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Hierodula transcaucasica Brunner von Wattenwyl, 1878 as Austria's second mantid species: evidence of a population in Vienna

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Abstract: *Hierodula transcaucasica* Brunner von Wattenwyl, 1878 as Austria's second mantid species: evidence of a population in Vienna. This paper presents the first documented evidence of the successful establishment of *Hierodula transcaucasica* Brunner von Wattenwyl, 1878 in Austria, marking the introduction of a second mantid species. Following an initial sighting of a female in 2023, field surveys in 2024 recorded multiple individuals, exuviae, and oothecae in Ernst-Paul-Zimper-Park (1220 Vienna), with an additional record from the Augarten (1020 Vienna). These findings suggest the existence of a population for at least one location in Vienna since 2023, if not earlier. The paper also offers a comprehensive review of all known records of *Hierodula* spp. in Austria to date and provides preliminary insights into the ecological interactions of *H. transcaucasica*, such as encountered habitat, ootheca deposition sites, and prey selection.

Kurzfassung: *Hierodula transcaucasica* Brunner von Wattenwyl, 1878 als zweite Fangschreckenart Österreichs: Nachweis einer Population in Wien. Diese Arbeit präsentiert den ersten Nachweis einer erfolgreichen Etablierung von *Hierodula transcaucasica* Brunner von Wattenwyl, 1878 in Österreich und stellt damit das Vorkommen einer zweiten Fangschreckenart für das Land fest. Nachdem bereits 2023 ein Weibchen gesichtet wurde, wurden durch gezielte Suche im Jahr 2024 mehrere Individuen, Exuvien und Ootheken der Art im Ernst-Paul-Zimper-Park (1220 Wien) nachgewiesen. Zudem gab es einen weiteren Fund im Augarten (1020 Wien). Diese Belege deuten auf das Bestehen einer Population an mindestens einem Standort in Wien seit 2023 oder länger hin. Diese Arbeit bietet darüber hinaus einen umfassenden Überblick über alle bisher bekannten Nachweise von *Hierodula* spp. in Österreich und liefert erste Einblicke in die ökologischen Interaktionen von *H. transcaucasica*, wie beispielsweise das angetroffene Habitat, die Ablageorte von Ootheken und die Beutewahl.

Keywords: *Hierodula*, Mantodea, Austria, alien species, establishment

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Introduction

Ongoing climate change, often coupled with intentional or unintentional human-mediated dispersal, has enabled many species to expand their geographic ranges (Skendžić et al. 2020, Naimi et al. 2022). This is also true for the order Mantodea (Burmeister, 1838) in Europe, commonly referred to as praying mantises (Battiston et al. 2017, Anselmo et al. 2023, Pintilioaie et al. 2023).

In recent years, online citizen science platforms such as iNaturalist.org, naturgucker.de, and observation.org have emerged as effective tools for collecting data on species records and distributions (Lloyd et al. 2020, Marchante et al. 2024). Relying primarily on citizen scientists, these platforms gather photographic and audio records uploaded by their users in large databases. Many platforms use image recognition algorithms to provide preliminary taxonomic identifications, with accuracy depending heavily on the availability of correctly identified reference images (Jakuschona et al. 2022).

On iNaturalist.org, observations are verified when species-level identifications are confirmed by at least two users, and achieve a two-thirds consensus among participating identifiers. Observations passing this verification process are valuable for scientific research, as they can be incorporated into the Global Biodiversity Information Facility (GBIF) dataset, enabling comprehensive data analysis and application in research (Moulin 2020, Svenningsen & Schigel 2024).

In recent decades, the European mantid *Mantis religiosa* (Linnaeus, 1758), which is autochthonous to Central Europe, has steadily expanded its geographic range northwards (Steger et al. 2020). While this species was once restricted to particularly warm and often small-scale localities, it has now been recorded from historically unsuitable latitudes as far north as Denmark and the northern Baltic regions (Schwarz & Ehrmann 2018, Rimšaitė et al. 2022), likely aided by climate change and increased average temperatures (Steger et al. 2020). Furthermore, this range expansion is still ongoing, as demonstrated by the recent report of a subadult larva in Sweden on August 2, 2024 (iNaturalist observation, lotand 2024).

In Austria, *M. religiosa*, historically only known from climatically favourable parts in the east, ranging from Carinthia to Lower Austria (Denner & Denner 2017), has extended its range as well and is now present in six out of nine federal states, with established populations only missing from Vorarlberg, Tirol, and Salzburg (Wieser & Kleewein 2012, Denner & Denner 2017).

Other mantid species in Europe are also experiencing notable range expansions (Schwarz & Ehrmann 2018). Particularly noteworthy and well-documented are the growing ranges of four species: *Ameles spallanzania* (Rossi, 1792), *Sphodromantis viridis* (Forsskål, 1775), *Hierodula patellifera* (Audinet-Serville, 1839), and *Hierodula transcaucasica* Brunner von Wattenwyl, 1878.

The smallest of these species, *A. spallanzania*, has been spreading northwards from its native Mediterranean distribution since the early 2000s (Anselmo et al. 2023). This northward expansion is well-documented in northern Italy and South Tyrol, with an apparent acceleration in the spread since 2010 (Ballini & Wilhalm 2014, Anselmo

2022, Anselmo et al. 2023). Multiple introductions are also reported from Hungary, primarily linked to human activity, such as the transport of plants via garden centres and vehicles (Vujić & Ivković 2023). Additionally, four individuals from different locations have recently been reported from Bulgaria, most likely also accidentally introduced (Vasilev et al. 2023).

In Austria, *A. spallanzania* was first reported near Graz in 2020. Observed in a tree nursery that sources plants from Italy, an image of the specimen was uploaded to iNaturalist on October 14, 2020 (iNaturalist observation, alexanderweihs 2020). The following year, another observation was confirmed at the same location (G. Kunz, personal communication, unpublished data). Given that no further reports have been made in the meantime, it remains unclear, however, whether these two observations represent unrelated introductions or an established population, leaving the status of *A. spallanzania* in Austria undetermined.

The other three spreading mantids are larger, sturdier representatives of the order. *Sphodromantis viridis*, an African species known from Andalusia and southern Spain since the 19th century, has recently expanded its range by natural means throughout the Iberian Peninsula and, likely as a result of human-assisted introduction, to numerous Mediterranean islands and as far east as Greece (Battiston et al. 2017, Battiston et al. 2020a). In Croatia, an established introduced population is known from Dubrovnik (Martinović et al. 2022), and very recently a specimen has been reported from a village about 15 kilometres northwest of Makarska (iNaturalist observation, adamlal 2024).

Hierodula patellifera, native to tropical Asia, has established populations in Italy and southern France (Battiston et al. 2020b). On iNaturalist (2024a), a dozen individuals have also been reported from the Croatian coast since August 2022, with over half of them observed in 2024.

The first documented occurrence of *H. patellifera* in Austria was confirmed in 2023 following the introduction of a specimen in a garden centre in Carinthia (Wurmitzer et al. 2023). Since then, no further sightings of the species have been reported for the country.

For the purpose of this paper, however, the rapid range expansion of another species of the genus *Hierodula* is of particular interest. Its taxonomic status is a subject of debate, with some authors classifying the species as *Hierodula transcaucasica* (Brunner von Wattenwyl, 1878), while others refer to it as *Hierodula tenuidentata* (Saussure, 1869).

Historically, the colour of the discoidal spines on the forefemora was used to distinguish between these two species: *H. transcaucasica* was described as having entirely black discoidal spines, while those of *H. tenuidentata* were defined to be black only at the tips (Giglio-Tos 1911, 1927). However, Battiston et al. (2018) refuted this characteristic based on the high morphological variability in the Italian populations they examined. Furthermore, they found no differences between the genitalia of the black-spined male allotype specimen from the Caucasus and those of a partially black-spined individual from Italy, which was part of a population exhibiting extensive intraspecific variation

in spine coloration. This led them to support treating *H. transcaucasica* as a synonym of *H. tenuidentata*, which would be the valid name if the two taxa were to be unified. Since then, this informal synonymization has been accepted in many subsequent publications (Pintilioaie et al. 2021, Kulijer et al. 2022, Vujić & Ivković 2023).

Nevertheless, comprehensive genetic studies and detailed analyses of individuals across the species' extensive Asian distribution are still lacking. Given this state of the evidence, some researchers continue to treat the two taxa as distinct, with *H. transcaucasica* being used for the recently established European populations (van der Heyden & Schwarz 2021). A recent niche analysis using global data by De Vivo (2024) followed this approach. The analysis separated the mantid populations into three groups: (1) *H. transcaucasica* from the Caucasus region, (2) *H. tenuidentata* from Asia (ranging from eastern Uzbekistan through India to Malaysia), and (3) the European populations. The results revealed high ecological niche overlap between the alien European populations and *H. transcaucasica* from the Caucasus, suggesting even a potential natural dispersal to Europe. In contrast, the ecological niche of *H. tenuidentata* from Asia showed only limited overlap with that of the European populations.

Observational platforms such as iNaturalist and GBIF, as well as databases like Mantodea Species File Online, also maintain the distinction between the two species.

Considering the results from De Vivo (2024), the lack of sufficient genetic data, and the need for further morphological studies across the full geographic range, this paper follows the taxonomic split. With *H. transcaucasica* we refer to the populations from the Caucasus as well as to the alien European populations, while the South Asian populations are referred to as *H. tenuidentata*.

Regardless of its name, this mantid species has shown high adaptability across diverse environments, thriving in urban, peri-urban, and natural habitats throughout Europe (László et al. 2023, Gomboc et al. 2024). In recent decades, the first European records of *H. transcaucasica* outside Ukraine were reported from Greece, Italy, and the Balkans (Battiston et al. 2017, Battiston et al. 2018, Cianferoni et al. 2018, Romanovski et al. 2019, Schwarz & Ehrmann 2019). Subsequent findings confirmed established populations in these regions, and indicated further expansion across Europe, likely aided by human-mediated dispersal. Recent records now extend as far west as France and Spain (van der Heyden 2021, Moulin & Rouard 2023), and as far North as Hungary and Germany (László et al. 2023, Staniczek 2023). This suggests that *H. transcaucasica* has the potential to become a widespread and established member of the local mantid fauna in multiple European countries.

In Austria, *H. transcaucasica* has not been widely documented until now, with only a few isolated sightings reported in recent years (GBIF.org 2024). This paper presents the first documented discovery and confirmed record of a *H. transcaucasica* population in Austria, which is established in Vienna's Ernst-Paul-Zimper-Park. The park's population was discovered following initial iNaturalist observations of a female in 2023 (iNaturalist observation, danielaio 2023) and a nymphal exuviae in 2024 (iNaturalist observation, blaurack 2024). Additionally, other recent records of this species across Vienna and Austria are discussed, with a particular emphasis on a second prospective population in

Vienna, which requires further investigation. This finding extends the known range of *H. transcaucasica* further into Central Europe and raises the number of mantid species in Austria to two.

Material and methods

Identifying *Hierodula transcaucasica* in Europe

Hierodula transcaucasica has a sturdier body structure than *M. religiosa* (Battiston et al. 2010), a difference particularly pronounced in the forecoxae and forefemora. This characteristic is helpful in differentiating the two species' exuviae. Additional key distinguishing features of *H. transcaucasica* individuals include a characteristic whitish pterostigma on the forewings (Figure 1a), which is absent in *M. religiosa* (Figure 1b), and the lack of a prominent dark or dark-bordered eyespot on the inner forecoxae, a feature present in *M. religiosa* (Figure 1d). Further differences include the proportions of the pronotum and the presence of multiple dark transverse stripes on the prosternum of *H. transcaucasica* (Figure 1c). Oothecae of *H. transcaucasica* also differ greatly in shape, colour, and preferred deposition site from those of *M. religiosa* (Pintilioaie et al. 2021).

In Europe, *H. transcaucasica* can be distinguished via morphological characteristics from its most similar relatives *S. viridis* and *H. patellifera*, both of which are of comparable size and also possess the whitish pterostigma. In comparison to *S. viridis*, the difference in width between the upper and lower part of the pronotum is much less significant in *H. transcaucasica*. Additionally, in *Hierodula* purple to dark horizontal lines on the ventral part of the thorax are present (Martinovic et al. 2022, László et al. 2023).

To differentiate the two species of *Hierodula*, besides the characteristics of male terminalia and genitalia, spines on the forecoxae are relevant: In *H. transcaucasica* these are smaller and without basal discs, while *H. patellifera* has more pronounced spines with distinct yellowish basal discs (Martinovic et al. 2022, Wurmitzer et al. 2023).

Data collection and field methods

On August 18, 2024, the second author (B. Kölz) discovered a mantid exuvia in Ernst-Paul-Zimper-Park (1220 Vienna, Austria). The exuvia was photographed and uploaded to iNaturalist, where the robust forelegs and overall body structure indicated to the first author (M. Oswald), who routinely verifies reports of mantids in Austria, that it did not belong to the native *M. religiosa*. The previous year, in 2023, an adult female of *H. transcaucasica* had already been photographed on a building adjacent to Ernst-Paul-Zimper-Park (iNaturalist observation, danielaio 2023).

Based on these findings, Ernst-Paul-Zimper-Park was searched for further exuviae or living individuals on August 21, 2024. To find exuviae, a thorough examination of the park grounds, in particular the areas beneath trees, was conducted between August 21 and August 24. Daily searches for live individuals continued from August 22 to August 31. In addition, potentially suitable nearby habitats, including Friedhof Kagran, Ladinigpark, and smaller public spaces to the north and east of Ernst-Paul-Zimper-Park, were surveyed for exuviae throughout August.

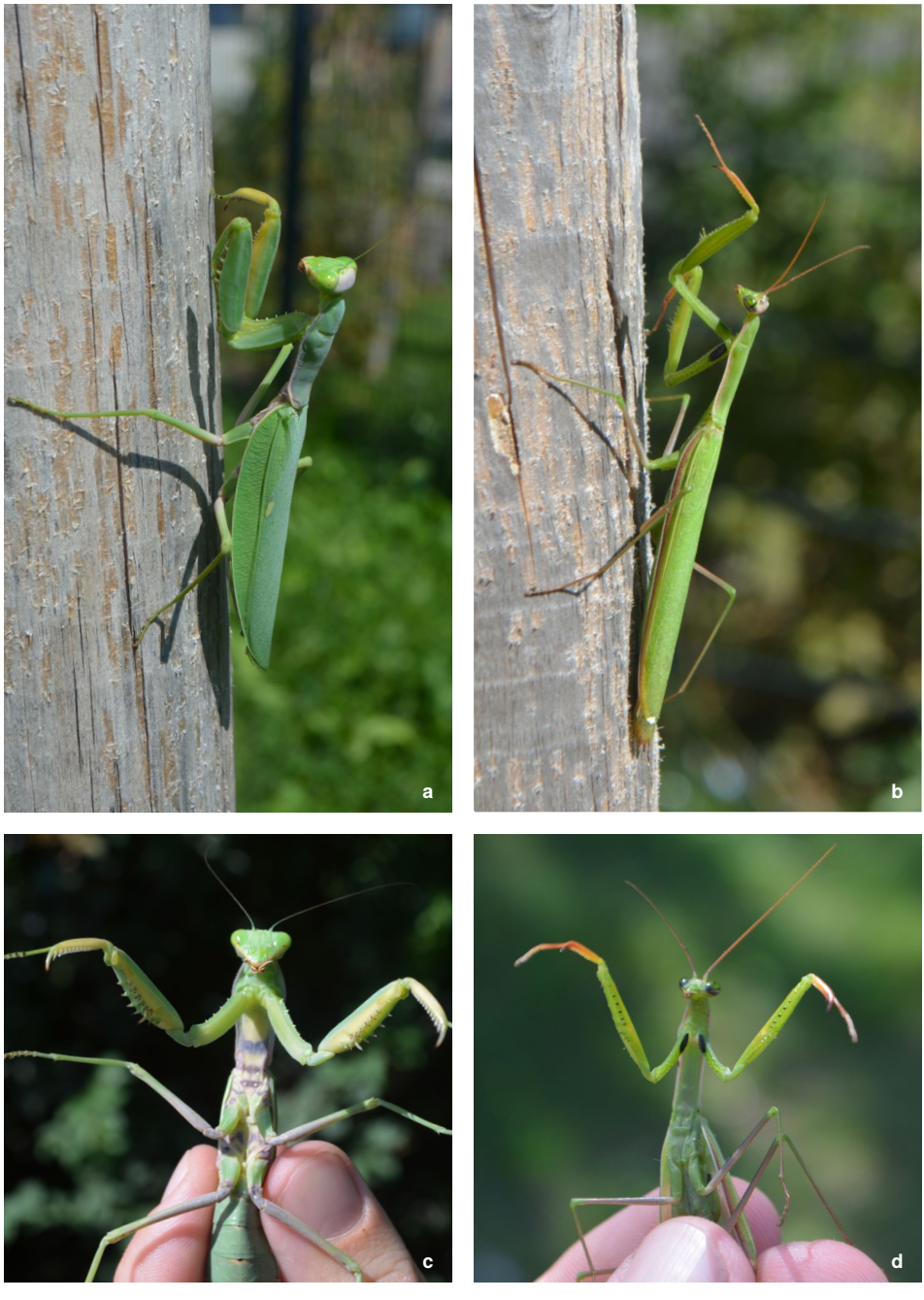

Fig. 1: Comparison of a female *Hierodula transcaucasica* (a, c) and a male *Mantis religiosa* (b, d). Key distinguishing features for these two species: *H. transcaucasica* with a whitish pterostigma on the forewings, dark horizontal stripes on the underside of the thorax, robust forecoxae and forefemora, and a broader pronotum versus *M. religiosa* lacking a visible pterostigma on the forewings, having a slender body shape, and displaying a dark or dark-bordered eyespot on the inner forecoxae. Both specimens were recorded in Ernst-Paul-Zimper-Park, 1220 Vienna. © Mario Oswald

Following observations of mating behaviour on August 30, frequent inspections of the park's trees were conducted in early September to locate oothecae. Based on the findings of Pintilioaie et al. (2021), the search strategy was adapted on September 5 to focus on the south-facing sides of smooth-barked trees, such as *Acer negundo,* and on branches between one and three meters above ground level. In subsequent weeks, routine checks of sites with previously recorded living specimens and egg cases yielded additional records.

In addition, all 'research-grade' *Hierodula* spp. records in Austria were retrieved from iNaturalist (2024b) and GBIF (GBIF.org 2024). These records were verified based on morphological characteristics and examined for relevant contextual information, such as the conditions under which the mantids were found. Subsequently, all reported locations of *Hierodula* spp. in Vienna other than Ernst-Paul-Zimper-Park were visited to conduct further searches for individuals, oothecae, and exuviae of *Hierodula* spp.

The distribution maps of *Hierodula* spp. records in Vienna and Austria were generated using ArcGIS Pro, incorporating GPS data from the authors' searches and GBIF records. The maps were created using the WGS 1984 coordinate system in Esri ArcGIS Pro 3.3.2. Esri online cartographic services and the openly-licensed WMTS basemap of Austria (basemap.at 2024) were utilized for visualization.

Field data, such as date, time, location, GPS coordinates, habitat characteristics and additional relevant information, were stored in the authors' database.

Results

Ernst-Paul-Zimper-Park

The first verified record of *H. transcaucasica* in this location is a photo of an adult female taken on October 24, 2023, observed on the wall of a building adjacent to the park grounds (iNaturalist observation, danielaio 2023). Approximately 10 months later on August 18, 2024, an exuvia was discovered under an *A. negundo* tree, prompting a subsequent search of Ernst-Paul-Zimper-Park for further exuviae and individuals from August 21 to August 24. During this search, we discovered a total of 59 exuviae under six different tree taxa (Figure 2). In many cases, exuviae from different larval stages were discovered close to each other, suggesting that they may have originated from the same individual. Additionally, 14 observations of adult *H. transcaucasica* individuals were recorded from August 21 to August 31, with up to six individuals observed on a single day. Only one instance of predation was recorded, when a female preyed upon an individual of the butterfly *Vanessa atalanta* (Figure 3a). Individuals were exclusively arboreal or shrub-dwelling, typically observed on foliage in the tree canopy and only seeking shelter on tree trunks during periods of heat or rain, likely to avoid harsh weather (Figure 3b). Mating behaviour between two individuals of *H. transcaucasica* was documented on August 30 on *Koelreuteria paniculata* (Figure 4). By mid-October, 10 oothecae were found across seven tree species during site visits (Figure 5). The last observation of a living specimen in Ernst-Paul-Zimper-Park occurred on 25 October, 2024. The first dead individual was discovered on 31 October, 2024, three days before

Fig. 2: Exuviae of *Hierodula transcaucasica* discovered on August 23 and 24, 2024, in Ernst-Paul-Zimper-Park, 1220 Vienna (a–c), and a single exuvia found in Augarten, 1220 Vienna (d). The approximate scale of two exuviae can be judged in comparison to one of the authors' hands (e). © Benjamin Kölz & Mario Oswald

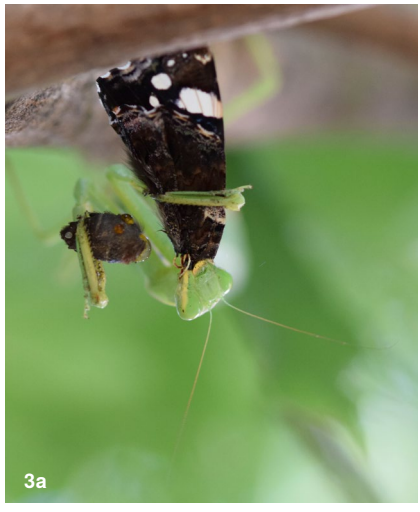

Fig. 3: *Hierodula transcaucasica* on *Acer* sp. preying on *Vanessa atalanta* (a), August 31, 2024, Ernst-Paul-Zimper-Park, 1220 Vienna. Yellow morph of *Hierodula transcaucasica* on a trunk of *Acer campestre* (b), August 26, 2024, Ernst-Paul-Zimper-Park, 1220 Vienna. © Benjamin Kölz **Fig. 4:** Mating of *Hierodula transcaucasica* on *Koelreuteria paniculata*, August 30, 2024, Ernst-Paul-Zimper-Park, 1220 Vienna. © Benjamin Kölz

Fig. 5: Ootheca of *Hierodula transcaucasica* on *Acer* sp., found on September 6, 2024 in Ernst-Paul-Zimper-Park, 1220 Vienna. © Benjamin Kölz **Fig. 6:** Dead specimen of *Hierodula transcaucasica* found beneath *Juglans regia* on October 31, 2024 in Ernst-Paul-Zimper-Park, 1220 Vienna. © Benjamin Kölz

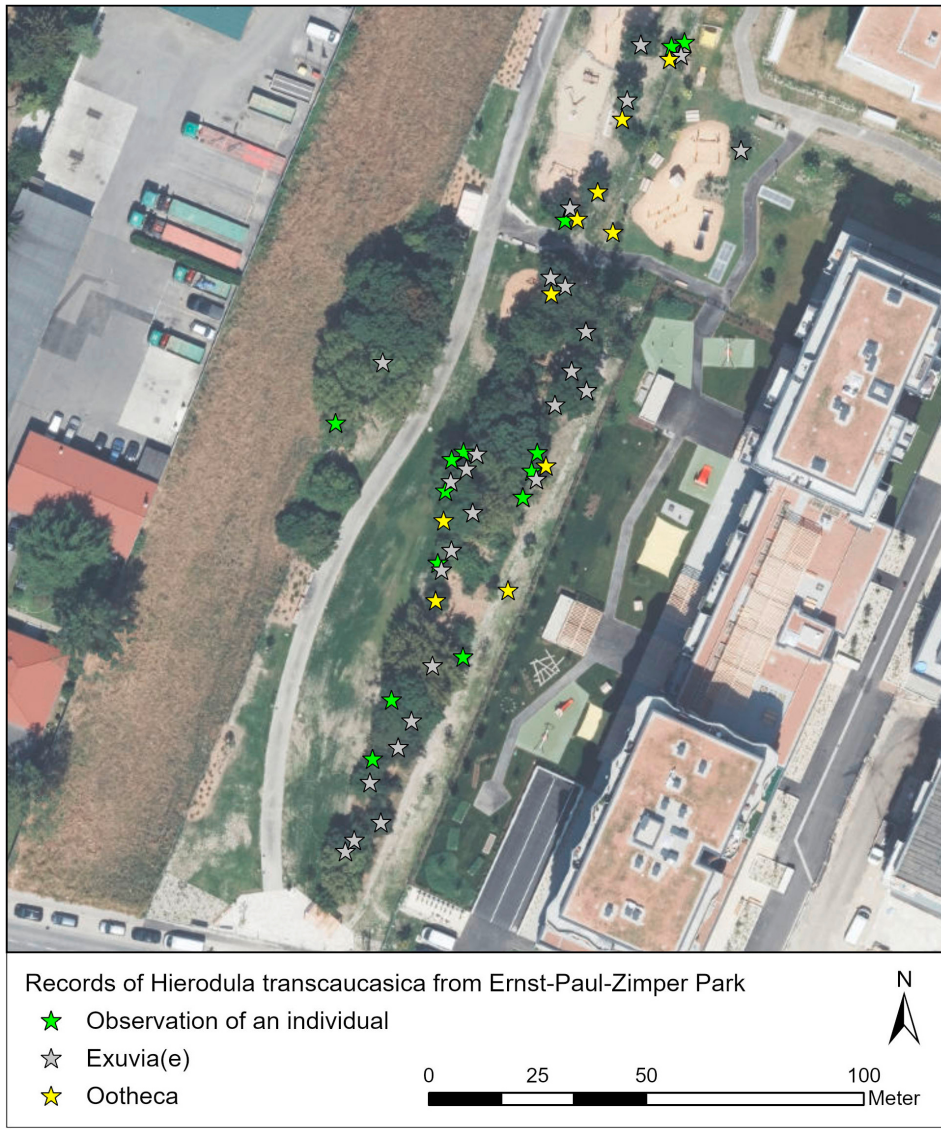

Fig. 7: All authors' records of *Hierodula transcaucasica* from Ernst-Paul-Zimper-Park. Each observation of an individual is indicated by a green star. Grey stars mark the place of one or several exuviae. Oothecae locations are marked by yellow stars.

temperatures in Vienna first fell to 0 °C (Figure 6). The exact locations of all findings from Ernst-Paul-Zimper-Park are shown in Figure 7.

Surveys of nearby public areas with suitable habitats, including Ladinigpark, playgrounds to the north and east of Ernst-Paul-Zimper-Park, and the adjacent Friedhof Kagran, yielded no records.

Augarten

A subadult female nymph of *H. transcaucasica* was reported from the Augarten (1020 Vienna, Austria) by an iNaturalist user (iNaturalist observation, alinagrantelt 2024) on July 27, 2024. During a subsequent site visit by the first author (M. Oswald) on August 21, an exuviae was discovered within 60 metres of the originally reported location. It was not possible to determine whether the exuviae corresponded to the reported specimen or whether it originated from another individual, as no further records were obtained during the survey in the Augarten.

Other records from Austria

The open data platform GBIF, which aggregates entries from various sources, including iNaturalist, observation.org, and Haus der Natur Salzburg, lists 14 reports of *Hierodula* spp. in Austria. One of these records is the first exuviae of *H. transcaucasica* found by the authors of this paper in Ernst-Paul-Zimper-Park, and another record is considered a duplicate (listed on observation.org as well as in the "Biodiversitätsdatenbank Salzburg"). Via the associated photographic evidence, six records were identified as *H. transcaucasica* based on morphology. Another six are listed as *H. tenuidentata*, most likely referring to specimens belonging to the same species as those listed as *H. transcaucasica* (for further details on taxonomic issues, see Introduction). The significant spatial distances and time intervals between most of these records, coupled with the absence of further observations in both subsequent and preceding years, suggest singular dispersal events rather than established populations of *H. transcaucasica* at these locations.

A further record of *H. transcaucasica* from East Tyrol is not listed in GBIF but is thoroughly documented on a private website (NATURundWISSEN.at 2024).

In 2024, seven individuals of *H. transcaucasica* in subadult or adult stages were found in Carinthia. All of these specimens were located in the same plant nursery in Velden am Wörthersee where one *H. patellifera* specimen was discovered in 2023. No evidence of prior reproduction was observed, and the individuals were subsequently taken into captivity. It is presumed that these individuals were introduced with ornamental plants from Italy in the year of their discovery (F. Wurmitzer, personal communication, in publication).

Thus, *H. transcaucasica* has been recorded in seven out of Austria's nine federal states so far, with documented sightings only missing from Styria and Burgenland.

An overview of the recorded findings of *Hierodula* spp. in Austria is presented in Table 1, including the sole record of *H. patellifera* for the country. Detailed information on the authors' individual observations of specimens and oothecae is provided in Tables 2 and 3. The locations of all findings of *H. transcaucasica/tenuidentata* as well as the not conclusively identifiable *Hierodula* spp. records are visualized in Figure 8.

Tab. 1: Summary of *Hierodula* spp. records from Austria, including proposed species identity, location, year of observation, and type of record (exuviae, live specimen, or oothecae).

Species (according to GBIF/authors)	Location	Year	Exuviae	Observations of living specimen	Oothecae
Vienna					
Hierodula transcaucasica	Mona-Lisa-Steiner-Weg, 1120 Vienna	2023	-	1	-
Hierodula transcaucasica	Ernst-Paul-Zimper-Park, 1220 Vienna	2023	-	1	-
Hierodula transcaucasica	Ernst-Paul-Zimper-Park, 1220 Vienna	2024	59	14	10
Hierodula transcaucasica	Augarten, 1020 Vienna	2024	1	1	-
Carinthia					
Hierodula patellifera	Gärtnerei Pichler-Koban, 9220 Velden am Wörthersee	2023	-	1	-
Hierodula transcaucasica	Gärtnerei Pichler-Koban, 9220 Velden am Wörthersee	2024	-	7	-
Tyrol					
Hierodula transcaucasica	Domanigweg, 6020 Innsbruck	2020	-	1	-
Hierodula transcaucasica	9782 Nikolsdorf (Osttirol)	2023	1	1	-
Vorarlberg					
Hierodula transcaucasica	Treietstraße, 6833 Klaus	2022	-	1	-
Salzburg					
Hierodula tenuidentata	Haus der Natur, 5020 Salzburg	2023	-	3	-
Hierodula tenuidentata	Wals-Siezenheim, 5071 Salzburg	2023	-	1	-
Hierodula tenuidentata	Leopoldskroner Moos, 5071 Salzburg	2023	-	2	-
Upper Austria					
Hierodula sp.	5211 Lengau	2023	-	1	-
Lower Austria					
Hierodula transcaucasica	Wüstegasse, 2511 Pfaffstätten	2024	-	1	-

Tab. 2: Detailed records of all living *Hierodula transcaucasica* specimens observed in Ernst-Paul-Zimper-Park, 1220 Vienna, by the authors. Abbreviations: BKN – Broken clouds, SCT – Scattered clouds, FEW – Few clouds.

Date, Time	Host tree	Temperature, Cloud cover	Ontogenetic stage	Sex
21.08.2024, 12:57	*Acer negundo*	25.5 C°, BKN	Adult	♀
21.08.2024, 13:56	*Acer negundo*	26.0 C°, BKN	Adult	♀
21.08.2024, 15:23	*Juglans regia*	26.5 C°, SCT	Adult	♂
21.08.2024, 15:55	*Juglans regia*	25.3 C°, SCT	Adult	♀
21.08.2024, 16:01	*Fraxinus excelsior*	25.3 C°, SCT	Adult	♀
21.08.2024, 16:32	*Acer platanoides*	23.7 C°, SCT	Adult	♂
23.08.2024, 17:06	*Koelreuteria paniculata*	30.3 C°, FEW	Adult	♀
24.08.2024, 18:07	*Fraxinus excelsior*	31.0 C°, FEW	Adult	♂
25.08.2024, 14:07	*Prunus cerasifera*	32.0 C°, FEW	Adult	♀
26.08.2024, 19:31	*Acer campestre*	23.3 C°, FEW	Adult	♂
30.08.2024, 18:13	*Koelreuteria paniculata*	25.6 C°, FEW	Adult	♀
30.08.2024, 18:15	*Koelreuteria paniculata*	25.6 C°, FEW	Adult	♀
30.08.2024, 18:15	*Koelreuteria paniculata*	25.6 C°, FEW	Adult	♂
31.08.2024, 17:58	*Acer* sp.	28.1 C°, FEW	Adult	♀

Tab. 3: Detailed records of all *Hierodula transcaucasica* oothecae observed in Ernst-Paul-Zimper-Park, 1220 Vienna, by the authors.

Date	Host tree	Orientation (attached – tip)	Height above ground level	Tree side
06.09.2024	*Acer platanoides*	NE – SW	1.69 m	S
17.09.2024	*Juglans regia*	WNW – ESE	2.47 m	E
19.09.2024	*Koelreuteria paniculata*	SSW – NNE	3.18 m	SE
20.09.2024	*Acer negundo*	NW – SE	2.53 m	NW
24.09.2024	*Acer platanoides*	NW – SE	~5.50 m	N
07.10.2024	*Prunus* sp.	ENE – WNW	~3.00 m	E
07.10.2024	*Fraxinus excelsior*	W – E	~3.00 m	E
11.10.2024	*Styphnolobium japonicum*	ESE – WNW	~3.50 m	ESE
13.10.2024	*Juglans regia*	NW – SE	~3.50 m	SE
13.10.2024	*Fraxinus excelsior*	vertical	~5.00 m	SE

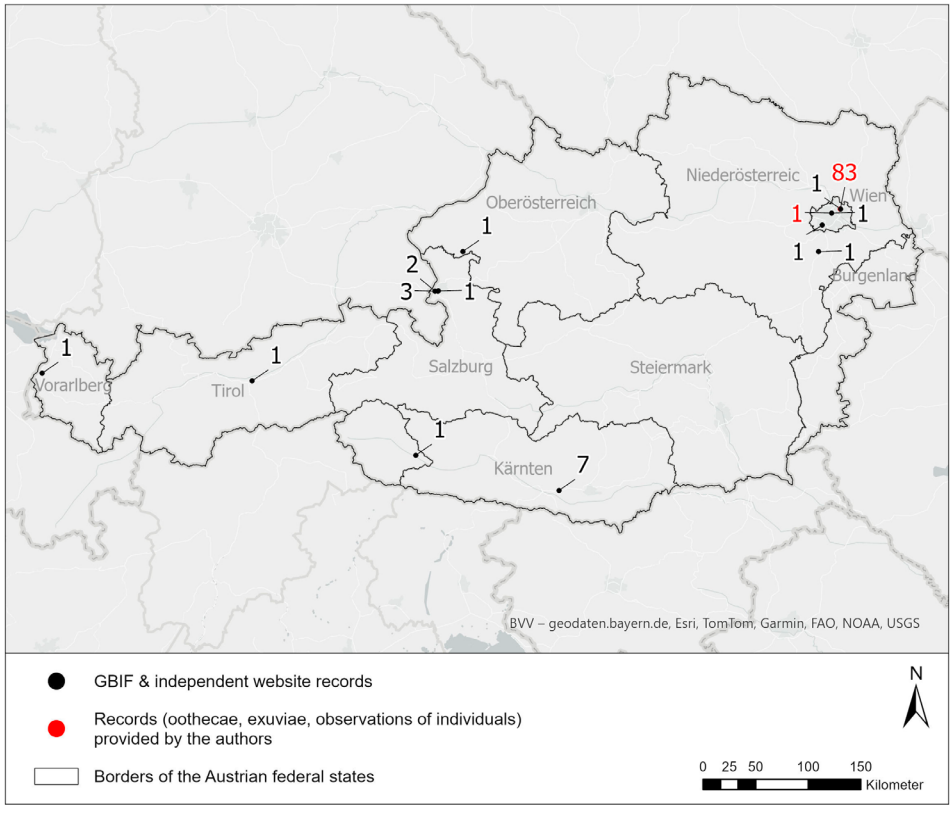

Fig. 8: Austrian records of *Hierodula* specimens identified as *Hierodula transcaucasica*, *Hierodula tenuidentata*, or *Hierodula* sp. The record of a single *Hierodula patellifera* is not depicted, but corresponds to the same location (plant nursery) as the seven *H. transcaucasica* records from Carinthia. Records marked in black are sourced from GBIF.org, with the exception of one record obtained from a private website. The records in red represent observations made by the authors of this paper during 2024.

Discussion

In 2024, multiple individuals of *H. transcaucasica* were observed at a single location (Ernst-Paul-Zimper-Park) in Vienna, showing evidence of successful larval development, mating, and ootheca deposition. Following the initial 2023 report of an adult female at this location (iNaturalist observation, danielaio 2023), and given the absence of a targeted follow-up search for additional individuals that year, at least three potential introduction scenarios are plausible. While none of these scenarios are supported by direct evidence, the first scenario listed below appears to us to be the most plausible:

1) Representing an isolated and recent introduction, potentially linked to the planting of ornamental trees and shrubs (Stadt Wien 2024, Quartiersmanagement Leben am Langen Felde 2024), the individual reported in 2023 may have been an already-mated female that deposited fertilized oothecae. The numerous individuals observed in 2024 may be the offspring from these oothecae.

2) The species may have already been established in the park by 2023, introduced through one or more oothecae or individual mantids at an earlier date. This scenario suggests the existence of an undetected or unreported population, which may have persisted in the area possibly for several years.

3) Multiple independent and recent introduction events are also a viable explanation for the observational data. In this case, the specimens observed in 2024 could be the descendants of one or more oothecae introduced in late 2023 or early 2024, while the individual from 2023 may not have reproduced.

While the introduction of *H. transcaucasica* to Europe solely via human-mediated pathways has been proposed (Pintilioaie et al. 2021), recent studies suggest that a natural range expansion from its native habitats in the Caucasus, potentially facilitated by climate change, may have occurred as well (Pintilioaie et al. 2023, Vujić & Ivković 2023). Human-assisted dispersal of the oothecae of *H. transcaucasica*, often attached by females to transported goods, vehicles, trains, and ornamental plants, is also a significant factor in the rapid spread of the species across Europe (Cianferoni et al. 2018). The genus *Hierodula* is renowned for its high reproductive rate, as females produce multiple oothecae, each containing from dozens to more than a hundred larvae (Mirzaee et al. 2021, Mirzaee et al. 2022). This reproductive strategy renders both mated individuals and the oothecae themselves highly effective agents of expansion. Numerous records of both *H. transcaucasica* and *H. patellifera* from public parks, garden centres, tree nurseries, and newly established green spaces, combined with their arboreal lifestyle, underscore the critical role of ornamental plants, particularly shrubs and young trees, as vectors of spread (Battiston et al. 2020b, Wurmitzer et al. 2023, Gomboc et al. 2024).

This appears to be the most likely introduction pathway for the population presented in this study as well: Ernst-Paul-Zimper-Park is located next to a large housing development, which was partially completed in early 2023 and features roughly 300 newly planted trees, shrubs, and grasses (Quartiersmanagement Leben am Langen Felde 2024). Furthermore, the park itself experienced an influx of new trees with many of them being planted shortly before the park was opened to the public in 2023 (Stadt Wien 2024).

Together with the high population density of *H. transcaucasica* in the park's populated area stretching from the playground to the 'Am langen Felde' road, which contrasts with the apparent absence of the mantid not only from the adjacent public spaces but also from the rest of the park, this suggests a recent introduction via imported plants. In Ernst-Paul-Zimper-Park, *H. transcaucasica* appears to have successfully reproduced and established a dense population by 2024, but the species has not yet had time to spread further.

In this context, another interesting aspect is the vegetation density of different parts of the park: Older tree plantings of different age, including an *A. negundo* planted in 1905 (Stadt Wien 2024), along with naturally established tree stands, form a significant part of the park's tree flora. These trees dominate some of the southern and peripheral areas, where they grow in relatively dense patches. The majority of the park, however, features only isolated trees, separated by trails, recreational structures, and frequently trimmed lawn. Interestingly, while individuals of *H. transcaucasica,* exuviae and oothecae were

observed both in areas with relatively high vegetation cover and in those where tree cover is low, only the southernmost third of the park, which contains all of the densely vegetated areas, appears to be populated.

Another location that provides a potentially suitable habitat for a population of *H. transcaucasica* is the Augarten in Vienna. In 2024, two records were documented: a female nymph (iNaturalist observation, alinagrantelt 2024) and an exuviae found by the first author (M. Oswald) near the reported individual. Given the park's favourable habitat features, including its size of approximately 52 hectares, numerous tree alleys, and untended woodland patches, it seems plausible that a population of *H. transcaucasica* may already have established in the Augarten. A targeted search for oothecae once trees and shrubs are leafless and visibility is enhanced remains to be conducted.

Outside of Austria, successfully reproducing populations are already established in the continental climate of the Pannonian Plain as far north as urban Budapest (Vujić & Ivković 2023, László et al. 2023). Although studies on the cold resistance of *H. transcaucasica*'s oothecae are lacking, adult specimens in Italy have shown high cold tolerance, surviving prolonged cold periods at temperatures as low as -5 °C (Di Pietro & Battiston 2021).

Furthermore, the majority of recorded specimens in Europe have been found in urban areas and anthropogenic habitats (van der Heyden 2018, Battison et al. 2018, Romanowski et al. 2019, László et al. 2023). It appears therefore likely that the Vienna urban area with its heat island effect features numerous habitats with favourable conditions, making the expansion of the species highly probable (Dimitrova 2014, Di Pietro & Battiston 2021, Vujić & Ivković 2023).

Due to the lack of ecological studies, assessing the impact of *H. transcaucasica* on the native fauna is challenging. So far, only one interspecific interaction has been documented: *H. transcaucasica* preying on an individual of the butterfly species *V. atalanta*. Notably, a high-density population of another introduced species, the southern green shield bug (*Nezara viridula*), is also present in Ernst-Paul-Zimper-Park. Since *N. viridula* often occupies elevated positions in the vegetation and on tree trunks, much like *H. transcaucasica*, we hypothesize that it may serve as an important local food source for the mantid, although evidence to support this is yet to be gathered.

Other than predator-prey relationships, the effect of *H. transcaucasica* on the mating behaviour of *M. religiosa* is also of some concern, as *M. religiosa* males are known to show mate attraction to females of other mantid species (Lelito & Brown 2008). While both *H. transcaucasica* and *M. religiosa* have been observed in Ernst-Paul-Zimper-Park (iNaturalist 2024c), their ecological niches show no apparent overlap: *H. transcaucasica* exhibits a strictly arboreal or shrub-dwelling lifestyle and appears to remain mostly within the foliage, frequently also sitting in the canopy. In contrast, *M. religiosa* is usually sighted on herbaceous plants in open grasslands, meadows, or fallows, suggesting distinct habitat preferences that reduce interspecific competition and conflict between these two mantid species.

Given the favourable climatic conditions in Vienna's Ernst-Paul-Zimper-Park, nymphs of *H. transcaucasica* are expected to emerge from the documented overwintering

oothecae in spring. This will be monitored to confirm the species' potential for further establishment and spread within and around the park, providing valuable insights into its capacity for establishment in urban environments, as well as its habitat preferences and behavioural patterns. Additionally, surveys should be extended to other suitable habitats across Vienna as well as other reported introduction sites to gain a better understanding of the ecological requirements and the potential range expansion of this newly introduced mantid species in Austria.

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