

# NEW RECORDS OF ALLOCHTHONOUS *HIERODULA TENUIDENTATA* SAUSSURE, 1869 (MANTODEA: MANTIDAE) FROM SOUTHEASTERN EUROPE, WITH EVIDENCE OF ITS SPREAD ACROSS THE PANNONIAN PLAIN

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In the last few years, the allochthonous mantid species, *Hierodula tenuidentata* Saussure, 1869 has spread vigorously across Europe. To date, the species has been recorded in many countries in the southern and eastern parts of the continent, Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Greece, Italy, Moldova, North Macedonia, Romania, Serbia, Slovenia, Spain, and Ukraine. On October 22, 2022, in Szeged, a city in the southern part of Hungary, one ochre-colored female specimen of *H. tenuidentata* was found. The finding presented in this article is the first recording of this species in Hungary and indicates the further spread of the species towards Central Europe. We also present a few new records of this species from Greece, North Macedonia, Romania, and Serbia. We discuss the spread of *H. tenuidentata* in the Pannonian Plain, as well as the potential importance of climate change and the heat island effect in population establishment in this part of Europe.

**Key words:** continental climate, Hungary, Dictyoptera, alien species, invasive species

**Vujić, M. & Ivković, S.: Novi nalazi strane vrste *Hierodula tenuidentata* Saussure, 1869 (Mantodea: Mantidae) iz jugoistočne Europe, s dokazima njenog širenja Panonskom nizinom. Nat. Croat., Vol. 32, No. 1, 69-79, 2023, Zagreb.**

Posljednjih se nekoliko godina alohtona vrsta bogomoljke *Hierodula tenuidentata* Saussure, 1869 intenzivno širi po Europi. Do danas je vrsta zabilježena u mnogim zemljama južnog dijela kontinenta, odnosno u Albaniji, Bosni i Hercegovini, Bugarskoj, Hrvatskoj, Grčkoj, Italiji, Moldaviji, Sjevernoj Makedoniji, Rumunjskoj, Srbiji, Sloveniji, Španjolskoj i Ukrajini. Dana 22. listopada 2022. u Szegedu, gradu u južnom dijelu Mađarske, pronađena je jedna smečkasta ženka vrste *H. tenuidentata*. Taj je nalaz prvi za ovu vrstu na području Mađarske i ukazuje na daljnje širenje prema srednjoj Europi. Ovdje smo predstavili i nekoliko novih nalaza ove vrste, iz Grčke, Sjeverne Makedonije, Rumunjske i Srbije. Raspravili smo širenje vrste *H. tenuidentata* u Panonskoj nizini, kao i o potencijalnom značaju klimatskih promjena i učinka toplinskih otoka u uspostavljanju populacije u ovom dijelu Europe.

**Ključne riječi:** kontinentalna klima, Dictyoptera, invazivna vrsta

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## INTRODUCTION

The giant Asian mantid *Hierodula tenuidentata* Saussure, 1869 is a mantid species native to much of Asia: India, Nepal, Malay Archipelago, Kazakhstan, Turkmenistan, Tajikistan, Uzbekistan, Afghanistan, Pakistan, Iran, Georgia, Armenia, Azerbaijan, as well as the Caucasus and southern Russia (Kalmykia) (PATEL & SINGH, 2016). In the last few years, the species has significantly expanded its distribution area in Europe (BATTISTON *et al.*, 2018; PINTILIOAIE *et al.*, 2021; MARTINOVIĆ *et al.*, 2022; VASILEV *et al.*, 2023). It is a large species where males can reach 45–63 mm, and females 55–61 mm, colored green, yellow, brown, or ochre (BATTISTON *et al.*, 2010). The large body size, clear white stigmas on the tegmina, as well as the absence of black or eye-like spots at the base of the first coxae, make this species unique among species naturally occurring in Europe. It can only be mistaken for two other alien species, *H. patellifera* Serville, 1839 and *Sphodromantis viridis* Forsskål, 1775. Little is known about the biology of *H. tenuidentata*. MIRZAEI *et al.* (2022) studied some details of the life cycle and biology of this species. PINTILIOAIE *et al.* (2022) analyzed the influence of some weather factors on the abundance dynamics.

*Hierodula tenuidentata* was previously in Europe mostly reported under its synonym name *H. transcaucasica* Brunner von Wattenwyl, 1878. The two names were for a long time considered to refer to separate species with partially separate distribution areas (e.g., PATEL & SINGH, 2016), although some authors have discussed synonymy in the past (EHRMANN, 2011). Finally, BATTISTON *et al.* (2018) concluded that *H. transcaucasica* is a synonym of *H. tenuidentata*; subsequently, various authors accepted the synonymy (e.g., PINTILIOAIE *et al.*, 2021; VUJIĆ *et al.*, 2021; KULIJER *et al.*, 2022; MARTINOVIĆ *et al.*, 2022). BATTISTON *et al.* (2018) examined many specimens and found high variability in shape, size and coloration of femoral spines (which were previously considered the character by which these two species can be separated). They also found that there are no significant differences in male genitalia between specimens with partially black femoral spines (considered the character of *H. tenuidentata*) and allotype genitalia described from Caucasian specimens (see BATTISTON & MASSA, 2008: pg. 18, Fig. 5). Still, however, numerous sites, databases, and online resources such as iNaturalist or Fauna Europaea have not adopted the valid name or have not accepted the synonymy, and this is also true for some authors (VAN DER HEYDEN, 2021; BRONSKOV & FILCHAKOVA, 2022).

So far, the distribution of *H. tenuidentata* in Europe has mainly included the southern part of the continent; it was recorded in Albania (VAN DER HEYDEN, 2018), Bosnia and Herzegovina (KULIJER *et al.*, 2022), Bulgaria (ROMANOWSKI *et al.*, 2019; SCHWARZ & EHRMANN, 2018; ZLATKOV *et al.*, 2020; Sevgili & Yılmaz, 2022; VASILEV *et al.*, 2023), Croatia (MARTINOVIĆ *et al.*, 2022), Greece (CIANFERONI *et al.*, 2018; SCHWARZ & EHRMANN, 2018; ROMANOWSKI *et al.*, 2019; LANGOUROV *et al.*, 2022; SEVGILI & YILMAZ, 2022), Italy (BATTISTON *et al.*, 2018; DI PIETRO & BATTISTON, 2021; SEVGILI & YILMAZ, 2022), Moldova (ZAHAROV & ROMANOVICH, 2021), North Macedonia (CIANFERONI *et al.*, 2018), Romania (PINTILIOAIE *et al.*, 2021), Serbia (VUJIĆ *et al.*, 2021), Slovenia, Spain (VAN DER HEYDEN, 2021) and Ukraine (PUSHKAR & KAVURKA, 2016; BRONSKOV & FILCHAKOVA, 2022; SEVGILI & YILMAZ, 2022).

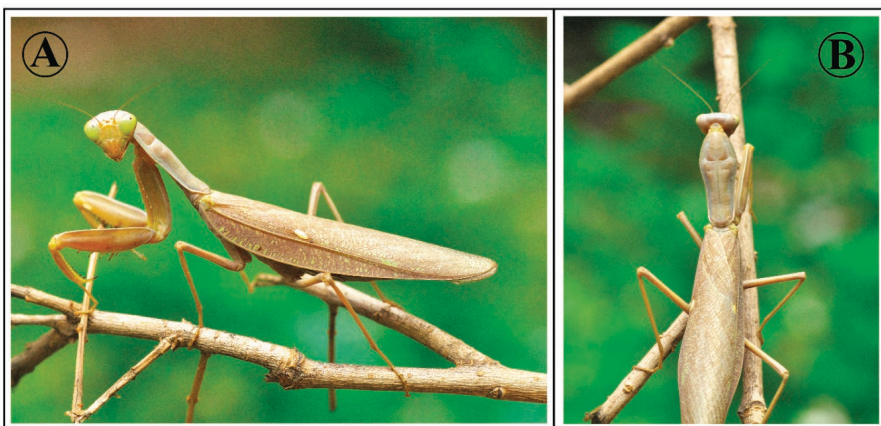
## MATERIAL AND METHODS

The mantid specimens from Hungary was collected by hand and preserved alive until they were photographed and then they were killed and stored in 96% ethanol, in the private collection of Slobodan Ivković. Additional data from Greece and a large

dataset of Serbian findings were collected with the help of citizen science, via the Facebook group "Insekti Srbije (Insects of Serbia)", and in the Results of this article the abbreviation "FB" is used for these data. Only some of the new records for Serbia were collected via Instagram (abbreviation "IG") and the Alciphron database of insects of Serbia. The data about all the Serbian records were deposited in the Alciphron database. The camera used for photography was a Sony A58 digital SLR camera equipped with a Tamron SP AF90 mm f/2.8 Di Macro lens. The distribution map (Fig. 2) was created using Google Earth Pro 7.3.6.9345 and Adobe Photoshop CS5 Version 12.0, and included only published data of *H. tenuidentata*, and new data presented in this article. The new data are marked as data with higher priority on the map presented. The distribution is based on published data (see Introduction) and our new records. The identification of all specimens was performed using the description, keys, and illustrations from available literature, e.g. BATTISTON *et al.* (2019), Battiston *et al.* (2020), and MARTINOVIĆ *et al.* (2022). *H. tenuidentata* can be easily distinguished from the species occurring in Europe most similar to it, *Sphodromantis viridis* and *Hierodula patellifera*, by morphological characters. Unlike that of *S. viridis*, the pronotum of *H. tenuidentata* is not significantly expanded in the upper part and purple to dark horizontal lines on the ventral part of the thorax are present (see illustrations in Battiston *et al.* 2019: pg. 92, Fig. 1, Fig. 2; MARTINOVIĆ *et al.*, 2022, pg. 59, Fig. 4A-B). This species can be separated from *H. patellifera* by characters of male terminalia and spines on the fore coxae, which are smaller, simple and without basal disc, unlike *H. patellifera*, which has more pronounced spines with basal discs (see illustrations in BATTISTON *et al.*, 2019: pg. 92, Fig. 2; MARTINOVIĆ *et al.*, 2022: pg. 57, Fig. 2C; pg. 58, Fig. 3B).

## RESULTS

An ochre-colored female *Hierodula tenuidentata* from the surroundings of Szeged (Fig. 1) occasioned the first published report of this species in Hungary. Furthermore, the iNaturalist site (<https://www.inaturalist.org/>) provides a few unpublished records of this species from Budapest and its surroundings. Szeged is situated in the southern



**Fig. 1.** The habitus of the ochre-colored specimen of *Hierodula tenuidentata* from Szeged, Hungary; A) lateral view; B) dorsal view. Photo: S. Ivković.

part of Hungary. The locality where the specimen was found has been completely anthropogenically disturbed and nearby there is a city cemetery (Alsóvárosi Temető). The specimen was likely attracted to the light advertisements in a supermarket, in front of which it was found. The new records from Greece are data collected via citizen science, and all the specimens were photographed in tourist places near the Aegean Sea. The photographs with appropriate information were posted in the Facebook group of insect lovers, enthusiasts, and citizen scientists 'Insekti Srbije (Insects of Serbia)'. The specimen from North Macedonia was collected in a natural, bushy, xerothermic habitat in the central part of the country, during an orthopterological survey. Only a nymph was found, but already with distinct identification characters. The specimen collected in the Botanic Park, the central part of the city of Timișoara, Romania was found dead, attached to the bark of *Acer negundo* and heavily damaged by molds and insects. The numerous new records from Serbia were largely collected with a help of citizen science, but also during regular field activities.

### List of all new records

HUNGARY: Szeged, Szabadkai út, N 46.242432°, E 20.126967°, 22.10.2022, 1♀, leg. S. Ivković;

The localities from iNaturalist data (reported under the synonym *H. transcaucasica*): Budapest: City Park (adults); Csongrád-Csanád County: Mórahalom (adults), Zákányszék (adults), Domaszék (adults, exuviae), Röszeke (adults, oothecae), Szeged (adult).

GREECE: Sithonia, Nikiti, the geographical coordinates are not specified, 15.07.2021, 1 nymph, photo: FB; Kassandra, Polychrono, the geographical coordinates are not specified, 05.08.2022, 1♂, photo: FB; Pieria, Leptokarya, the geographical coordinates are not specified, 19.08.2022, 1♂, photo: FB;

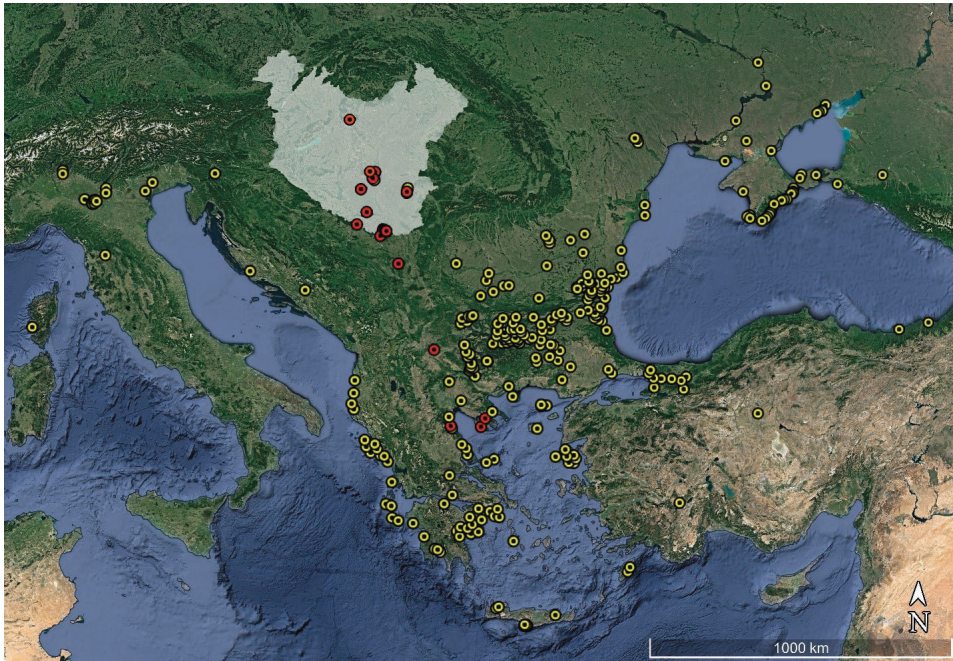
NORTH MACEDONIA: Sveti Nikola, Mečkuevci, N 41.922570°, E 22.073040°, 23.07.2022, 1 nymph, leg. S. Ivković;

ROMANIA: Timișoara, Botanic Park, N 45.761429°, E 21.224469°, 03.01.2023, 1♀, leg. M. Vujić (a dead specimen collected from an *Acer negundo* trunk);

SERBIA: Autonomous Province of Vojvodina, Zasavica, N 44.971358°, E 19.53396°, 10.10.2020, 1♀, photo: M. Stanković; Bačka Topola, N 45.814086°, E 19.633806°, 09.11.2021, 1♀, photo: FB; 10.08.2022, 1♀, photo: FB; 21.08.2022, 1♀, photo: FB; 27.08.2022, 2♀, photo: FB; Kanjiža, N 46.075378°, E 20.052465°, 06.08.2022, 1 nymph, photo: Z. Gavrilović; Novi Sad (Spens), N 45.245841°, E 19.845516°, 24.08.2022, 1♂, photo: M. Grahovac; Novi Sad (Rumenački put), N 45.271081°, E 19.807882°, 20.08.2022, 1♀, photo: FB; 22.08.2022, 1♀, photo: FB; Central Serbia, Kragujevac, N 44.008865°, E 20.902972°, 24.08.2022, 1♀, leg. F. Vukajlović, Belgrade, Mite Ružića, N 44.792222°, E 20.515833°, 14.10.2020, 1♀; 25.09.2021, 1♂, photo: L. Radovanović; Blok 9a, N 44.833611°, E 20.414167°, 11.07.2021, 1 nymph, photo: FB; Trg Politike, N 44.815278°, E 20.464444°, 21.07.2021, 1 nymph, photo: FB; Lazara Avramovića, N 44.779444°, E 20.485556°, 28.07.2021, 01.08.2021, 1 nymph, photo: O. Šaponja; Batutova, N 44.795833°, E 20.498333°, 08.08.2021, 1 nymph, photo: FB; Cvijićevo, N 44.816944°, E 20.477778°, 14.08.2021, 1 nymph, photo: FB; Avijatičarski trg, N 44.840556°, E 20.413333°, 19.08.2021, 1♀, photo: IG; Bulevar Despota Stefana, N 44.816944°, E 20.474722°, 20.08.2021, 1♀, photo: FB; Šumice, N 44.781667°, E 20.503889°, 24.08.2021, 1♀, photo: FB; 09.08.2022, 1♀, photo: IG (single specimen found in *Corylus avellana* shrub); 19.08.2022, 1♀, photo:

FB; Olimp, N 44.795278°, E 20.503889°, 24.08.2021, 1♀, photo: FB; Resavska, N 44.80250°, E 20.459167°, 1 nymph, photo: IG; Žarkovo, N 44.761389°, E 20.410278°, 30.08.2021, 1♀, leg. N. Marinković; Dvadesetsedmog marta, N 44.812222°, E 20.472778°, 09.09.2021, 1♀, photo: FB; Narodnih heroja, N 44.82250°, E 20.407778°, 10.09.2021, 1♀, photo: FB; Lion, N 44.796944°, E 20.494722°, 12.09.2021, 21.09.2021, 1♀, photo: IG; Generala Mihajla Živkovića, N 44.794444°, E 20.498889°, 13.09.2021, 1♂, photo: IG; Zvezdara, N 44.805556°, E 20.499444°, 15.09.2021, 1♀, photo: FB; Bogoslovija, N 44.815278°, E 20.490556°, 27.09.2021, 1♀, photo: IG; Kej oslobođenja, N 44.836389°, E 20.418889°, 01.10.2021, 1♀, photo: FB; Voždovac, N 44.775278°, E 20.477778°, 04.10.2021, 1♀, photo: FB; Blok 70, N 44.799722°, E 20.396667°, 05.10.2021, 1♀, photo: FB; Knjeginje Ljubice, N 44.819722°, E 20.461389°, 08.10.2021, 1♀, photo: IG; Jevremovac Botanical Garden, N 44.815556°, E 20.473056°, 13.10.2021, 1♀, photo: IG, 25.08.2022, 1♀, photo: V. Bjelica; Južni Bulevar, N 44.793333°, E 20.478056°, 27.10.2021, 1♀, photo: FB; Savamala, N 44.812778°, E 20.453611°, 28.10.2021, 1♀, photo: G. Basta; Studentski grad, N 44.824167°, E 20.399722°, 30.10.2021, 1♀, leg. M. Vujić; Umka, N 44.679167°, E 20.308056°, 12.06.2022, 4 nymph, photo: FB; Vračar, N 44.801944°, E 20.475278°, 13.06.2022, 3 nymph, photo: FB; Predsedništvo, N 44.810278°, E 20.464167°, 13.06.2022, 1 nymph, photo: FB; Siniše Stankovića, N 44.7625°, E 20.408611°, 13.06.2022, 1 nymph, photo: FB; Gandijeva, N 44.806944°, E 20.384722°, 02.07.2022, 1 nymph, photo: V. Lakušić; Paviljoni, N 44.830556°, E 20.404722°, 02.07.2022, 1 nymph, photo: FB; Lion, N 44.7975°, E 20.495556°, 10.07.2022, 1 nymph, photo: FB; Fočanska, N 44.794167°, E 20.515556°, 30.07.2022, 11.08.2022, 1 nymph, photo: S. Panjković; Crveni park, N 44.801111°, E 20.478611°, 31.07.2022, 1 nymph, photo: FB; Glasinačka, N 44.782051°, E 20.502108°, 09.08.2022, 1♀, leg. M. Vujić (collected from *Tilia cordata* trunk); Ustanička, N 44.787511°, E 20.477057°, 10.08.2022, 1♂, photo: FB; Banovo Brdo, N 44.776842°, E 20.415513°, 10.08.2022, 20.08.2022, 1♂, photo: FB; Blok 63, N 44.806698°, E 20.383788°, 20.08.2022, 1♂, photo: FB; Plavi most, N 44.780512°, E 20.502273°, 13.08.2022, 1♂, photo: FB; Ljermontovljeva, N 44.782997°, E 20.492266°, 14.08.2022, 1♀, photo: FB; Gospodar Jovanova, N 44.819156°, E 20.46392°, 16.08.2022, 1♀, photo: FB; Tašmajdan Park, N 44.809732°, E 20.469938°, 16.08.2022, 21.08.2022, 1♀, photo: FB; Blok 62, N 44.803419°, E 20.376868°, 17.08.2022, 1♀, photo: FB; Novo Mirijevo, N 44.785493°, E 20.546144°, 19.08.2022, 1♀, photo: FB; Sarajevska, N 44.804427°, E 20.45604°, 19.08.2022, 1♀, photo: FB; Bulbulder, N 44.802912°, E 20.492597°, 19.08.2022, 1♀, photo: J. Maslovarić; Mirijevo I, N 44.795727°, E 20.5216°, 20.08.2022, 1♀, photo: FB; Peđe Milosavljevića, N 44.818129°, E 20.375179°, 20.08.2022, 1♀, photo: FB; Blok 39, N 44.814624°, E 20.410275°, 21.08.2022, 1♀, photo: FB; Patrisa Lumumbe, N 44.815266°, E 20.509777°, 21.08.2022, 1♀, photo: FB; Knjeginje Zorke, N 44.802428°, E 20.471169°, 24.08.2022, 1♀, photo: FB; Vojislava Ilića, N 44.785068°, E 20.500515°, 26.08.2022, 1♂, leg. M. Vujić (single male in *Ligustrum ovalifolium* shrub); Autokomanda, N 44.789511°, E 20.471501°, 27.08.2022, 1♀, photo: FB; Jovana Rajića, N 44.795907°, E 20.48822°, 27.08.2022, 1♀, photo: FB; Uzun Mirkova, N 44.820025°, E 20.455526°, 27.08.2022, 1♀, photo: FB; Vojvođanska, N 44.809639°, E 20.380026°, 27.08.2022, 1♀, photo: FB; Vojvode Savatija, N 44.801354°, E 20.490461°, 15.09.2022, 1♀, leg. V. Lakušić (predation on *Phaneroptera nana* Fieber, 1853).

Records based on oothecae only: Belgrade, Karaburma, N 44.812494°, E 20.506332°, 13.10.2022, 1 ootheca, photo: IG (attached to the wall); Jevremovac Botanical Garden, N 44.816147°, E 20.473359°, 14.10.2022, 1 ootheca, leg. M. Vujić (attached to a decorative concrete jar); 01.03.2023, 1 ootheca, leg. M. Vujić (attached to a twig of an unidentified shrub).



**Fig. 2.** The currently known distribution of *Hierodula tenuidentata* in Mediterranean and Eastern Europe, based on the published and new data; yellow targets – published data, red targets – new data; white blurred area – the approximate territory of Pannonian Plain.

## DISCUSSION

The increasing amount of data in recent years indicates the establishment of *Hierodula tenuidentata* populations in the Pannonian Plain (Fig. 2). The first records in the Pannonian Plain are from 2019, Zemun, northern Belgrade, Serbia, at the southern border of Pannonian Plain (VUJIĆ *et al.*, 2021), and Timișoara, Romania (PINTILIOAIE *et al.*, 2021), although there is a high probability that the species was already present in the region even a few years before.

PINTILIOAIE *et al.* (2021) recorded 135 *H. tenuidentata* oothecae in Timișoara, and of them, 18 were probably from 2018. In 2020 and 2021, the number of recorded specimens rapidly increased, in the context of both areas newly occupied and new findings at already known localities (PINTILIOAIE *et al.*, 2021; VUJIĆ *et al.*, 2021). Since very few records were published by VUJIĆ *et al.* (2021), *H. tenuidentata* became the most frequently recorded mantid species in the urban areas of Belgrade, both in the northern (Pannonian) and the southern (Balkan) parts of the city. From 2020, the species was known to occur at various localities in Vojvodina Autonomous Province (northern Serbia) and it was recorded exclusively in human settlements, both urban and suburban (Novi Kneževac, Zasavica, Bačka Topola, Novi Sad, Kanjiža) (VUJIĆ *et al.*, 2021). However, the species was found more than one time only in Bačka Topola and Novi Sad, where numerous specimens were observed in private gardens, making these places the only localities where the presence of an established population is certain. The specimens found in Novi Kneževac and Kanjiža (Serbia) probably belong to the same continuous

(sub)population as the specimen found in Szeged (Hungary) given that the distance between the Serbian records and the Hungarian record is only about 20 km. There is also a possibility that this (sub)population shares a common origin and connection with the populations from Belgrade and/or Timișoara, where *H. tenuidentata* occurs regularly (PINTILIOAIE *et al.*, 2021; VUJIĆ *et al.*, 2021). The species was already recorded in the countries surrounding Hungary, such as Croatia, Slovenia, and Ukraine (PUSHKAR & KAVURKA, 2016; VAN DER HEYDEN, 2021; MARTINOVIĆ *et al.*, 2022). However, each one of these findings is much more distant than those previously mentioned (Fig. 2).

The origin of certain specimens or doubtfully established populations in the Pannonian Plain cannot currently be assumed on the basis of geographical proximity, unlike the ones from Zasavica, Bačka Topola, and Novi Sad. It is difficult to identify the possible origin of the Pannonian Plain populations, as well as whether they share the same origin. There is a probability that specimens originated from areas around the Black Sea, such as Ukraine, or from the southern Balkans and the areas around the Aegean and the Marmara Sea. In the second case, the distribution corridor crosses over the territory of Bulgaria, North Macedonia, and Serbia and this scenario is quite possible, since areas around the Aegean, Marmara and Black Seas have long-established populations and there are numerous resorts along the coast often visited by tourists from the continental parts of the Balkans and Pannonian Plain.

The ways in which *H. tenuidentata* spreads have not been determined with certainty. Traffic and the transport of people and goods are more likely mechanisms of the distribution (Battiston *et al.*, 2018) than natural migration. Evidence for this could also be its virtually synanthropic nature, given that it almost exclusively occurs in urban and suburban areas. It is especially pronounced in Pannonian Plain and some more continental parts of the Balkan Peninsula, but generally elsewhere (e.g., central Serbia, central, western and northern Bulgaria) (PINTILIOAIE *et al.*, 2021; VUJIĆ *et al.*, 2021; MARTINOVIĆ *et al.*, 2022; VASILEV *et al.*, 2023), given that there are a very small number of findings of the species in natural habitats, compared to the total amount of data. VASILEV *et al.* (2023) published a very large dataset on the presence of *H. tenuidentata* in Bulgaria, considering the species is widespread but more common in the southern part of the country. They also found that the species in Bulgaria occurs almost exclusively in the settlements, except for a few findings, which is in accordance with literature data, as well as our observations. The specimen from Mečkuevci (North Macedonia) is unique among new records presented here, due to the fact that it was found in a natural habitat, consisting of bushy, thermo- and xerophilic vegetation. All the other recorded specimens were related to anthropogenic habitats. The new records from Greece presented in this article are exclusively related to tourist places on the coast of Aegean Sea. The same is true for the new records from Timișoara and Szeged, where the specimens were found in the city park and near the cemetery, respectively. The specimen from Timișoara was found dead and largely damaged by insects and molds, but still attached to the bark of *Acer negundo*.

It is quite possible that the spread of *H. tenuidentata* across the Pannonian Plain as well as the continental Balkans was enabled or facilitated by the phenomenon of climate change in this region. Climate change in the context of global warming is happening faster than predicted (XU *et al.*, 2018), and it surely has an impact on the community of insects, especially the spreading of invasive and alien species (GUTIERREZ & PONTI, 2014). The Pannonian Plain and Balkans are under severe pressure from inva-

sive insects, which can also be seen in the example of Mantodeans, which have established new populations or expanded their natural range towards northern or more continental parts (SZINETÁR & KENYERES, 2020; MARTINOVIĆ *et al.*, 2022; VASILEV *et al.*, 2023). The territory of Serbia is strongly affected by global warming, with a significant temperature increase of 1.2 °C during the period of 1961-2015 (VUKOVIĆ *et al.*, 2018). The data of the meteorological yearbook on climate data of the Hydrometeorological Institute of the Republic of Serbia (e.g., ANONYMOUS, 2019, 2020, 2021, 2022) also provide some information useful in the search for an explanation for the increasing number of established populations of invasive, thermophilic and non-native insects. These data clearly show that some parts of Serbia, including Belgrade and southern Pannonian Plain, in the last few years, have had a similar climate trend. The mentioned area consistently has the highest average minimal air temperatures, and mean year air temperature, but the minimum of the days with the occurrence of a frost (Anonymous, 2019, 2020, 2021, 2022). The cold tolerance of *H. tenuidentata* has not been studied yet, but some indirect data indicate that the species probably prefers higher temperatures (e.g., PINTILIOAIE *et al.*, 2022). Although the native distribution of this species covers much of Asia (PATEL & SINGH, 2016), a large part of its range is characterized by warm, tropical or subtropical climate. PINTILIOAIE *et al.* (2022) studied the influence of weather on *H. tenuidentata* and *M. religiosa* in one locality in Romania and mentioned that from the year of first observation of species in 2019, the mean winter temperatures at the site were 2 °C higher than the multiannual mean in last few decades. DI PIETRO & BATTISTON (2021) found that in Italy, even adults can survive quite cold conditions, even frost and down to -5 °C, but also survive prolonged cold periods with mean temperatures between 0 and 5 °C. They also concluded that its ability to withstand cold can play a role in the spreading and colonization of new habitats across Europe (DI PIETRO & BATTISTON, 2021). The heat island effect around Belgrade (Serbia) is evident and has an impact on local climate factors (MILOVANOVIĆ *et al.*, 2020). The heat island effect is also pronounced in the city of Budapest in Hungary (PONGRACZ *et al.*, 2011). The combination of well-evidenced global warming and the heat island effect around cities probably plays a very important role in establishing a population of *H. tenuidentata* in conditions of the continental climate of the Pannonian Plain and some parts of the Balkan Peninsula.

Interestingly, *H. tenuidentata* is not the first introduced mantid recorded in Hungary. In 2020 a Mediterranean species *Ameles spallanzania* (Rossi, 1792) was found in the southern part of the country, near the Croatian border, but no established populations were recorded (SZINETÁR & KENYERES, 2020). *Hierodula tenuidentata* is thus probably the only non-native mantid with an established population in the Pannonian Plain. In contrast to the Pannonian Plain, the Balkan Peninsula and the central parts of Romania are experiencing a more pronounced pressure from the spreading of allochthonous mantids, or range expansion of native species (CAZACU, 2019; MARTINOVIĆ *et al.*, 2022; VASILEV *et al.*, 2023).

## CONCLUSIONS

This species was reported precisely for Hungary for the first time.

*Hierodula tenuidentata* is spreading over the Pannonian Plain, in Serbia, Hungary, and Romania. By the combination of information from the literature and new records from this article, the presence of established populations at some sites in the Pannonian Plain



is evident. The presence of established subpopulations was confirmed in at least three sites in Serbia (Belgrade, Bačka Topola, Novi Sad) and one site in Romania (Timișoara). Established subpopulations are suspected on the sites where oothecae and adult specimens were repeatedly found over several years.

The new records from Hungary and Romania represent another in a series of proofs of the presence of established populations in the Pannonian Plain, as well as potential spread towards northern parts of Central Europe. Although the number of records in Serbia is now quite large, the species is largely restricted to just some cities and settlements. There is a possibility that the lack of targeted surveys virtually makes the species not very widespread, especially in the Balkan part of the country. Despite the previous fact, there is also a possibility that the territory of Serbia is a corridor for the spread of *H. tenuidentata* towards the Pannonian Plain, carried by vehicles of tourists who spent time in areas where the species has established populations, such as Greece and Bulgaria.

The spreading of *H. tenuidentata* across the Pannonian Plain was probably enabled by traffic and transportation of people and goods and facilitated by recent climate change in the context of global warming, as well as the heat island effect in and around cities.

It is not unrealistic to expect that in the coming years this species will expand its range further north, colonizing an increasingly large area of Europe. It is of particular importance to monitor the impact on indigenous species, especially the native mantids. Of special interest will be monitoring of the status of its populations after harsher winters in Pannonian Plain, as well as examining current adaptations to the local climatic conditions.

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