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Hidden in plain sight: six millipede species (Myriapoda: Diplopoda) new for the fauna of Switzerland

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Abstract: Diplopoda are poorly studied in many regions. The last comprehensive work on the millipede fauna of Switzerland was published in 1993 and listed 124 outdoor-living species. Recent sampling efforts have resulted in the discovery of six millipede species of European origin that were not previously known to occur in Switzerland: *Cylindroiulus britannicus* (Verhoeff, 1891), *C. salicivorus* Verhoeff, 1908, *C. vulnerarius* (Berlese, 1888), *Heteroiulus intermedius* (Brölemann, 1892), *Anamastigona pulchella* (Silvestri, 1894) and *Macrosternodesmus palicola* Brölemann, 1908. None of them is currently invasive in Switzerland, but some are rapidly expanding across Europe and other regions of the world. A species which was previously only known from northern Italy, *H. intermedius*, was found in a forest close to Bellinzona. It is likely a native Swiss species which has previously been overlooked. The other five species were collected in human-made habitats in the city of Basel and its surroundings, suggesting human-caused introduction. Two species, *C. britannicus* and *M. palicola*, likely have an Atlantic origin, while the three remaining species, *C. salicivorus*, *C. vulnerarius* and *A. pulchella*, are originally from Italy. The biogeography of these six species is discussed, and photographs of specimens of each species and their gonopods are presented.

Keywords: Basel - Bellinzona - faunistics - invasive species - new records - non-native species - soil fauna - urban biodiversity.

INTRODUCTION

Millipedes (Diplopoda) constitute a highly diverse group of arthropods, with more than 11 000 described species worldwide (Enghoff *et al.,* 2015). However, they are poorly studied in many regions and estimates of their real diversity are as high as 80 000 species (Hoffman, 1980), though caution has been advised considering such estimates (Brewer *et al.,* 2012). Most millipede species are soil dwelling detritivores, feeding mostly on decaying plant material, but some can feed on fungi, faeces, algae, and rarely, dead invertebrates (David, 2015). They play an important role in litter decomposition in temperate forests, consuming up to 15% of the annual leaf fall (Golovatch & Kime, 2009). While millipedes seem to have a low assimilation efficiency, they are important for nitrogen mineralization (Cárcamo *et al.,* 2000; David, 2015). Most millipede species have a relatively low dispersal ability, which results in small distribution ranges and in a high number of endemic and microendemic species (Golovatch & Kime, 2009). Higher taxonomic levels have also limited geographical ranges, making them a suitable group for biogeographical studies (Enghoff, 2015). However, many species have recently expanded their distribution ranges, some of them being recorded in new biogeographical regions. In some cases this is clearly due to human-related transport, and some of these species became invasive (Stoev *et al.,* 2010). Despite their diversity, ubiquity and ecological importance, millipedes are a yet understudied group of arthropods (Brewer *et al.,* 2012).

In Switzerland the most recent comprehensive work on millipede faunistics was written by Pedroli-Christen (1993), who listed 126 millipede taxa (124 species, two of them with two subspecies each) occurring outdoors. While her work is an exhaustive compilation of the known records and a starting point for studying the Swiss millipede fauna, the nomenclature is out of date and a new list including recent synonyms and records is urgently needed. Only the record of one additional millipede species, *Polydesmus rupicursor* Verhoeff, 1907, found in southeastern Switzerland (Bogyó *et al*., 2013), was published since Pedroli-Christen (1993). According to the known distribution of *P. rupicursor* in northern

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Italy (Kime & Enghoff, 2011) it is not clear whether this species recently arrived in Switzerland, or if it is native to the country. The most recent works of A. Pedroli-Christen, R. Hoess and A. Scholl were published in the 1990s and early 2000s (e.g. Pedroli-Christen & Scholl, 1996; Stojalowska & Pedroli-Christen, 1996; Hoess & Scholl, 1999; Hoess, 2000; Hoess & Scholl, 2001). The absence of active diplopodologists in Switzerland since then has resulted in incomplete knowledge of the current species distribution of this group. Specialists working abroad, who received material collected in Switzerland (e.g. Vilisics *et al.,* 2012), partially mitigated this problem. However, much remains unknown. For example, Wittenberg (2005) stated that millipedes are a neglected group for which it is not possible to provide a list of invasive species for Switzerland. He suggested that their number (together with Chilopoda) should not be more than ten species and these species should not be a threat to the native biodiversity and ecosystems. However, in recent times at least one invasive millipede species, *Oxidus gracilis* (Koch, 1847) (Polydesmida, Paradoxosomatidae), caused problems in rural areas of Switzerland because of its swarming behaviour (see Macbeth, 2018). The consequences for local biodiversity from the invasion by this or other non-native millipede species in urban areas, as well as their potential to colonise rural or natural areas are not known. Recent surveys resulted in six new millipede records for Switzerland, which are presented in this paper. Comments on their distribution ranges and their presence in Switzerland are provided, together with photographs of the specimens and their gonopods.

MATERIAL AND METHODS

Most of the specimens examined were collected in two biodiversity surveys focusing on soil-surface-active invertebrates. The first survey was conducted in 26 urban forests and 26 grasslands in the city of Basel and its surroundings in 2014 (see Melliger *et al.,* 2018 for a detailed description of the survey sites). In the second survey invertebrates were sampled in 35 private gardens in Basel and nearby municipalities during summer and autumn 2018. Additional specimens were captured during sporadic millipede sampling in the region of Basel and in the canton of Ticino in the years 2017 and 2018. Three methods were used to sample millipedes: active capture, hay baits and pitfall traps.

The active capture was conducted by visually searching under stones, deadwood and leaf litter, and in the case of the private gardens also under pots and in compost heaps. The active capture in gardens was conducted for 15 min./visit, and each garden was visited twice each in early summer, late summer and autumn (a total of 90 min search per garden). The specimens were collected with forceps and directly put in 70% ethanol.

Pitfall traps had a diameter of 5.8 cm and were filled with 60 ml of saturated brine as preservative. Five pitfall traps were placed in each private garden and operated for 7-day periods in early summer, late summer and autumn each. The traps were protected from rain and animal interference by a roof consisting of a plastic square of 27 x 27 cm. During the 2014 survey, 12 pitfall traps of the same type as in the gardens were set in two parallel rows of 6 traps in forests and grasslands in Basel and its surroundings. Pitfall traps were separated by 5 m. No roofs were used to avoid drawing attention in these publicly accessible locations. Pitfall traps were operated for 7-day periods each in spring, summer and autumn. In forest sites pitfall traps were operated for two additional periods in summer. Five hay baits (Tuf *et al.,* 2015) were placed in each garden in the same periods as the pitfall traps were operating. Hay baits were subsequently transported to the laboratory and individually placed in Berlese funnels for a standard period of 10 days to extract the arthropods. Two hay baits were used in December 2017 and September 2018 in one of the sampling points of the 2014 surveys, an urban forest fragment in Basel. These hay baits were operated for a month and placed in Berlese funnels for 10 days.

Although the gardens were surveyed using three methods, specimens of all six species new for Switzerland were exclusively collected by active capture. Due to privacy reasons the exact coordinates of the private gardens are not given, but a nearby point of the same street instead. Some male specimens were dissected for the study of their gonopods. Examples of all species were determined using a Leica M205 C and photographed using a Keyence VHX-6000 microscope. All specimens examined are deposited in the collection of the Naturhistorisches Museum Basel (NMB, registration numbers given).

TAXONOMIC PART

Order Julida Brandt, 1833
Family Julidae Leach, 1814
Genus *Cylindroiulus* Verhoeff, 1894
Cylindroiulus britannicus (Verhoeff, 1891)

Fig. 1

Iulus britannicus Verhoeff, 1891.
Cylindroiulus pollicaris Attems, 1904.
Cylindroiulus pollinaris. – Attems, 1933 (misspelling of *pollicaris*).

Material examined: NMB-699a; 1 male & 1 female; Switzerland, Basel-Landschaft, Liestal, 47°29’54.47”N, 7°43’59.91”E, 380 m; 10.04.2018; J. D. Gilgado leg.; active capture under stones at the margin of a path in agricultural land. – NMB-699b; 2 males & 1 female; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′33.03″N, 7°34′16.22″E, 315 m; 12.06.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-699c; 1 male; same data but 17.10.2018. –

NMB-699d; 1 male; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′27.19″N, 7°33′23.18″E, 325 m; 26.07.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-699e; 1 male; same data but 16.10.2018. – NMB-699f; 1 male; Switzerland, Basel-Stadt, 47°31′33.86″N, 7°35′26.82″E, 360 m; 09.08.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-699g; 1 male, 4 females & 1 juvenile; same data but 26.09.2018. – NMB-699h; 2 males & 1 female; same data but 03.10.2018.

Distribution: In Europe this species is known from Austria, the British Isles, the Czech Republic, Denmark, Finland, France, Germany, Lithuania, the Netherlands, Norway, Poland, Portugal (mainland, Azores and Madeira Islands), Romania, Russia (Central European Russia and north-western Russia), Spain (mainland and Canary Islands), Sweden and Ukraine. It has been introduced to Africa, Australia, North and South America and the Oriental region (Kime & Enghoff, 2017).

Remarks: This species is commonly found associated with decomposing deadwood, but also in soils close to deadwood and in leaf litter. The species may have a Lusitanian or Atlantic origin as it is a very common species in the British Isles, but it is nowadays a synanthropic cosmopolitan species (Kime & Enghoff, 2017).

Cylindroiulus salicivorus Verhoeff, 1908

Fig. 2

Cylindroiulus salicivorus Verhoeff, 1908.
Castaneoiulus salicivorus. – Verhoeff, 1930.

Material examined: NMB-700a; 1 male; Switzerland, Basel-Stadt, private garden, 47°34′01.05″N, 7°34′41.16″E, 260 m; 31.05.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-700b; 1 female; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′11.68″N, 7°33′49.24″E, 345 m; 20.06.2018; J. D. Gilgado *et al.* leg.; active capture.

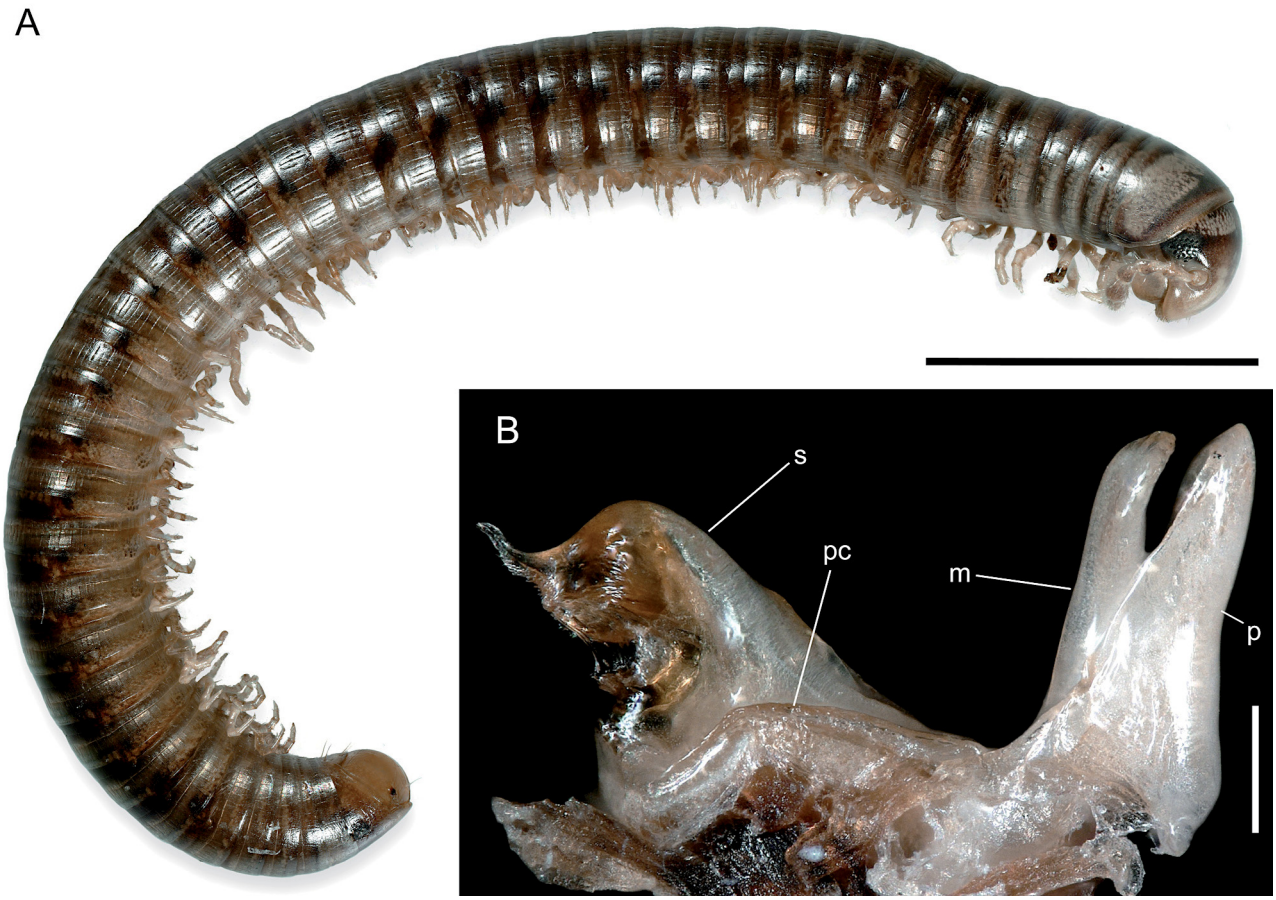

Fig. 1. *Cylindroiulus britannicus* (Verhoeff, 1891). (A) Dissected adult male from Basel-Stadt (NMB-699g). Scale bar 2 mm. (B) Gonopod of specimen from Liestal (NMB-699a) in lateral view. Scale bar 0.1 mm. Abbreviations: m, mesomerite; p, promerite; pc, lateral rim of paracoxite; s, solenomerite.

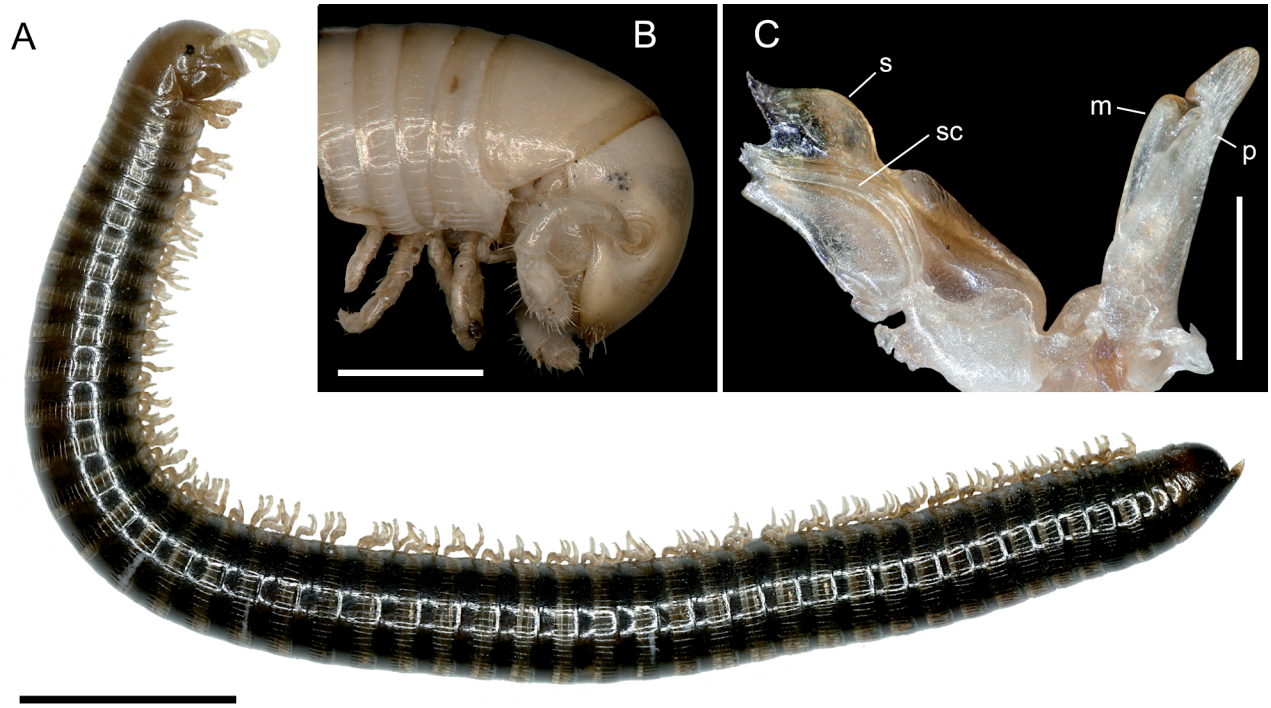

Fig. 2. *Cylindroiulus salicivorus* Verhoeff, 1908. (A) Adult female from Binningen (NMB-700b). Colour darkened due to preservation. Scale bar 2 mm. (B) Detail of head and anterior part of trunk of dissected male from Basel-Stadt (NMB-700a). Scale bar 0.5 mm. (C) Gonopod of same male specimen in lateral view. Scale bar 0.2 mm. Abbreviations: m, mesomerite; p, promerite; s, solenomerite; sc, sperm channel.

Distribution: Germany, Great Britain, Italy (Kime & Enghoff, 2017).

Remarks: *Cylindroiulus salicivorus* seems to naturally occur south of the Alps, were it has been recorded from wet grasslands with *Salix* trees and from humus beneath *Castanea* trees. The records from Scotland are from botanical gardens (Lee, 2006), and the record from Germany is from Karlsruhe Palace (Spelda, 2005), suggesting that it was introduced to these two locations (Kime & Enghoff, 2017).

Cylindroiulus vulnerarius (Berlese, 1888)

Fig. 3

Mesoiulus vulnerarius Berlese, 1888.
Typhloiulus vulnerarius (Berlese, 1888): auct.
Cylindroiulus ellingseni Verhoeff, 1912.

Material examined: NMB-701a; 1 male; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′09.67″N, 7°34′38.27″E, 300 m; 01.06.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-701b; 3 females; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′01.31″N, 7°34′52.79″E, 345 m; 10.08.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-701c; 1 juvenile; same data but 28.09.2018.

Distribution: Belgium, British Isles, Czech Republic, France, Germany, Italy, the Netherlands, Sweden. Also introduced into North America (Kime & Enghoff, 2017).

Remarks: This species is usually found in decaying wood and organic matter (such as compost or debris) in contact with the soil. *Cylindroiulus vulnerarius* has probably an Italian origin, since most records outside this country are in urban or suburban environments (Kime & Enghoff, 2017). However, as inferred from its presence in caves in Belgium and its abundance in the Netherlands and the British Isles, it is possible that in these areas this species had survived recent glaciations in microrefugia (Kime, 2004; Kime & Dethier, 2010; Kime & Enghoff, 2017).

Genus *Heteroiulus* Verhoeff, 1897

Heteroiulus intermedius (Brölemannn, 1892)

Fig. 4

Julus intermedius Brölemann, 1892.
Allajulus salvadorii Silvestri, 1896.

Material examined: NMB-272b; 1 male; Switzerland, Ticino, Bellinzona, forest close to settlements, 46°12′06.61″N, 9°02′17.88″E, 265 m; 01.04.2018; J.

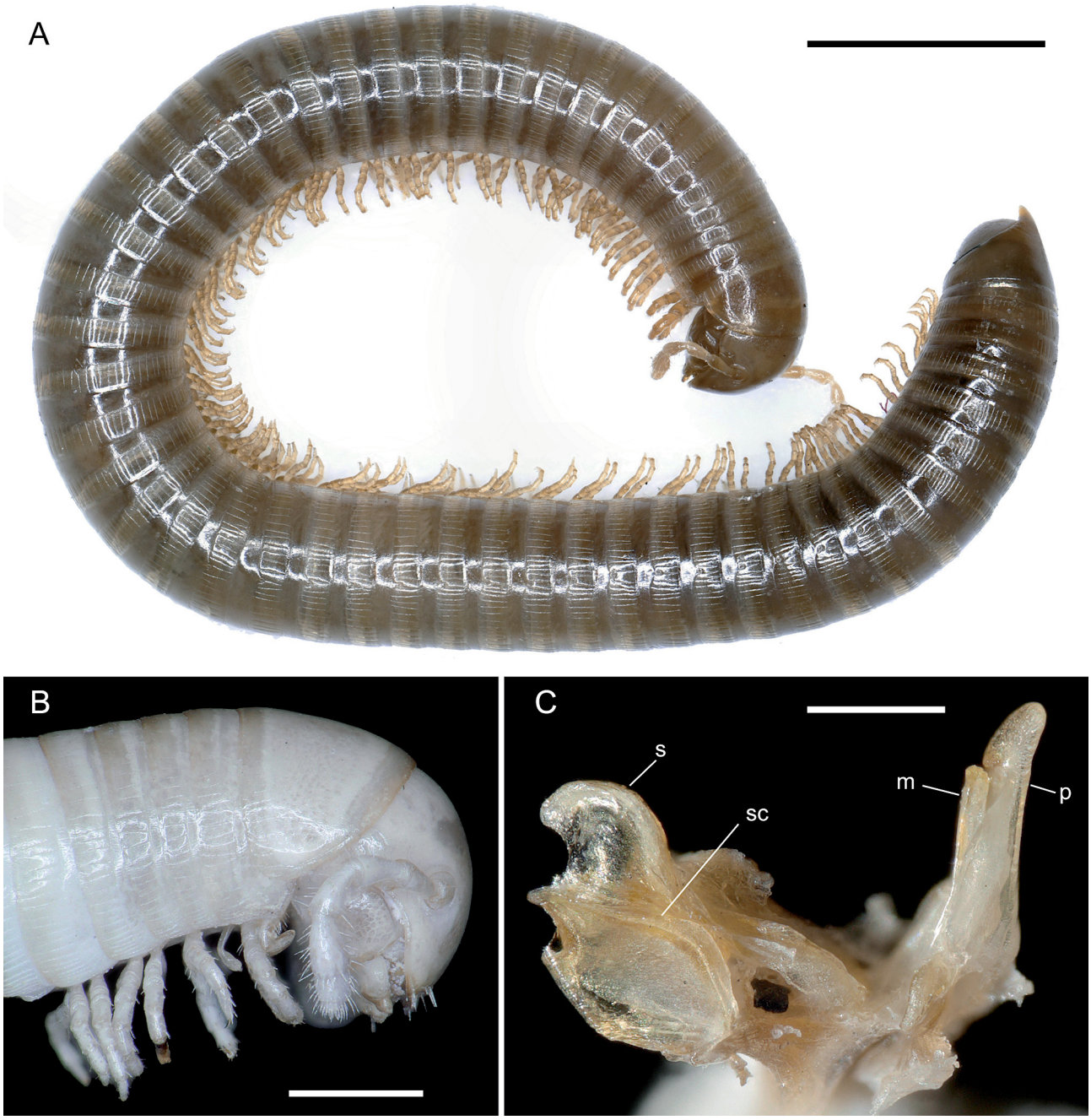

Fig. 3. *Cylindroiulus vulnerarius* (Berlese, 1888). (A) Adult female from Binningen (NMB-701b). Scale bar 2 mm. (B) Detail of head and anterior part of trunk of male (NMB-701a). Scale bar 0.5 mm. (C) Gonopod of same specimen in lateral view. Scale bar 0.2 mm. Abbreviations: m, mesomerite; p, promerite; s, solenomerite; sc, sperm channel.

D. Gilgado & V. Martínez-Pillado leg.; active capture under a stone.

Distribution: Northern Italy (Kime & Enghoff, 2017).

Remarks: This species is known to inhabit the deep and decomposed litter layer in *Castanea*, *Carpinus* and *Quercus* forests (Kime & Enghoff, 2017).

Order Chordeumatida Pocock, 1894
Family Anthroleucosomatidae Verhoeff, 1899
***Anamastigona pulchella* (Silvestri, 1894)**
Fig. 5

Craspedosoma pulchellum Silvestri, 1894.
Anamastigona attemsi Verhoeff, 1900.

Material examined: NMB-702a; 4 juveniles; Switzerland, Basel-Stadt, meadow beside forest

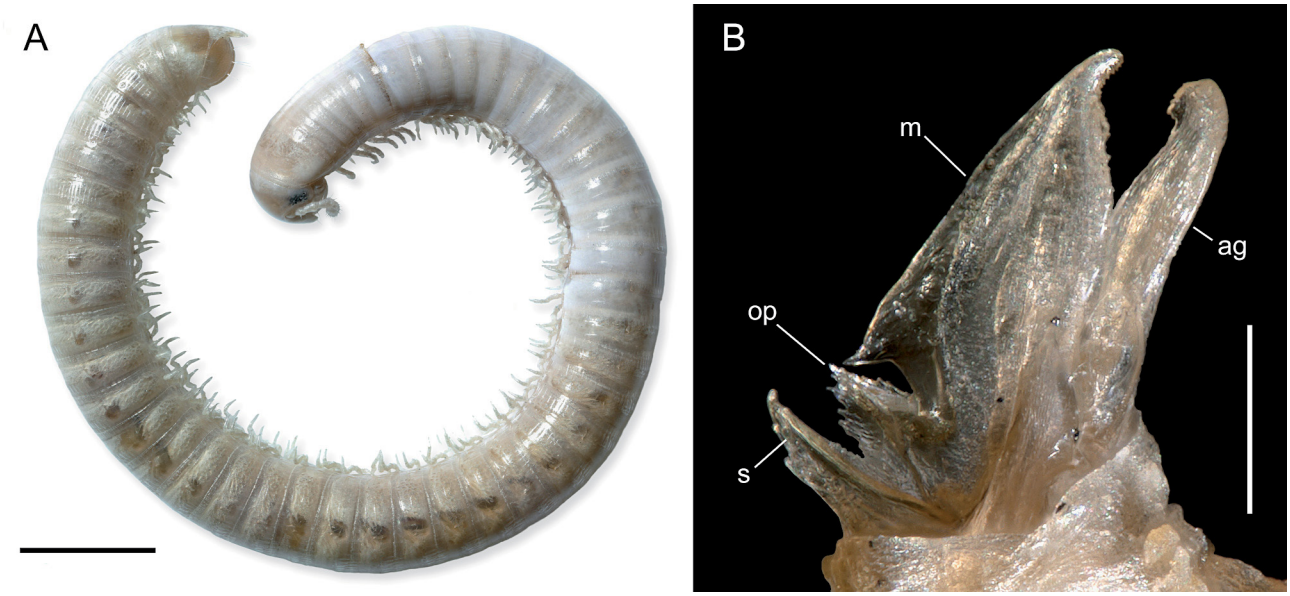

Fig. 4. *Heteroiulus intermedius* (Brölemannn, 1892). (A) Dissected adult male from Bellinzona (NMB-272b). Scale bar 1 mm. (B) Gonopod of same male specimen in lateral view. Abbreviations modified after Enghoff *et al*. (2013): ag, anterior gonopod; m, mesomerite; op, "opuntia-like" appendage; s, solenomerite. Scale bar 0.1 mm.

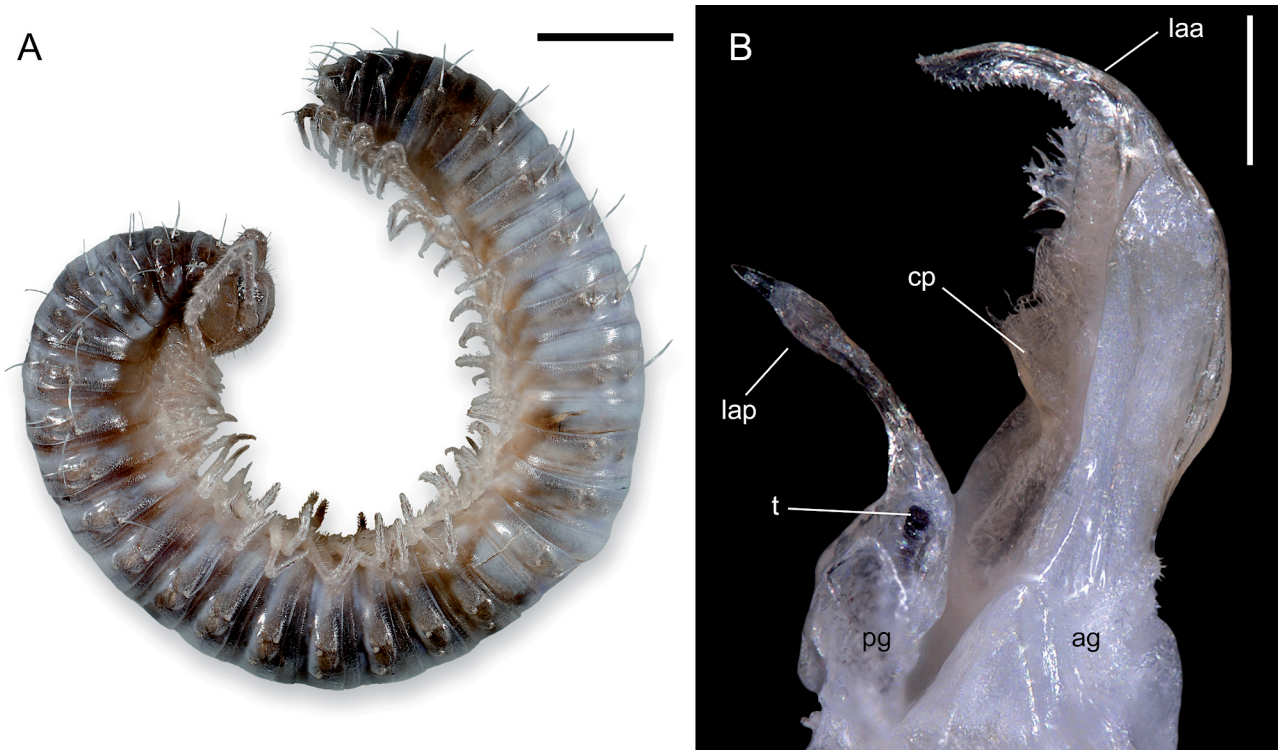

Fig. 5. *Anamastigona pulchella* (Silvestri, 1894). (A) Adult female from Basel-Stadt (NMB-702e). Several setae are missing, and the colour is faded because of handling and preservation, respectively. Scale bar 1 mm. (B) Gonopod of male (NMB-702g) in lateral view. Scale bar 0.1 mm. Abbreviations: ag, anterior gonopod; cp, colpocoxite; laa, lateral arm of anterior gonopod; lap, lateral arm of posterior gonopod; t, telopodite; pg, posterior gonopod.

fragment, 47°34′21.20″N, 7°36′52.43″E, 255 m; 26.06.2014; B. Braschler & R. Melliger leg.; pitfall trap. – NMB-702b; 4 juveniles; Switzerland, Basel-Stadt, forest fragment, 47°34′20.57″N, 7°36′52.45″E, 255 m; 03.07.2014; B. Braschler & R. Melliger leg.; pitfall trap. – NMB-702c; 1 male; same data but 21.10.2017; J. D. Gilgado leg.; active capture, gonopods on microscope slide mount. – NMB-702d; 1 male; same data but 21.10.2017; J. D. Gilgado leg.; active capture, gonopods on microscope slide mount. – NMB-702e; 4 females, 38 juveniles; same data but 17.01.2018; J. D. Gilgado leg.; hay bait. – NMB-702f; 1 subadult male, 8 juveniles; same data but 14.05.2018; J. D. Gilgado leg.; active capture. – NMB-702g; 3 males; same data but 30.10.2018; J. D. Gilgado leg.; active capture. – NMB-702h; 2 juveniles; Switzerland, Basel-Stadt, grassland in park, 47°33′52.08″N, 7°37′59.08″E, 265 m; 02.07.2014; B. Braschler & R. Melliger leg.; pitfall trap. – NMB-702i; 1 female; same data but 01.10.2014. – NMB-702j; 1 juvenile; Switzerland, Basel-Stadt, forest fragment, 47°31′44.71″N, 7°36′09.39″E, 310 m; 14.07.2014; B. Braschler & R. Melliger leg.; pitfall trap. – NMB-702k; 2 females; same data but 29.09.2014. – NMB-702l; 1 subadult male, 3 females; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′07.63″N, 7°33′40.24″E, 345 m; 04.10.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-702m; 3 females; same data but 27.09.2018.

Distribution: British Isles, France, Germany, Italy and Portugal (including Madeira) (Gregory *et al.,* 2015).

Remarks: This species seems to be native to central and southern Italy, and it has spread due to human activity (Lindner *et al.,* 2010). In the British Isles it can be found in cultivated or anthropized woodlands, gardens and parks, in deadwood and leaf litter, under moss, or in soil interstices, showing a preference for damp localities (Gregory *et al.,* 2015). In Germany it was found under deadwood in a resting area of a highway, close to ornamental flower beds (Lindner *et al.,* 2010).

Order Polydesmida Leach, 1815
Family Macrosternodesmidae Brölemann, 1916
Genus *Macrosternodesmus* Brölemann, 1908
Macrosternodesmus palicola Brölemann, 1908

Fig. 6

Macrosternodesmus palicola Brölemann, 1908.
Titanosoma jurassicum Verhoeff, 1910.

Material examined: NMB-703a; 1 male; Switzerland, Basel-Stadt, private garden, 47°33′40.182″N, 7°34′42.937″E, 270 m; 31.05.2018; J. D. Gilgado *et al.* leg.; active capture. – NMB-703b; 1 female; same data but 07.06.2018. – NMB-703c; 1 female; Switzerland, Basel-Landschaft, Binningen, private garden, 47°32′01.31″N, 7°34′52.79″E, 345 m; 01.06.2018; J. D. Gilgado *et al.* leg.; active capture.

Distribution: France, Belgium, British Isles, Czech Republic, Denmark, Germany, Luxembourg, the Netherlands, Norway and Sweden (Kime & Enghoff, 2011; Tajovský & Tuf, 2016).

Remarks: This is a very small millipedes species, only up to 4 mm long (Blower, 1985). According to Kime & Enghoff (2011) this species has an Atlantic distribution and may be originally native to deciduous woodlands (mostly *Fagus* forests) on calcareous soils. However, nowadays most records of this species are from human-made biotopes.

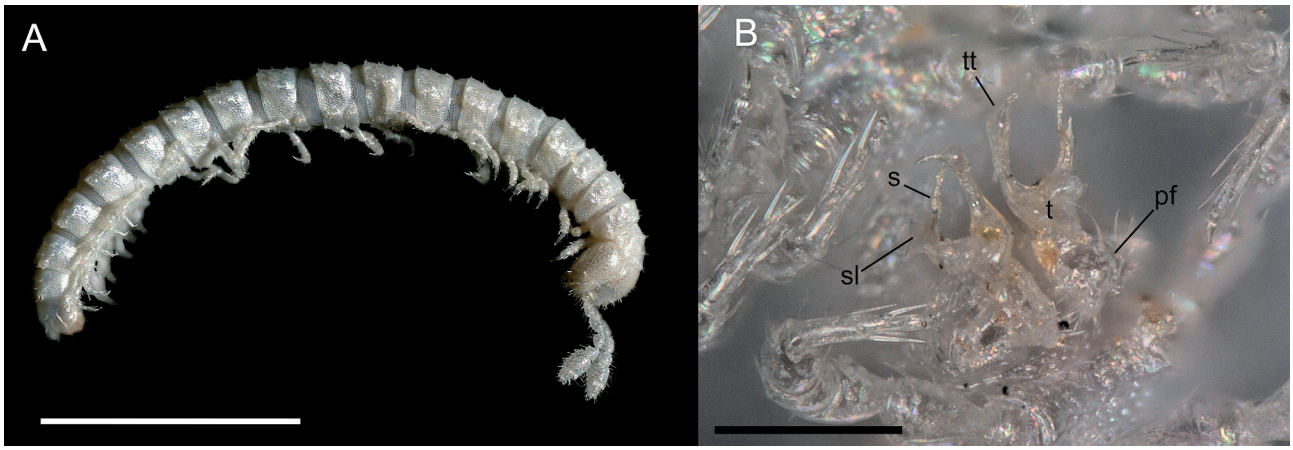

Fig. 6. *Macrosternodesmus palicola* Brölemann, 1908. (A) Adult female from Binningen (NMB-703c). Scale bar 1 mm. (B) Gonopods of male (NMB-703a) from Basel in ventral view. Scale bar 0.1 mm. Abbreviations: pf, prefemoral part of telopodite; t, telopodite; tt, tip of telopodite; s, solenomerite; sl, subrectangular lamella.

DISCUSSION

Sampling efficiency

Despite using several methods for millipede sampling in the gardens in 2018, all specimens of five newly recorded species (*C. britannicus*, *C. salicivorus*, *C. vulnerarius*, *A. pulchella* and *M. palicola*) were exclusively collected by active search. The fact that hay baits did not capture specimens of these species in gardens could be explained by their short exposure period (1 week). Tuf *et al.* (2015) showed a peak in the millipede richness attracted by hay baits after an exposure of eight weeks. Furthermore, the weather conditions during summer led to some hay baits going dry soon and thus probably becoming ineffective. Therefore including hand collecting seems to be the best way not to miss the less abundant species, at least with trap exposure times of only a week. This is probably why the study by Vilisics *et al.* (2012) carried out with pitfall traps in gardens of Zurich, Lugano and Luzern found only 10 common millipede species.

Species origin and distribution

All six newly recorded species have a European origin. All except *H. intermedius* are synanthropic in at least a part of their distribution range. This characteristic, together with their absence in the checklist of Pedroli-Christen (1993), suggests a recent introduction into Switzerland by humans. The most probable way of introduction is the trade of cultivated plants and soil material in greenhouses for gardening. This is likely the most common way of introduction for millipedes in general, including those from tropical areas (Stoev *et al.,* 2010). More detailed information on each species is given below.

Cylindroiulus britannicus seems to have a Lusitanian or Atlantic origin and it is expanding its geographical range across the world (Kime & Enghoff, 2017). Its presence in gardens in Basel suggests human introduction and most likely it arrived quite recently. The presence of this species in agricultural land in Liestal suggests that the species may also be able to colonise semi-natural areas.

Cylindroiulus salicivorus is native to northern Italy, and its previously recorded localities north of the Alps [two in Scotland (Lee, 2006), one in Germany (Spelda, 2005)], like the location in Basel, are all in human-made environments. This is thus very likely a species introduced to Switzerland. Records of *C. salicivorus* outside its native range are scarce, so to date its potential to colonise new areas seems to be low.

Cylindroiulus vulnerarius has probably also an Italian origin, and outside this range the species is mostly synanthropic (Kime & Enghoff, 2017). Even, as it has been hypothesized, if this species has survived the glaciations in microrefugia in some parts of Europe (Kime, 2004; Kime & Dethier, 2010; Kime & Enghoff, 2017), it has a high "dispersal ability" and is very likely a newcomer to Switzerland.

Heteroiulus intermedius was found in southern Switzerland, and its known distribution range in northern Italy is approximately at the same latitude (or at most 30 km more southern) as the Swiss locality (Kime & Enghoff, 2017). It was found close to settlements and close to the railway station in the town of Bellinzona. The latter find is in a forested area in the lower part of a mountain slope. While it could be an introduced species, its distribution range suggests that it is likely a native species in Switzerland.

Anamastigona pulchella also has an Italian origin, and it seems to be expanding its geographical range due to human activity (Lindner *et al.,* 2010). It was found synanthropic at four localities in Basel, in one garden, in urban forests and urban grasslands. This suggests a human introduction in Switzerland. *Anamastigona pulchella* does not seem to be a rare species in Basel and may be found in more localities in the country. Although Lindner *et al.* (2010) claim that the species is probably not invasive despite its plasticity, attention should be paid to its range expansion.

Macrosternodesmus palicola is a species of very small millipedes and thus easily overlooked. At natural sites, mostly in the southern and western part of its distribution range, it has been found in *Fagus* forests on calcareous soils (Kime & Enghoff, 2011), a type of habitat also present in the region of Basel. However, the species was found only in gardens in Basel and most of its records elsewhere are from human-made habitats (Kime & Enghoff, 2011). Therefore it is possible that this species occurs naturally in Switzerland, but more likely it arrived recently.

Ecological implications

These six newly recorded species represent an increase of 4.8% in the previously known number of Swiss millipede species (125 species, excluding greenhouse species; Pedroli-Christen, 1993; Bogyó *et al*., 2013). In general, introduced millipedes in Europe pose a minor threat to biodiversity and to human economic activities (Stoev *et al.,* 2010). However, ongoing climate change is strongly affecting central Europe (Beniston *et al.,* 1994; Scherrer *et al.,* 2006; Rebetez & Reinhard, 2008) and this may promote invasions by millipedes from warmer regions in the future. There is at least one example of an invasive millipede species that was once restricted to greenhouses and is nowadays able to colonise outdoor locations in Europe: the introduced Asian species *Oxidus gracilis*. This species is considered as a pest in several countries of Europe because of the damage it causes to several cultivated plants (Stoev *et al.,* 2010). *Oxidus gracilis* was found in Europe at the end of the 19th century and the beginning of the 20th century (Tömösváry, 1879; Latzel, 1884; Evans, 1900; Pocock, 1902), and it was reported for the first time in Basel by Bigler (1913). At

that time it only occurred in greenhouses. Less than 30 years ago, *O. gracilis* was known from three localities in Switzerland (Basel, Bern and the island of Brissago in the canton of Ticino), mostly from greenhouses or botanical gardens, and rarely from gardens and compost heaps (Pedroli-Christen, 1993). However, nowadays it widely occurs outdoors in Switzerland. It is known to infest gardens in rural areas (Macbeth, 2018), and today it is one of the most frequent and abundant species in gardens in Basel (*in preparation*). *Oxidus gracilis* seems to be sensitive to long exposures to temperatures below 0 ºC (Causey, 1943; Palmén, 1949), therefore the reason behind the increase of its frequency and abundance in Switzerland is likely related to more favourable climatic conditions during winter (Beniston *et al.,* 1994; Scherrer *et al.,* 2006; Rebetez & Reinhard, 2008). What happened with *O. gracilis* (arrival in greenhouses, establishment outdoors in urban areas and becoming a pest) could be repeated in the future with other species of introduced millipedes in Switzerland. The lack of Swiss millipede specialists may be hindering our follow up on the actual abundance and distribution of native and alien millipede species in the country, and little is known on how climate change may be affecting them and their distribution ranges in Switzerland.

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REFERENCES

Attems C. 1904. Neue palaearktische Myriopoden nebsts Beiträgen zur Kenntnis einiger alten Arten. *Archiv für Naturgeschichte* 70(1): 179-196.

Attems C. 1933. VII. Myriapodes. *In*: Voyage de MM. L. Chopard et A. Méquignon aux Açores. *Annales de la Société entomologique de France* 102: 23-24.

Beniston M., Rebetez M., Giorgi F., Marinucci M.R. 1994. An analysis of regional climate change in Switzerland. *Theoretical and Applied Climatology* 49(3): 135-159.

Berlese A. 1888. Acari, Myriopoda et Scorpiones hucusque in Italia reperta. Volumen VI. Fasc. LI-LX. *Sumptibus Auctoris, Padova*, 10 pp.

Bigler W. 1913. Die Diplopoden von Basel und Umgebung. *Revue suisse de Zoologie* 21: 675-793.

Blower J.G. 1985. Millipedes: keys and notes for the identification of the species. Vol. 35. *In*: Kermack D.M., Barnes R.S.K. (eds), Synopses of the British Fauna, new series. *Linnean Society, London,* 242 pp.

Bogyó D., Vilisics F., Moretti M., Trivellone V. 2013. Isopoda and Diplopoda fauna of vineyards in Southeast-Switzerland (p. 14). *In*: Abstract book of the 12th Central European Workshop on soil zoology in České Budějovice, Czech Republic.

Brandt J.F. 1833. Tentaminum quorundam monographicorum Insecta Myriapoda Chilognathi Latreillii spectantium prodromus. *Bulletin de la Société Impériale des Naturalistes de Moscou* 6: 194-209.

Brewer M.S., Sierwald P., Bond J.E. 2012. Millipede taxonomy after 250 years: classification and taxonomic practices in a mega-diverse yet understudied arthropod group. *PLoS One* 7(5): e37240.

Brölemann H.W. 1892. Contributions à la faune myria-podologique méditerranéenne. Dix espèces nouvelles. *Annales de la Société Linnéenne de Lyon* 29: 91-126.

Brölemann H.W. 1908. Description d'un genre nouveau et d'une espèce nouvelle de Myriapodes de France. *Bulletin de la Société entomologique de France* 1908(7): 94-96.

Brölemann H.W. 1916. Essai de classification des Polydesmiens. *Annales de la Société entomologique de France* 84: 523-608.

Cárcamo H.A., Abe T.A., Prescott C.E., Holl F.B., Chanway C.P. 2000. Influence of millipedes on litter decomposition, N mineralization, and microbial communities in a coastal forest in British Columbia, Canada. *Canadian Journal of Forest Research* 30(5): 817-826.

Causey N.B. 1943. Studies on the life history and the ecology of the hothouse millipede, *Orthomorpha gracilis* (CL Koch 1847). *American Midland Naturalist* 29(3): 670-682.

David J.F. 2015. Diplopoda - Ecology [pp. 303-327]. *In*: Minelli A. (ed.). Treatise on Zoology-Anatomy, Taxonomy, Biology. The Myriapoda, volume 2. *Brill, Leiden-Boston*, X+482 pp.

Enghoff H. 2015. Diplopoda - geographical distribution [pp. 329-336]. *In*: Minelli A. (ed.). Treatise on Zoology-Anatomy, Taxonomy, Biology. The Myriapoda, volume 2. *Brill, Leiden-Boston*, X+482 pp.

Enghoff H., Petersen G., Seberg O. 2013. The aberrant millipede genus *Pteridoiulus* and its position in a revised molecular phylogeny of the family Julidae (Diplopoda: Julida). *Invertebrate Systematics* 27(5): 515-529.

Enghoff H., Golovatch S., Short M., Stoev P., Wesener T. 2015.

Diplopoda - taxonomic overview [pp. 363-453]. *In*: Minelli A. (ed.). Treatise on Zoology-Anatomy, Taxonomy, Biology. The Myriapoda, volume 2. *Brill, Leiden-Boston*, X+482 pp.

Evans W. 1900. Scottish Myriapoda. *The Annals of Scottish Natural History* 1900: 127.

Golovatch S.I., Kime R.D. 2009. Millipede (Diplopoda) distributions: A review. *Soil Organisms* 81(3): 565-597.

Gregory S.J., Davidson M.B., Owen C., Anderson R. 2015. *Anamastigona pulchella* (Silvestri, 1894) – first British records for England, Scotland and Wales (Chordeumatida: Anthroleucosomatidae). *Bulletin of the British Myriapod & Isopod Group* 28: 31-37.

Hoess R. 2000. Bestimmungsschlüssel für die *Glomeris*-Arten Mitteleuropas und angrenzender Gebiete (Diplopoda: Glomeridae). *Jahrbuch des Naturhistorischen Museums Bern* 13: 3-20.

Hoess R., Scholl A. 1999. *Glomeris undulata* Koch and *Glomeris conspersa* Koch are conspecific. - Enzyme electrophoretic evidence and taxonomical consequences (Diplopoda: Glomeridae). *Revue suisse de Zoologie* 106(3): 643-661.

Hoess R., Scholl A. 2001. Allozyme and literature study of *Glomeris guttata* Risso, 1826, and *G. connexa* Koch, 1847, a case of taxonomic confusion (Diplopoda: Glomeridae). *Zoologischer Anzeiger* 240(1): 15-33.

Hoffman R. 1980. Classification of the Diplopoda. *Muséum d'histoire naturelle, Genève*, 237 pp.

Kime R.D. 2004. The Belgian millipede fauna. *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique, Entomologie* 74: 35-68.

Kime R.D., Dethier M. 2010. Les Myriapodes des milieux souterrains de Belgique. *Bulletin des Chercheurs de la Wallonie* hors-série 3: 67-78.

Kime R.D., Enghoff H. 2011. Atlas of European millipedes (Class Diplopoda), vol. 1: orders Polyxenida, Glomerida, Platydesmida, Siphonocryptidae, Polyzoniida, Callipodida, Polydesmida. *Pensoft Publishers*, *Sofia*, 282 pp.

Kime R.D., Enghoff H. 2017. Atlas of European millipedes, vol. 2: order Julida (class Diplopoda). *European Journal of Taxonomy* 346: 1-299.

Koch C.L. 1847. System der Myriapoden mit den Verzeichnissen und Berichtigungen zu Deutschlands Crustaceen, Myriapoden und Arachniden [pp. 1-196]. *In*: Panzer K., Herrich-Schäffer A. (eds). Kritische Revision der Insectenfauna Deutschlands, III. Bändchen. *Pustet, Regensburg*, 270 pp.

Latzel R. 1884. Die Myriapoden der Österreichisch-Ungarischen Monarchie. 2. Bd.: Die Symphylen, Pauropoden und Diplopoden. *Alfred Hölder, Wien,* 414 pp.

Leach W.E. 1814. Crustaceology. *In*: Brewster D. (ed.). *The Edinburgh Encyclopaedia* 7: 383-437.

Leach W.E. 1815. A tabular view of the external characters of four classes of animals, which Linn. arranged under Insecta; with the distribution of the genera composing three of these classes into orders, &c. and descriptions of several new genera and species. *Transactions of the Linnean Society of London* 11: 306-400.

Lee P. 2006. Atlas of the Millipedes (Diplopoda) of Britain and Ireland. *Pensoft, Sofia*, 216 pp.

Lindner E.N., Reip H.S. Spelda J. 2010. *Anamastigona pulchella* (Silvestri, 1898) (Diplopoda: Chordeumatida: Anthroleucosomatidae) - ein für Deutschland neuer Tausendfüßer. *Schubartiana* 4: 1-8.

Macbeth A. 2018. Plague of secreting millipedes of Asian origin tormenting Swiss village. Available at https://www.thelocal.ch/20180726/plague-of-secreting-millipedes-of-asian-origin-tormenting-swiss-village (accessed on 15 December 2019).

Melliger R.L., Braschler B., Rusterholz H.-P., Baur B. 2018. Diverse effects of degree of urbanisation and forest size on species richness and functional diversity of plants, and ground surface-active ants and spiders. *PloS One* 13(6): e0199245.

Palmén E. 1949. The Diplopoda of Eastern Fennoscandia. *Annales zoologici Societatis zoologicobotanicae fennicae Vanamo* 13(6): 1-53.

Pedroli-Christen A. 1993. Faunistique des mille-pattes de Suisse (Diplopoda). *Documenta Faunistica Helvetiae* 14: 1-167.

Pedroli-Christen A., Scholl A. 1996. *Rhymogona* (Diplopoda: Craspedosomatidae) un genre monospécifique. Deuxième partie: Révision basée sur les résultats morphologiques, génétiques et faunistiques [pp. 53-60]. *In*: Geoffroy J.-J., Mauriès J.-P., Nguyen Duy-Jacquemin M. (eds). Acta Myriapodologica. *Mémoires du Muséum National d'Histoire Naturelle* N. S. 169: 1-682.

Pocock R.I. 1894. Chilopoda, Symphyla and Diplopoda from the Malay Archipelago [pp. 307-404]. *In*: Weber M. (ed.). Zoologische Ergebnisse einer Reise in Niederländisch Ost-Indien, Band 3. *Brill, Leiden,* 476 pp.

Pocock R.I. 1902. Myriapoda. *The Victoria History of the County of Surrey* 1: 176-178.

Rebetez M., Reinhard M. 2008. Monthly air temperature trends in Switzerland 1901-2000 and 1975-2004. *Theoretical and Applied Climatology* 91(1-4): 27-34.

Scherrer S.C., Appenzeller C., Liniger M.A. 2006. Temperature trends in Switzerland and Europe: Implications for climate normals. *International Journal of Climatology* 26(5): 565-580.

Silvestri F. 1894. Contribuzione alla conoscenza dei Chilopodi, Symphili, Pauropodi e Diplopodi dell'Umbria e del Lazio. *Bollettino della Società Romana per gli Studi Zoologici* 3(5-6): 191-201.

Silvestri F. 1896. Nuovo Diplopodi e Chilopodi dell'Italia settentrionale. *Bollettino del musei di zoologia e di anatomia comparata della Reale Università di Torino* 11(233): 1-5.

Spelda J. 2005. Improvements in the knowledge of the myriapod fauna of southern Germany between 1988 and 2005 (Myriapoda: Chilopoda, Diplopoda, Pauropoda, Symphyla). *Peckiana* 4: 101-129.

Stoev P., Zapparoli M., Golovatch S., Enghoff H., Akkari N., Barber A. 2010. Myriapods (Myriapoda). Chapter 7.2. *BioRisk* 4(1): 97-130.

Stojalowska W., Pedroli-Christen A. 1996. The taxa of *Rhymogona* (Diplopoda: Craspedosomatidae): a ring species. Part one: Genetic analysis of population structure [pp. 45-51]. *In*: Geoffroy J.-J., Mauriès J.-P., Nguyen Duy-Jacquemin M. (eds). Acta Myriapodologica. *Mémoires du Muséum National d'Histoire Naturelle* N.S. 169: 1-682.

Tajovský K., Tuf I.H. 2016. An annotated checklist of the millipedes (Diplopoda) recorded in the Czech Republic. *Acta Societatis Zoologicae Bohemicae* 80(1): 33-37.

Tömösváry Ö. 1879. Néhány hazánkban előforduló Myriopodáról. *Orvos-Természettudományi Értesitő, Kolozsvár* 3: 22-25.

Tuf I.H., Chmelík V., Dobroruka I., Hábová L., Hudcová P., Šipoš J., Stašiov S. 2015. Hay-bait traps are a useful tool for

sampling of soil dwelling millipedes and centipedes. *ZooKeys* 510: 197-207.

Verhoeff K.W. 1891. Ein Beitrag zur mitteleuropäischen Diplopodenfauna. *Berliner entomologische Zeitschrift* 36(1): 115-166.

Verhoeff K.W. 1894. Beiträge zur Diplopoden-Fauna Tirols. *Verhandlungen der Zoologisch-botanischen Gesellschaft in Wien* 44: 9-34.

Verhoeff K.W. 1897 (for 1896). Beiträge zur Kenntnis paläarktischer Myriopoden. IV. Aufsatz: Ueber Diplopoden Tirols, der Ostalpen und anderer Gegenden Europas, nebst vergleichend-morphologischen und biologischen Beobachtungen. *Archiv für Naturgeschichte* 62(3): 187-242.

Verhoeff K.W. 1899. Beiträge zur Kenntniss paläarktischer Myriopoden. VIII. Aufsatz: Zur vergleichenden Morphologie, Phylogenie, Gruppen- und Art-Systematik der Chordeumiden. *Archiv für Naturgeschichte* 65(1): 138-219.

Verhoeff K.W. 1900. Beiträge zur Kenntnis paläarktischer Myriopoden. XIII. Aufsatz: Zur vergleichenden Morphologie, Phylogenie, Gruppen- und Art-Systematik der Ascospermophora. *Archiv für Naturgeschichte* 66(1): 347-402.

Verhoeff K.W. 1907. Über Diplopoden. 7. (27.) Aufsatz: Europäische Polydesmiden. *Zoologischer Anzeiger* 32(12-13): 337-354.

Verhoeff K.W. 1908. Über Diplopoden. 10. (30.) Aufsatz: Zur Kenntnis der Juliden und über einige Polydesmiden. *Archiv für Naturgeschichte* 73(1): 423-474.

Verhoeff K.W. 1910. Über Diplopoden. 42. Aufsatz: Neue Polydesmiden aus Mitteleuropa und ihre Verwandten. *Zoologischer Anzeiger* 36(6-7): 132-145.

Verhoeff K.W. 1912. Zwei neue mitteleuropäische *Cylindroiulus*-Arten. (Über Diplopoden, 55. Aufsatz.). *Zoologischer Anzeiger* 40(8-9): 220-227.

Verhoeff K.W. 1930. Über Diplopoden aus Italien, namentlich Piemont. 114. Diplopoden-Aufsatz. *Zoologische Jahrbücher, Abteilung für Systematik, Ökologie und Geographie der Tiere* 59: 387-446.

Vilisics F., Bogyó D., Sattler T., Moretti M. 2012. Occurrence and assemblage composition of millipedes (Myriapoda, Diplopoda) and terrestrial isopods (Crustacea, Isopoda, Oniscidea) in urban areas of Switzerland. *ZooKeys* 176: 199-214.

Wittenberg R. (ed.). 2005. An inventory of alien species and their threat to biodiversity and economy in Switzerland. CABI Bioscience Switzerland Centre report to the Swiss Agency for Environment, Forests and Landscape. The environment in practice no. 0629. *Federal Office for the Environment, Bern*, 417 pp.