster GIS environment in Bosnia and Herzegovina. In essence, this research represents a systematic effort to compile and analyze data on Amegilla species, both within Bosnia and Herzegovina and in its neighboring regions. The utilization of predictive modeling techniques, coupled with bioclimatic variables, enables a deeper understanding of the distribution dynamics of these species, contributing valuable insights to the field of biodiversity and ecological research.

2. Material and Methods

The ecological niche modeling of the genus *Amegilla*, a diverse dataset was assembled to analyze their distribution in the western Balkan region. This dataset included a total of 40 GPS points from the western Balkan area, with 27 of them representing records from Bosnia and Herzegovina. To build this dataset, a combination of literature data and various sources of distribution data were utilized. Literature review provided an overview of published information on bee diversity in the Balkan Peninsula. These sources covered several countries, including Bosnia and Herzegovina (Apfelbeck, 1896), Croatia (Vogrin, 1918), Serbia (Mudri-Stojnić, 2012, 2018, 2021, Nieto et al., 2014, Kuhlmann et al., 2020, Rafajlović and Seleši, 1958, Vogrin, 1955, 1918, Mocsáry, 1897, Markov 2017, Markov et al., 2016, Živojinović, 1950, Petrik, 1958, Lebedev, 1931), Slovenia (Gogala, 2023) and Montenegro (Apfelbeck, 1896). Additional distribution data for

Amegilla species were collected from various online platforms, including the Atlas Hymenoptera, Global Biodiversity Information Facility (GBIF), and iNaturalist. These sources contributed to creating a more diverse dataset for the western Balkan region. The additional data source for the distribution of genus *Amegilla* in Bosnia and Herzegovina was the entomological collection of the National History Museum in Bosnia and Herzegovina and the bee collection created by field research of bees in the period 2018-2023.

The analysis of the distribution of *Amegilla* species was conducted using the Maxent 3.4.4 (Steven et al. 2023), a widely used tool for ecological niche modeling. Climate data layers with a spatial resolution of 1 km² (Fick and Hijmans, 2018) were obtained from the WorldClim database and processed to ensure consistency in terms of resolution and coordinate system (WGS 84 CRS) for the entire western Balkan Peninsula. Out of the 19 available bioclimatic variables, 12 were selected for use in the modeling process, while the remaining seven were excluded due to their lack of significance or high correlation with other variables (Table 1). Discontinuity in used bioclimatic variables was tested according to Booth (2022). In the modeling process, raster layers for the western Balkans were cut "as an extent" to cover the entire pixel and aligned in the QGIS program. The pixel values for each climate variable were then assigned to each GPS point representing *Amegilla* species' presence using QGIS 3.10. The ecological niche model was developed using the maximum entropy method implemented in Maxent 3.3 (Phillips et al. 2006), and the resulting model was projected onto geographic space, creating a predictive map. Model testing was conducted through 10 repetitions using the Bootstrap method, with 40 GPS points of *Amegilla* species included in the analysis. Twenty-five percent of the points were reserved for testing the model.

Table 1. Climate variables used in ecological niche modeling

Variable acronym	Description of the bioclimatic variable	Variable acronym	Description of the bioclimatic variable
Bio1	Annual Mean Temperature	Bio10	Mean Temperature of Warmest Quarter
Bio4	Temperature Seasonality (standard deviation ×100)	Bio11	Mean Temperature of Coldest Quarter
Bio5	Max Temperature of Warmest Month	Bio12	Annual Precipitation
Bio6	Min Temperature of Coldest Month	Bio15	Precipitation Seasonality (Coefficient of Variation)
Bio7	Temperature Annual Range (BIO5-BIO6)	Bio18	Precipitation of Warmest Quarter
Bio8	Mean Temperature of Wettest Quarter	Bio19	Precipitation of Coldest Quarter
Bio9	Mean Temperature of Driest Quarter		

3. Results

As previously mentioned, both Croatia and Serbia have documented the presence of five *Amegilla* species: *Amegilla albigena*, *Amegilla garrula*, *Amegilla quadrifasciata*, *Amegilla magnilabris*, and *Amegilla salviae*. While *Amegilla salviae* is one of the five species recorded in Serbia and Croatia, it has yet to be officially documented in Bosnia and Herzegovina. However, the possibility of the presence of *Amegilla salviae* in Bosnia and Herzegovina cannot be ruled out entirely. This is particularly plausible considering the species' Mediterranean distribution and the fact that it has been observed in neighboring regions. In terms of distribution patterns, the data reveals an equal representation among the species *Amegilla albigena*, *Amegilla garrula*, and *Amegilla quadrifasciata*, each with a range of 8 to 11 records (Table 3, Figure 1.). On the other hand, *Amegilla magnilabris* has only been identified in Sarajevo, standing as the sole locality within Bosnia and Herzegovina where this species has been observed.

Table 2. Overview of species from the genus Amegilla for Bosnia and Herzegovina and neighboring countries on the Western Balkan Peninsula: BiH - Bosnia and Herzegovina, Srb - Serbia, Croatia - Croatia, Slo - Slovenia

Species	BiH	Srb	Cro	Slo
1. *Amegilla (Zebramegilla) albigena* (Lepeletier, 1841)	+	+	+	+
2. *Amegilla (Amegilla) garrula* (Rossi, 1790)	+	+	+	+
3. *Amegilla (Zebramegilla) magnilabris* (Fedtschenko, 1875)	+	+	+	
4. *Amegilla (Amegilla) quadrifasciata* (de Villers, 1789)	+	+	+	+
5. *Amegilla (Zebramegilla) salviae* (Morawitz, 1876)		+	+	

The vertical distribution profile of *Amegilla* species in Bosnia and Herzegovina shows distinctive patterns. Approximately 75% of the recorded findings of *Amegilla* species fall within the altitude range of 0 to 300 meters above sea level. However, all the findings of *Amegilla* species at altitudes exceeding 300 meters above sea level exclusively belong to the species *Amegilla garrula*. *Amegilla garrula* is known to be associated with the Mediterranean and sub-Mediterranean regions of Bosnia and Herzegovina, particularly within the altitude range of 0 to 600 meters above sea level. Importantly, during field research conducted in both the Pannonian and Dinaric climate regions of Bosnia and Herzegovina, no *Amegilla* species were recorded. However, discoveries of *Amegilla* species in the northern regions of Pannonia in neighboring Croatia, along with data from Central Europe, indicate the potential extension of their habitat further north. This, in turn, raises the possibility of their presence in the Semberia and Pannonian regions of Bosnia and Herzegovina. This anticipation is supported by the broader geographic distribution of these species, as highlighted by Rasmont, 2014.

Species belonging to the genus *Amegilla* are predominantly found in xerothermic habitats within the Mediterranean and sub-Mediterranean regions. However, in the Dinaric region of Bosnia and Herzegovina, these species have been documented in the canyon part of the Neretva River, characterized by a significant sub-Mediterranean influence and xerothermic environments. The *Amegilla* species recorded in Bosnia and Herzegovina exhibit a distribution pattern that extends into neighboring European countries such as Serbia, Croatia, and Slovenia. Interestingly, while *Amegilla salviae* and *Amegilla magnilabris* have not been recorded in Slovenia, *Amegilla albigena*, *A. magnilabris*, A. *quadrifasciata*, and *A. garrula* have all been documented in these adjacent regions. This suggests that *Amegilla* species can migrate northward, with records extending as far as Germany (Rasmont, 2014). The multiple records of *Amegilla salviae* and *A. magnilabris* in the Western Balkan region indicate that these species are primarily distributed in Mediterranean areas but are also capable of inhabiting xerothermophilic habitats within continental regions. The discovery of *Amegilla* (*Zebramegilla*) *magnilabris* in the Sarajevo area further suggests the potential presence of this species in the Dinaric region, especially within thermophilic habitats that exhibit a strong Mediterranean influence.

The distribution and habitat preferences of *Amegilla* species in Bosnia and Herzegovina and the broader Western Balkan region are characterized by a blend of Mediterranean and continental influences, underscoring the adaptability and ecological versatility of these bee species.

Table. 3. Overview of species from the genus Amegilla with localities in Bosnia and Herzegovina and the source of data, which were used for species modeling, given in format yyyymmdd, ECNHMBIH-entomological collection Natural History Museum Bosnia and Herzegovina, DD-data deficient

Name	Locality	Date	Data source
1. *Amegilla albigena*	Bijeljina	20190702	Field data
2. *Amegilla albigena*	Klek_Neum	20190702	Field data
3. *Amegilla albigena*	Mostar	20190722	Field data
4. *Amegilla albigena*	Zavala	20180714	Field data
5. *Amegilla albigena*	Herceg Novi	192107??	ECNHMBiH
6. *Amegilla garula*	Krmeci	20180617	Field data
7. *Amegilla garula*	Krmeci	20180617	Field data
8. *Amegilla garula*	Klek_Neum	20180617	Field data
9. *Amegilla garula*	Klek_Neum	20180617	Field data
10. *Amegilla garula*	Fortica	20190722	Field data
11. *Amegilla garula*	Ovčari	20200615	Field data
12. *Amegilla garula*	Zavala	20200612	Field data
13. *Amegilla garula*	Ustiprača	1882????	ECNHMBiH
14. *Amegilla magnilabris*	Sarajevo	DD	ECNHMBiH
15. *Amegilla magnilabris*	Herceg Novi	192107??	ECNHMBiH
16. *Amegilla quadrifasciata*	Krmeci	20180616	Field data
17. *Amegilla quadrifasciata*	Krmeci	20180616	Field data
18. *Amegilla quadrifasciata*	Klek_Neum	20180617	Field data
19. *Amegilla quadrifasciata*	Češljari	20200612	Field data

| 20.	*Amegilla quadrifasciata*	Dobromani	20200612	Field data
21.	*Amegilla quadrifasciata*	Batković	20210724	Field data
22.	*Amegilla quadrifasciata*	Bosanski Brod	1875????	ECNHMBiH
23.	*Amegilla quadrifasciata*	Ustiprača	1882????	ECNHMBiH
24.	*Amegilla quadrifasciata*	Jablanica	1882????	ECNHMBiH
25.	*Amegilla magnilabris*	Sarajevo	DD	ECNHMBiH
26.	*Amegilla quadrifasciata*	Bosanski Brod	1875/ inv. Num.	ECNHMBiH
27.	*Amegilla garrula*	Ustiprača	1882/46	ECNHMBiH
28.	*Amegilla sp?*	Ustiprača	1882/46	ECNHMBiH
29.	*Amegilla sp?*	Jablanica	1882/46	ECNHMBiH
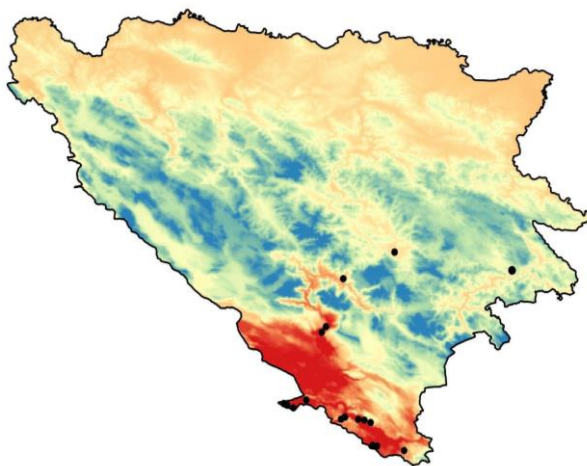
Figure 1. Distribution of finds of species from the genus Amegilla in Bosnia and Herzegovina shown by black dots on the Bio1-Annual Mean Temperature background

The predictive model depicting habitat suitability for species within the *Amegilla* genus across Bosnia and Herzegovina and the broader Western Balkan Peninsula is presented in (Figures 2-4.). This model offers a detailed resolution of 1x1 km. To gain insights into the factors shaping habitat suitability, the influence of climate variables is delineated in (Table 2.). Among these variables, two standout factors with the most significant statistical influence have been identified and highlighted for emphasis. Specifically, in the ecological niche model for *Amegilla albigena*, the variable Bio9 (Mean Temperature of Driest Quarter) exhibited the most pronounced impact on habitat suitability. For *Amegilla garrula*, the Bio1 (Annual Mean Temperature) variable played a pivotal role in shaping its ecological niche model. Meanwhile, in the case of *Amegilla quadrifasciata*, the ecological niche model was primarily influenced by the Bio11 (Mean Temperature of Coldest Quarter) variable (Table 2.).

Table. 2. Analysis of variable contributions with estimates of relative contribution of the environmental variables to the Maxent model Percent contribution%/Permutation importance; the model is reevaluated on the permuted data, and the resulting drop in the training AUC is normalized to percentages

	bio_1	bio_5	bio_6	bio_9	bio_10	bio_11	bio_12	
Amegilla albigena	28.4%/0		6.8%/9.8	38%/0	10.2%/37.1	12.2%/0		AUC T = 0.888 AUC P=0.5
Amegilla garula	36.2%	2.8%/9.6		0.2%	1.9%/57.8	7.7%	7.5%/25	AUC T = 0.915 AUC P=0.5
Amegilla quadrifasciata	12.3%/91.3	3.7%		16.1%	18.5%	47.5%		AUC T = 0.856 AUC P=0.5

The ecological niche model for species within the genus *Amegilla* is visually represented with a color gradient, ranging from colder to warmer colors, illustrating the suitability of different habitats. Habitats within the Mediterranean and sub-Mediterranean regions exhibit a high level of ecological suitability for *Amegilla* species. This underscores the significance of temperature-related variables in shaping the ecological niche models for these species, indicating that temperature plays a critical role in determining their potential distribution.
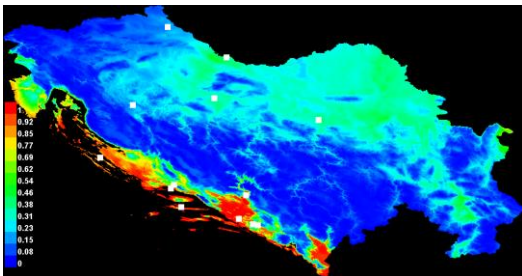

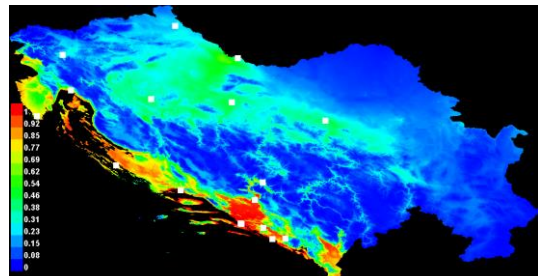Figure 2. The representation of the Maxent model for Amegilla albigena

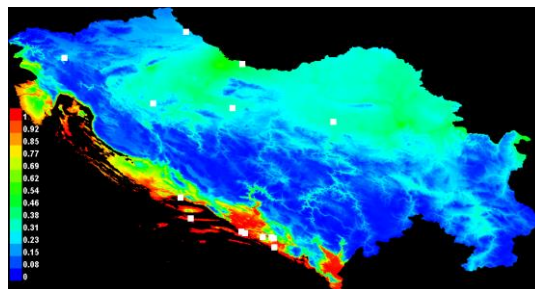Figure 3. The representation of the Maxent model for Amegilla garula

Figure 4. The representation of the Maxent model for Amegilla quadrifasciata

Discussion

Species from the genus *Amegilla* are widespread in the Mediterranean area of Herzegovina and spread from the south to the north. Climatic conditions change significantly as the altitude increases, the conditions on the horizontal profile of Bosnia and Herzegovina change and cause the absence of species in hilly, mountainous and alpine areas. *Amegilla* species pass through the canyon of the

Neretva River to Jablanica, which is one of the northernmost localities in the Dinarides in Bosnia and Herzegovina. Members of the genus are recorded in the Pannonian region where they are strongly influenced by the warm climate of the Pannonian and Peripannonian areas along the Sava and Drina rivers. The ecological niche of the species will be considered through three dimensions: climatic conditions, nutrition and nesting places. The area with a continental climate includes the temperature valence of *Amegilla* species. In the Pannonian area, the nesting site is most likely the limiting factor. In the area of the vegetation where the groundwater level and humidity are high, which is not conducive to the species that nest in the soil. Finding microhabitats with dry vertical cliffs and embankments is a limiting factor for species in the Pannonian area. In the foothills and mountainous area of the Dinarides, temperature is a limiting factor for species.

It was not possible to obtain information about the habitats where the individuals were collected from literature data and museum collections. Field data provides conclusive evidence that species predominantly reside within the Mediterranean and sub-Mediterranean regions, specifically favoring rocky terrain. However, it is noteworthy that the majority of these specimens were procured from locations characterized by pre-existing maquis vegetation and deposols. Remarkably, every locality in which these specimens were collected exhibited a common feature - the predominance of skeletal soils, accounting for a substantial 80% of the soil composition. One exception to this trend pertains to the species *Amegilla garrula*, which exhibits a distinct ecological niche within the sub-Mediterranean area. Here, it diverges from the rocky habitat preference exhibited by other species from the genus and instead favors meadow communities with a pronounced thermophilic character, comprising approximately 20% of its observed habitat range. This species primarily feeds on plant species belonging to the Lamiaceae family, including *Salvia officinalis* and *Salvia pratensis*, as well as those from the Boraginaceae family, such as *Echium vulgare* and *E. italicum*. These specific plant preferences provide valuable insights into the ecological interactions and dependencies of *Amegilla garrula* within its chosen habitat, offering a glimpse into its foraging behavior and the intricate relationships it forms with its plant hosts.

4. **Conclusions**

Field research conducted in Bosnia and Herzegovina has provided valuable insights into the diversity of bee species within the *Amegilla* genus. Specifically, three species have been definitively confirmed through field research: *Amegilla albigena*, *A. quadrifasciata*, and *A. garrula*, all of which represent significant findings for Bosnia and Herzegovina.

Furthermore, the species *Amegilla magnilabris* has been recorded, with records based on collections stored in the National History Museum of Bosnia and Herzegovina. This underscores the importance of museum collections in expanding our knowledge of the distribution of bee species.

Notably, although the species *Amegilla salviae* is known to exist in the broader region of the western Balkan peninsula, it was not conclusively confirmed during the fieldwork conducted in Bosnia and Herzegovina. This absence in the current research is interesting, given that neighboring countries have recorded the presence of this species. Therefore, it is reasonable to anticipate that future research efforts in Bosnia and Herzegovina may eventually establish the presence of *Amegilla salviae*. This expectation is supported by the fact that this species is distributed in neighboring countries such as Croatia and Serbia, suggesting that it may indeed be part of the local bee fauna but has yet to be documented in Bosnia and Herzegovina. Consequently, the continued exploration and study of bee populations in Bosnia and Herzegovina are likely to yield additional insights into the distribution and diversity of *Amegilla* species in this area.

While it's worth noting that in the Peripanonian region there are no records on the presence of species from this genus, it is reasonable to anticipate that members of the genus may potentially inhabit this area, particularly within open stony dry habitats. This expectation is based on the genus's general ecological preferences, which tend to favor such habitats. These species are predominantly distributed in Mediterranean and sub-Mediterranean regions, typically up to elevations of 600 meters above sea level. Their favored habitats include open xerothermophilic environments characterized by arid and warm open habitats.

Interestingly, modeling efforts aimed at predicting the distribution of species from this genus have shown a strong correlation with Mediterranean and thermophilic habitats, aligning with their known ecological preferences. The model also demonstrates a notably high degree of correlation with the canyon of the Neretva river in the Dinaric area, indicating that this specific locality might be particularly of value for the presence of these species. This finding underscores the significance of understanding and identifying suitable habitats for these species, as it can assist in conservation efforts and enhance our knowledge of their distribution patterns.

5. References

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