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EXPANSION OF THE INVASIVE BALKAN SLUG *TANDONIA KUSCERI* (STYLOMMATOPHORA: MILACIDAE): A NEW FRONTIER IN NORTHERN UKRAINE AND OTHER NEW RECORDS

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ABSTRACT: The distribution of the invasive slug *Tandonia kusceri* is reviewed and mapped with our new findings and previously unpublished recent reports based on photographs from citizen science databases (iNaturalist, UkrBIN). Two new colonies of *T. kusceri* were found and monitored in Kyiv city (Northern Ukraine) during the 2021–2022. These colonies are about 350 km north from the nearest previously published records of this species, as well as any other species of Milacidae in Eastern Europe. The slugs inhabit the urban open and semi-open landscapes of Kyiv city together with several other invasive molluscs, in one locality notably together with *Oxychilus translucidus*, *Harmozica ravergiensis* and *Xerolenta obvia*. One specimen of *T. kusceri* was found in a basement of a private estate in Radyvyliv town (Rivne region, Northern Ukraine) in 2020, but it is unknown whether it represents an established colony. Previously unpublished reports of *T. kusceri* on iNaturalist include two reliable findings from the Caucasian region, in Georgia and Russia, both in 2021. These are the first reports of any *Tandonia* in Caucasus, as well as in the mentioned countries, with one in Georgia being the eastmost frontier for this genus. In addition to a previously published 2013 report of *T. kusceri* near Chicago, USA, there are multiple iNaturalist reports of this slug in southern Ontario, Canada (600 km east of Chicago), starting from 2017. Moreover, there are several new reports of *T. kusceri* in Ukraine, including Kherson, Dnipro, Kryvyi Rig, Marhanets and Kamianets-Podilskyi cities. Considering that most of our new *T. kusceri* records are from the 2020s, it is most likely that slug has invaded these regions very recently and is still continuing to expand northward and eastward in Europe. This species is expected to further extend its range both in Europe and North America.

KEYWORDS: citizen science; Europe; Gastropoda; Mollusca; terrestrial molluscs

INTRODUCTION

Invasions by terrestrial molluscs, especially slugs, in new regions outside their natural ranges are often causing significant consequences both to human enterprises and to natural ecosystems (SVERLOVA et al. 2006, ROWSON et al. 2014, ZEMANOVA et al. 2017). Therefore, each new case of extension in the ranges of such organisms requires attention. About 12 species of terrestrial slugs are expanding their ranges in Eastern Europe, with several being extremely important pests (SVERLOVA et al. 2006, SON 2010, BALASHOV & BAIDASHNIKOV 2012, BALASHOV 2016, BALASHOV et al. 2018a, GURAL-SVERLOVA et al. 2019, TURÓCI et al. 2020, BALASHOV & MARKOVA 2021). One of these invasive species is *Tandonia kusceri* (Wagner, 1931) (Milacidae), a large slug (up to 10 cm) originally distributed in the central and northern parts of the Balkan peninsula: in Bulgaria, the European part of Turkey, northern Greece, North Macedonia, southern Serbia and Dobrudzha in eastern Romania (WIKTOR 1987, 1996, WELTER-SCHULTES 2012, GEORGIEV & IVANOVA 2015, GEORGIEV 2016). At least since 1902 *T. kusceri* is also present in Odessa region of Ukraine

(LINDHOLM 1908, SON 2004, SVERLOVA et al. 2006, GURAL-SVERLOVA et al. 2019). It is not completely clear if this was a case of an early invasion or a natural occurrence on the northern border of its indigenous range. In the 1990s and 2000s *T. kusceri* was shown to expand eastward in Southern Ukraine, to Mykolaiv region and Crimea (KRAMARENKO & SVERLOVA 2001, SON 2004, LEONOV 2007). In 2013 *T. kusceri* was found near Chicago in the USA (GERBER 2014), which was the only published record from outside of Europe until now. Since the 2010s *T. kusceri* was shown to occur in northeastern Montenegro (TELEBAK et al. 2013), Moldova (BALASHOV et al. 2013), Slovakia (KORÁBEK et al. 2016, ČEJKA et al. 2020), Samothraki Island in Greece (GEORGIEV 2017), Transcarpathian Ukraine (GURAL-SVERLOVA et al. 2019), Hungary (TURÓCI et al. 2020), northern Serbia (GOJŠINA 2021) and Austria (DUDA et al. 2022).

In 2021 we found *T. kusceri* in Kyiv city, very far from its previously published records, and noticed numerous other interesting recent reports by the general public in online databases (iNaturalist, UkrBIN) that are becoming a significant tool for the study of invasive species (LARSON et al. 2020). Therefore, the goal of our study was to review present distribution of *T. kusceri* and to examine its new colonies in Kyiv city.

MATERIAL AND METHODS

Slugs were examined from the two recently-discovered colonies of *T. kusceri* in Kyiv city (Figs 1–2): (1) under and near a railway bridge on Protasiv Yar str., Kyiv city, 50°25'38.1"N, 30°30'25.4"E, 25.05.2021 and 26.10.2022 (4 specimens, collected by both authors); (2) a private estate on Verhnogirska str., Chorna Gora area, Kyiv city, 50°24'29.2"N, 30°32'02.7"E, 27.09.2021, 01.05.2022 and 22.10.2022 (19 specimens, collected by ANDRIY SIMON, his photos available on iNaturalist: 96367778, 114194154, 140058328). We also have a single *T. kusceri* slug found (3) in a basement of a private estate in Radyvyliv town, Rivno region, Ukraine, 50°07'21.0"N, 25°14'52.2"E, October 2020 (collected by VOLODYMYR BATOCHENKO).

Material was collected, handled and identified using common methods for working with terrestrial slugs (KERNEY et al. 1983, ROWSON et al. 2014, BALASHOV 2016) and is kept in the Collection of terrestrial molluscs of I. I. Schmalhausen Institute of Zoology (Kyiv, Ukraine).

Identification of the slugs was according to WIKTOR (1987) with consideration of a recently published study (SCHALLENBERG et al. 2022). Identification was verified by the structure of genitalia (Fig. 3) for both areas in Kyiv with two slugs from each location dissected, as well as for the single slug from Radyvyliv.

For the map (Fig. 4), together with our new findings, we started with the published data (GROSSU 1983, WIKTOR 1987, KRAMARENKO & SVERLOVA 2001, SON 2004, LEONOV 2007, BALASHOV et al. 2013, TELEBAK et al. 2013, GEORGIEV & IVANOVA 2015, GEORGIEV 2016, 2017, GURAL-SVERLOVA et al. 2019, ČEJKA et al. 2020, TURÓCI et al. 2020, GOJŠINA 2021, DUDA et al. 2022). The following reports from the online databases iNaturalist (www.inaturalist.org) and UkrBIN (www.ukrbin.com) were added: (4) roadsides near Khashuri town, Georgia, 41°58'28.2"N, 43°33'15.4"E, 02.10.2021 (iNaturalist 100049633); (5) Znamensky settlement, Krasnodar city, Russia, 45°03'21.9"N, 39°09'59.2"E, 11.04.2021 (iNaturalist 73601907); (6) Antonivka settlement, Kherson city, Kherson region, Ukraine, 46°39'49.7"N, 32°43'23.8"E, 11.09.2021 (iNaturalist 94775904); (7) Kazanka settlement, Mykolaiv region, Ukraine, 47°49'52.1"N, 32°49'42.4"E, 21.07.2022 (iNaturalist 127360607); (8) Marhanets city, Dnipro region, Ukraine, 47°38'53.2"N, 34°37'28.9"E, 26.12.2022 (iNaturalist 145098511); (9) Kryvyi Rig city, Dnipro region, Ukraine, 48°04'55.7"N, 33°30'34.3"E, 28.07.2018 (UkrBIN 82947, 82948); (10) Dnipro city,

Figs 1–2. *Tandonia kusceri* from Kyiv city: 1 – Protasiv Yar, 2 – Chorna Gora

Dnipro region, Ukraine, 48°25'28.8"N, 35°08'00.8"E, 23.11.2021 (UkrBIN 225306, "*Limax*"); (11) Kamianets-Podilskyi city, Khmelnytskyi region, Ukraine, 48°40'23.5"N, 26°33'40.0"E, 17.09.2019 (UkrBIN 128174).

Additionally the following iNaturalist reports from North America are discussed in this paper: (12) Chicago, Illinois, USA, 41°55'00.3"N, 87°40'31.3"W, 22.06.2018 (iNaturalist 13698184); (13) same, 41°58'19.8"N, 87°42'08.1"W, 12.09.2019 (iNaturalist 32623349); (14) Hamilton, Ontario, Canada, 43°13'45.4"N, 79°47'02.8"W, 24.10.2017 (iNaturalist 8537677, 8537850, 8660885); (15) Burlington, Ontario, Canada, 43°22'22.5"N, 79°44'17.3"W, 27.08.2020 (iNaturalist 57974578); (16) Toronto, Ontario, Canada, 43°40'40.0"N, 79°19'03.8"W, 07.03.2020 (iNaturalist 39669123); (17) same, 43°40'11.4"N, 79°22'52.9"W, 28.05.2020 (iNaturalist 47683484); (18) same, 43°40'06.7"N, 79°19'16.6"W, 06.08.2020 (iNaturalist 55664533); (19) same, 43°40'40.3"N, 79°17'36.1"W, 09.04.2021 (iNaturalist 73437673).

We only used those observations from the online databases where we were able to confirm or make reliable identifications as *T. kusceri*. Accuracy of coordinates for such observations relies on the faithfulness of the users who uploaded them (many of these users are biologists or experienced amateur naturalists, at least most of them are reliable). The reliability of the most important reports is additionally addressed below.

RESULTS

The two colonies of *T. kusceri* were sampled in Kyiv city, in Protasiv Yar and Chorna Gora areas, on the distance of 3 km from each other, near the central part of the city. Both sites are along the same branch of a railroad, in Protasiv Yar directly next to a railway bridge and in Chorna Gora in 250 m from the rails.

The first single specimen of *T. kusceri* in Protasiv Yar was found by us on 25.05.2021. We studied the area again on 26.10.2022 and found 3 more slugs after an intense search at sunset. In Chorna Gora the first 7 slugs were collected on 27.09.2021, several more were observed on 01.05.2022 and over 12 specimens were collected on 22.10.2022. Therefore, on the both sites the colonies of *T. kusceri* are confirmed to survive for over a year, including wintering in 2021–2022.

In Protasiv Yar slugs were found on a large kerb of footpaths at the edge of the road and in the litter of a narrow strip of vegetation (mostly grass) along these footpaths. Most of the slugs were found directly next to the structures of the bridge. There are numerous small holes among the large structures of concrete and stones, which could be similar to the natural rocky habitats and could provide some refuges for surviving during the cold and dry periods. On the strip of vegetation along the road there are very abundant colonies of the invasive snails *Harmozica ravergiensis* (Férussac, 1835) and *Xerolenta obvia* (Menke, 1828). Moreover, several specimens of such molluscs as *Cochlicopa lubrica* (Müller, 1774), *Oxychilus translucidus* (Mortillet, 1854) and *Deroceras reticulatum* (Müller, 1774) were found there. The invasive *X. obvia* is a Central European species whose natural range is overlapping with that of *T. kusceri*, while *H. ravergiensis* and *O. translucidus* are invasive species of Caucasian origin (Balashov 2016). *Harmozica ravergiensis* was not reported from Kyiv city before now, but a report from a nearby village was published (Balashov et al. 2018b). In recent years this species was found by us in Kyiv city not only on this site, but rather widely in and around the Protasiv Yar area, including a nearby park.

In Chorna Gora *T. kusceri* lives in a private estate and its findings were associated mostly with a heap of stones (building materials). Such slugs as *Deroceras reticulatum*, *Deroceras* cf. *caucasicum* (Simroth, 1901), *Limacus* cf. *maculatus* (Kaleniczenko, 1851) and *Limax maximus* Linnaeus, 1758 were also found on the site.

One specimen of *T. kusceri* was collected in a basement of a private estate in Radyvyliv town (Rivno region, Northern Ukraine) in the October 2020. This slug was reported to represent a small colony that lives in a basement and was never seen in this estate outside the basement. But we can only confirm a single slug that was sent to us. Several specimens of the invasive slugs *Deroceras caucasicum* and *Krynickillus melanocephalus* Kaleniczenko, 1851 were collected in the same area of Radyvyliv town outdoors and were sent to us together with *T. kusceri* in the same vial.

We have studied the genitalia in the four specimens from Kyiv (Fig. 3) and in one specimen from Radyvyliv. All correspond well to the descriptions of *T. kusceri*, first of all by the very long epiphallus, which does not occur in the other species of *Tandonia* (Wiktor 1987, Balashov 2016, Schallenberg et al. 2022).

Externally *T. kusceri* differs from the other *Tandonia* species by the large size (up to 10 cm), by the small dark spots on the lighter background of the back and especially on the mantle, as well as by the dark bands on the sides of the mantle (Figs 1–2). By these external characters *T. kusceri* cannot be confused with two other *Tandonia* species known from Eastern Europe, *T. cristata* (Kaleniczenko, 1851) and *T. kaleniczenkoi*

(Clessin, 1883), as well as with the widely distributed invasive *T. budapestensis* (Hazay, 1880). All of these slugs are much smaller and of significantly different colouration (WIKTOR 1987, BALASHOV 2016). The only similar species that can be confused with *T. kusceri* is *T. rustica* (Millet, 1843). This genetically distinct species is distributed in Western and Central Europe, with the eastmost isolated populations in Czechia, Hungary and central Romania (GROSSU 1983, WIKTOR 1987, TURÓCI et al. 2020, SCHALLENBERG et al. 2022). This is partly overlapping with the non-indigenous distribution of *T. kusceri* (Fig. 4) and is close enough to our present findings to consider *T. rustica* as a possibility for the similar-looking slugs. But *T. rustica* is not tending to live in the anthropogenic environment and it appears to be a non-synanthropic species in contrast to *T. kusceri*. It was even proposed to distinguish *T. rustica* from *T. kusceri* by its occurrence in the natural woodland habitats in contrast to the disturbed synanthropic habitats of *T. kusceri* (SCHALLENBERG et al. 2022). Also, there are not any recent reports about expansion of *T. rustica* outside its previously known range, especially eastward. Distribution of *T. rustica* in Czechia, Hungary and Romania, in our opinion, appears to be native (although, it is not completely clear from existing data). Therefore, all recent findings of similar-looking slugs outside native distribution of *Tandonia* are likely to represent *T. kusceri*, not *T. rustica*. We consider it possible to identify the observations of such *Tandonia* slugs from Eastern Europe, Caucasus and North America in the online databases as probable *T. kusceri* or *T.* cf. *kusceri*. But we have not used for our map (Fig. 4) any photo reports of the similar slugs from Central Europe within known distribution of *T. rustica*, although there are some notable reports that could represent *T. kusceri* (e.g., iNaturalist 92488593, 95456860, 136267415). SCHALLENBERG et al. (2022)

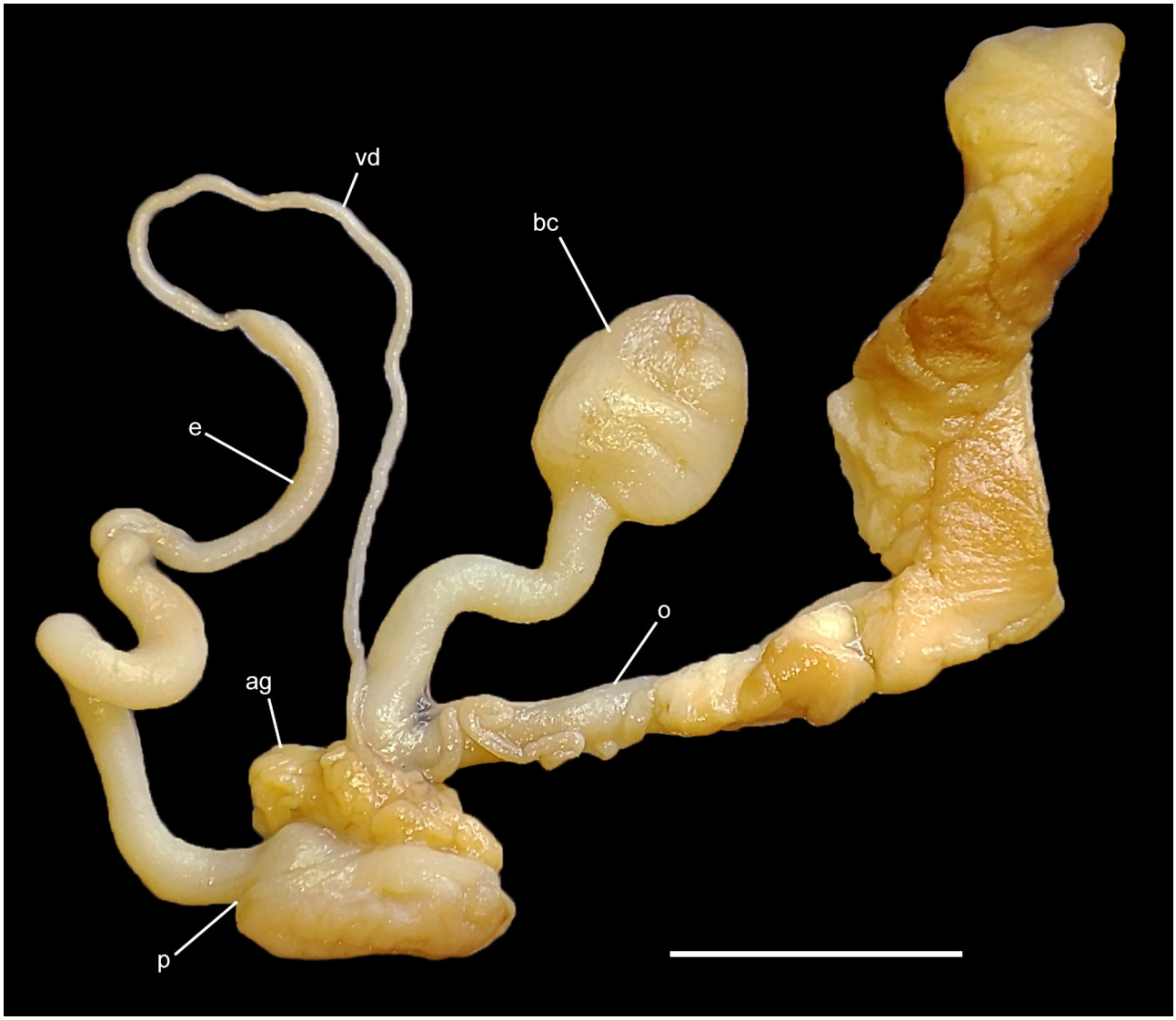

Fig. 3. Genitalia of *Tandonia kusceri* from Protasiv Yar in Kyiv city (collected 22.10.2022): ag – accessory gland, bc – bursa copulatrix, e – epiphallus, o – oviduct, p – penis, vd – vas deferens. Scale bar 5 mm

suggested that all reports of *T. rustica* from Romania may represent *T. kusceri*, but GROSSU (1983) distinguished these two species as distributed in different parts of Romania and illustrated the genitalia of both species showing the main differences in the current understanding of these species, first of all in the length of the epiphallus.

The most notable observations of *T.* cf. *kusceri* in the online databases are two from the Caucasian region, in Georgia and Russia: on the roadsides near Khashuri town in Georgia on 02.10.2021 (iNaturalist 100049633) and among the private estates in Znamensky settlement of Krasnodar city in Russia on 11.04.2021 (iNaturalist 73601907). At least 3 specimens of *T.* cf. *kusceri* are present on the photographs from each of these sites. Before now no *Tandonia* species was reported to occur neither in Georgia nor in Russia (SYSOEV & SCHILEYKO 2009). Considering that both of these findings are outside of the previously known distribution of *Tandonia* the reliability of these records should be especially addressed regarding the possibility of the erroneously indicated coordinates and other data.

Near Khashuri *T.* cf. *kusceri* was observed by a student-biologist from Germany. He has uploaded several more observations from the same locality on the same day and many more from his trip in Georgia. In personal communications it was confirmed that location is correct.

In Krasnodar *T.* cf. *kusceri* was observed by a local naturalist who has uploaded over 1,200 various observations from this city on iNaturalist. The observation of *T.* cf. *kusceri* fits well in the general pattern of these observations. A land snail *Helix lucorum* Linnaeus, 1758 and a woodlouse *Armadillidium vulgare* (Latreille, 1804) (Isopoda) were observed on the same day together with *T.* cf. *kusceri*. The animals were observed using the iNaturalist Android Application for a smartphone, therefore the coordinates and date were detected and indicated in the database automatically by the device. The accuracy of coordinates was detected as 3 m (within 3 meters from the exact co-

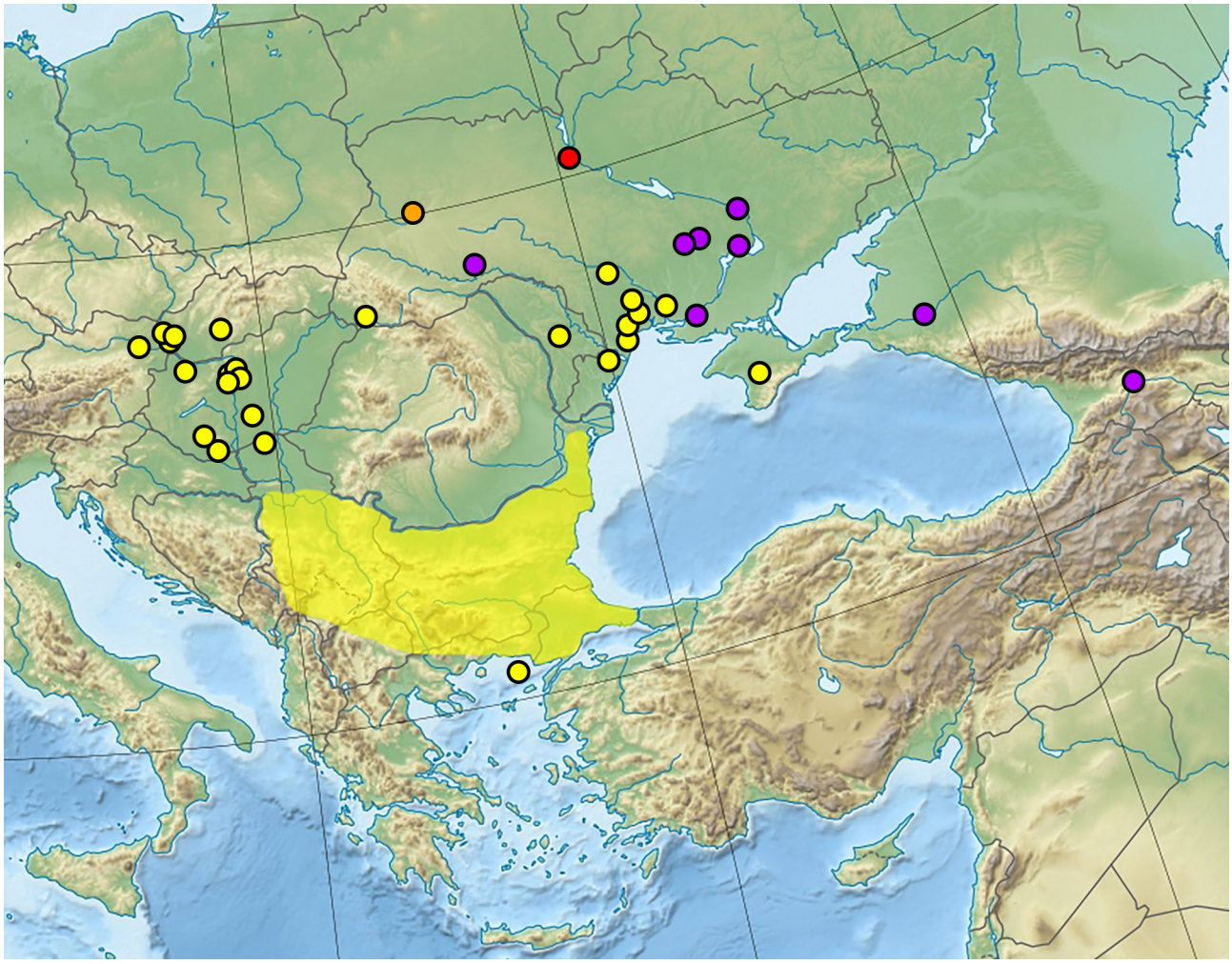

Fig. 4. Distribution of *Tandonia kusceri* (except colonies in North America). Shaded area – relatively continuous (native?) distribution; yellow dots – previously published records; red dot – our new findings in Kyiv; orange dot – finding in a basement in Radyvyliv town, Rivno region; purple dots – new reports based on photographs from iNaturalist and UkrBIN

ordinates). Coordinates and date detected by the device are present also in the metadata of the uploaded photo. We consider it as a high-quality record with the highest reliability possible for a report from an online database.

Other notable records of *T.* cf. *kusceri* on iNaturalist and UkrBIN (Fig. 4) include findings in the several settlements of Ukraine where this species was not reported to occur before now: on the left bank of Dnipro River in Antonivka settlement of Kherson city (Kherson region), in Kazanka settlement (Mykolaiv region), in Marhanets, Kryvyi Rig and Dnipro cities (Dnipro region) and in Kamianets-Podilskyi city (Khmelnytskyi region) (Fig. 4). All of these records apparently represent outdoor colonies in the urban landscapes, but there are no confirmations of wintering and long survival. We have studied each case and consider them reliable, but we will not address their reliability individually here, because the reports are not far from the confirmed non-indigenous distribution of *T. kusceri* (Fig. 4).

In addition to the finding of *T. kusceri* in 2013 near Chicago in the USA (Gerber 2014) there are a few iNaturalist reports of *T.* cf. *kusceri* from Chicago city in 2018 and 2019, as well as numerous reports from southen Ontario, Canada (600 km east of Chicago), starting from 2017 (see "Material and methods").

DISCUSSION

Present data show a significant expansion of *Tandonia kusceri* in Europe (Fig. 4) and North America during recent years. Before the 2010s this species was reported to expand from its native range only to the western and central parts of Southern Ukraine (Odessa and Mykolaiv regions, Crimea). All other reports about expansion of *T. kusceri*, both previously published and presented here, are from the last decade. This is suggestive of very recent processes that are still ongoing. Most of the *T. kusceri* expansion in Europe is happening in two directions: northward and eastward (Fig. 4). Therefore, this species is mainly expanding to regions with a colder and more continental climate compared to its native range. A similar situation is taking place with many other organisms in Europe during the last decades, including several terrestrial slugs, most notably *Arion vulgaris* Moquin-Tandon, 1855, *Limacus flavus* (Linnaeus, 1758), *Limacus maculatus*, *Krynickillus melanocephalus* and *Deroceras caucasicum* that all have invaded Kyiv city recently (Sverlova et al. 2006, Son 2010, Rowson et al. 2014, Balashov 2016, Balashov et al. 2018a, Turóci et al. 2020, Balashov & Markova 2021). The first two of these species originated in Southern Europe and are currently expanding northward and eastward, while the other three species are of Caucasian-Crimean origin and are expanding mostly northward and westward. The slug *L. flavus* started to expand its range much earlier than other mentioned species, but it was associated with basements and other artificial underground habitats, only recently being found to live in the open-air habitats of Kyiv city (Balashov & Markova 2021). Consequently, it appears that *T. kusceri* is expanding its range mainly in response to global climate changes and is representing the general trends of the "southern" biodiversity moving northward in Europe. Another necessary factor for the successful invasions of *T. kusceri* is probably globalisation.

Observations of *T.* cf. *kusceri* on iNaturalist from Chicago city, USA, in 2018 and 2019, are suggesting that after *T. kusceri* was found near Chicago in 2013 (Gerber 2014) this slug has survived in this area and spread further. Numerous iNaturalist reports of *T.* cf. *kusceri* in southen Ontario, Canada, in and around Toronto city (600 km east of Chicago), during 2017–2021, are indicative of a further expansion of this species in North America. Therefore, apparently, *T. kusceri* has become an established invasive species in North America.

It is not clear whether the expansion of *T. kusceri* to North America is a result of the climate changes or just an occasion that happened starting from 2010s only because of the globalisation. But considering that slugs has invaded the temperate regions of North America, with a climate that is more comparable to that in the central part of Eastern Europe, rather than in the central Balkans, it appears to be possible that these invasions are also mainly a result of global climate changes, as in Europe. In this case perhaps it means that *T. kusceri* is a more successful invader in regions where climate has become suitable for it during the recent climate changes, rather than in the regions with climate more comparable to the current climate in the area of its native distribution.

It is notable that in Northern Ukraine *T. kusceri* is co-occurring with several invasive mollusc species of the Caucasian origin (see above), while the present data (Fig. 4) are showing that it has also invaded the area of their native distribution in the Caucasian region. It is indicative of a possibility for the Balkan and Caucasian species not only to invade northward into the regions with colder climate, but also for an exchange of biodiversity between these regions.

The mechanisms of the *T. kusceri* invasions are not clear. Most terrestrial slugs are transported accidentally among plants, especially horticultural cargos (Bergey et al. 2014). But association of the

T. kusceri colonies in Kyiv with a railroad and with rocks may suggest that perhaps in some cases this slug is invading with building materials or on train carriages. Such mechanisms exist for several xerophilous land snails, in Eastern Europe most notably *Xeropicta derbentina* (Krynicki, 1836) and *Xerolenta obvia* (Gural-Sverlova & Gural 2017, Balashov et al. 2018c, Gural-Sverlova et al. 2022). The latter species occurs with *T. kusceri* near a railway bridge in the Protasiv Yar area. *Tandonia kusceri* is a relatively xerophilous slug that tend to live in the open and rather dry habitats, so perhaps it could survive such transportation in some cases.

As far as we know there are no reports about the economic importance of *T. kusceri*. Therefore, it appears not to be a significant pest, but this topic requires additional studies.

In summary, *T. kusceri* has spread rapidly in the last decade and is expected to extend its range greatly in the near future, even more so with further climate changes. In Europe this species is spreading mostly northward and eastward from its native range in the Balkans and should be expected to become widespread in Ukraine, Romania, Moldova and southwestern Russia, as well as to invade Czechia and Poland, probably also Belarus, Baltic countries and elsewhere, as it has already happened with some other invasive slugs. In North America *T. kusceri* appears to be becoming an established species in Illinois and southern Ontario and, therefore, should be expected to spread further at least in the northern USA and southern Canada. From a species of local importance *T. kusceri* is very quickly becoming a widely distributed invader.

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