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Source: Arachnologische Mitteilungen: Arachnology Letters, 64(1) : 73-82

Published By: Arachnologische Gesellschaft e.V.

URL: https://doi.org/10.30963/aramit6409

Arachnologische Mitteilungen / Arachnology Letters 64: 73-82 Karlsruhe, Dezember 2022

Spiders (Araneae) from green roofs in north-west Switzerland – faunistic data with two species new to Switzerland

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doi: 10.30963/aramit6409

Abstract. Extensive green roofs are recognised as being a suitable habitat for some specific plants and arthropods that are resistant to very extreme hot and dry conditions. Little is known about spider species visiting and living on green roofs. In 2018 and 2019, 29 green roofs in Basel and four roofs in Aarau (Switzerland) were sampled using pitfall traps during the entire growing season. In the sampling period, 18467 adult spiders were collected and identified into 123 species. Two species were collected for the first time in Switzerland: *Erigone dentosa* O. Pickard-Cambridge, 1894 and *Runcinia grammica* (C. L. Koch, 1837). According to the Red List of Germany (and especially Baden-Württemberg), 26 species are of special interest from a nature conservation perspective. On the other hand, four species are alien species (i.e. they originate from other continents), and 14 species are expanding their range northward. Green roofs may therefore harbour endangered species, but there is also the possibility that the newly invading species may become dominant. Only after many years or even decades will it be possible to judge whether green roofs are primarily substitutes for lost habitats or stepping-stones for new invaders.

Keywords: endangered species, faunistics, neobionts, urban ecology

Zusammenfassung. Spinnen (Araneae) von begrünten Dächern der Nordwestschweiz – faunistische Angaben mit zwei Erstnachweisen für die Schweiz. Extensiv gepflegte, begrünte Dächer gelten als geeignete Habitate für einige Pflanzen und Gliedertiere, die an extrem heisse und trockene Bedingungen angepasst sind. Nur wenig ist bekannt über Spinnen, welche begrünte Dächer besiedeln. In den Jahren 2018 und 2019 wurden 29 begrünte Dächer in Basel und vier in Aarau während der gesamten Vegetationsperiode mit Hilfe von Bodenfallen besammelt. Dabei wurden 18467 adulte Spinnen aus 123 Arten gesammelt. Zwei Arten wurden erstmalig für die Schweiz nachgewiesen: *Erigone dentosa* O. Pickard-Cambridge, 1894 und *Runcinia grammica* (C. L. Koch, 1837). Gemäss den Roten Listen für Deutschland (und speziell von Baden-Württemberg) sind aus naturschutzfachlicher Sicht 26 Arten von besonderem Interesse. Andererseits stammen vier Arten ursprünglich aus anderen Kontinenten (alien species) und 14 Arten sind in Arealerweiterung aus dem Süden nach Norden begriffen. Begrünte Dächer können also bedrohten Arten einen Lebensraum bieten, aber gleichzeitig besteht auch die Gefahr, dass neu eindringende Arten dominant werden (invasive Arten). Erst nach langjähriger Beobachtung wird es möglich sein, zu beurteilen, ob begrünte Dächer vor allem Ersatzlebensräume für bedrohte Arten oder eher Trittsteine für potentiell invasive Arten darstellen.

Implementation of green roofs in urban planning and new flat roof buildings aims to reduce heat-island effects of the city and provide urban habitats for a specific flora and fauna and thus contribute to improving urban biodiversity (Oberndorfer et al. 2007). The main difference between green roofs and ground level sites is the thin substrate layer without a connection to deeper layers, which leads to extreme habitat conditions. In areas with prolonged dry periods in summer, the substrate can dry out from extensively to completely. On the other hand, in cooler seasons with reduced evaporation the roof habitats can often become waterlogged (Brenneisen 2009). Green roofs containing diversity of vegetation structure and variation of substrate thickness can provide greater species richness compared to standard green roofs (Brenneisen 2009, Gonsalves et al 2021) and may be a substitute for brownfield sites with respect to invertebrate abundance and diversity (Kadas 2006) (Fig. 1).

Furthermore, these studies showed that green roofs serve not only as stepping-stones, but also as possible permanent sites. For smaller animals, green roofs may even provide larger populations and can thus also be considered as "source" habitats in the sense of the metapopulation principle for the dispersal of species. In recent years, all over the world, numerous studies have examined the effects of flat roofs on vegetation and arthropod populations (McKinney et al. 2019, Dromgold et al. 2020, Kyrö et al. 2020, Sanchez Domingues et al. 2020). Most of these studies were based on short term sampling or only analysed effects on higher taxonomic levels. Nevertheless, in Switzerland a few studies recently analysed faunistic data for several arthropod groups, such as ground beetles (Pétremand et al. 2018a), wild bees (Braaker et al. 2014, Pétremand et al. 2018b, Passasseo et al. 2020, 2021) and hoverflies (Passasseo et al. 2021). These studies highlighted the role played by green roofs as resources and habitats for endangered and xerothermophilic species within urban areas.

Spiders (Araneae) on green roofs have been studied in several European countries: Austria (Komposch 2004, Milasowszky & Hepner 2017), Great Britain (Kadas 2006), France (Madre et al. 2013), Germany (Balkenhol et al. 1998, Kühn & Buchholz 2009, Ksiazek-Mikenas et al. 2018) and Switzerland (Brenneisen & Hänggi 2006). Quite often, quantitative data at higher taxonomic levels are analysed with high accuracy while the composition of the fauna at species level, the qualitative data, are neglected. Therefore, the spider fauna and its development on green roofs is currently poorly known.

Brenneisen & Hänggi (2006) presented one of the earliest sets of faunistic data of spiders on green roofs for central Europe. Some of the same roofs (together with new ones) were re-sampled in 2013 and again later (Kyrö et al. 2018, Pétremand et al. 2018a). A complete ecological analysis of these datasets is being prepared for subsequent publication. In this paper, only faunistic data on spider species with two new species for the Swiss fauna and some further remarkable species for Switzerland are presented.

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Academic editor: Konrad Wiśniewski

submitted 4.8.2022, accepted 3.12.2022, online 28.12.2022

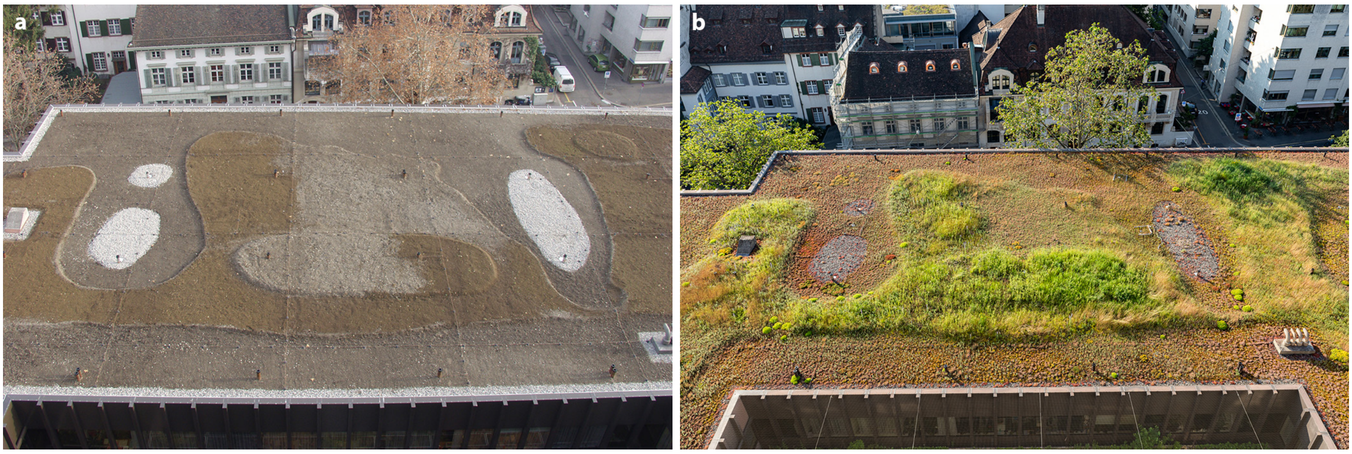

Fig. 1: Green roof of the University Hospital Basel, Klinikum 2. The pictures show a diverse substrate composition and varying thickness thereof. **a.** after installation in 2003 (Photo: Stephan Brenneisen); **b.** how vegetation composition is adapting to the different habitat conditions over the years. The picture was taken in 2021 (Photo: Andreas Hofstetter)

Material and methods

Site characteristics

In the city of Basel 29 sites on 17 different buildings and, in addition, four sites on one building in Aarau were investigated. The panel of green roofs chosen aims to cover the diversity of green roof types found in the Basel agglomeration. Green roofs that have received the greatest interest recently are extensive green roofs. They are composed of lightweight layers of free-draining material that support low-growing, tough, drought-resistant vegetation. Generally, the depth of growing medium is from a few centimetres up to a maximum of around 15 cm. These roof types have great potential for wide application because, being lightweight, they require little or no additional structural support from the building. Moreover, the vegetation is adapted to the extreme roof top environment (wind exposure, high temperatures, drought) and therefore the roofs require little in the way of maintenance. The diversity of substrates on the green roofs investigated went from low substrate layers (8 cm) to 15 cm with some additional even deeper substrate structures up to 30 cm, and additional elements such as logs and larger stones.

Sampling design

Sampling was carried out with pitfall traps from the beginning of April to the end of October in 2018 and from the end of March to the end of October in 2019. Some, but not all sites were investigated in both years. Ten traps were set per site. Pitfall traps were plastic tubes (diameter 7 cm, 10 cm deep) with another small plastic cup (diameter 6 cm, 7 cm deep) inside, half filled with 10% acetic acid to conserve any organisms trapped. The traps were replaced every 14 days; during hot and dry periods every 7 days.

The material was manually sorted into the groups "ground beetles", "arachnids" and "others". Determination of the spiders mainly followed the internet key "Araneae – spiders of Europe" (Nentwig et al. 2022) and original literature was used where useful. Taxonomical literature is only listed for the species discussed in the text. Nomenclature follows the World Spider Catalog (WSC 2022). Photos were made using a KEYENCE 6000 with auto-stacking. A reference collection is stored in the Natural History Museum of Basel.

Results

The total capture included 123 species of spiders with 18467 adult individuals (Appendix 1). As is usual for pitfall captures, the number of males (12492) was clearly higher than that of the females (5975). Twenty-two families were registered. The family Linyphiidae with 33 species was the most diverse, followed by Lycosidae (17), Salticidae (14), Gnaphosidae (12), Thomisidae (11) and Theridiidae (10). The species with the highest numbers of specimens were: *Agyneta rurestris* – 3058 (2165 ♂♂, 893 ♀♀), *Xysticus kochi* – 1884 (1638 ♂♂, 246 ♀♀), *Erigone dentipalpis* – 1839 (1563 ♂♂, 276 ♀♀), *Steatoda albomaculata* – 1672 (1231 ♂♂, 441 ♀♀), *Asagena phalerata* – 1259 (979 ♂♂, 280 ♀♀), *Phlegra fasciata* – 1101 (598 ♂♂, 503 ♀♀), *Zelotes exiguus* – 1003 (633 ♂♂, 370 ♀♀), *Pelecopsis parallela* – 784 (211 ♂♂, 573 ♀♀) and *Attulus penicillatus* – 689 (375 ♂♂, 314 ♀♀). In the case of about a third of the species (40 species), just one individual representative was caught.

New species for the Swiss fauna

LINYPHIIDAE

***Erigone dentosa* O. Pickard-Cambridge, 1894** (Figs 3–4)

SWITZERLAND: Basel: Burgfelderstrasse 101, Felix Platter Spital, green roof, construction 2010, compost on straw, 5–10 cm, seeding: hay from a dry meadow, 1000 m^2, 47.56457°N, 7.56502°E, Fig. 2a, 1 ♂, 4.–18. Jun. 2018.

Further material of this species was caught on another roof (Schulhaus Sandgruben, Basel), Fig. 2b. The results from this roof are not otherwise included in this paper because of technical problems. Four males (2 ♂♂: 5.–16. Apr. 2019, 1 ♂: 16.–30. Apr. 2019, 1 ♂: 14.–28. May 2019) and one female (1 ♀: 4.–19. Jul. 2019) were sampled.

Determination and taxonomic note. Crosby & Bishop (1928), Kekenbosch & Baert (2013), Arco et al. (2019), Unruh (2020).

The configuration of the male palp as well as the structures of the female epigyne suggest that the species belongs to the *psychrophila*-group. The embolic division of the male palp resembles *E. cristatopalpus* Simon, 1884, while the dorsal edge of the tibia shows a notch as in *E. tenuimana* Simon, 1884 or *E. aletris* Crosby & Bishop, 1928 (Fig. 3b). The female epigyne (Fig. 4) mostly resembles that of *E. cristatopalpus*.

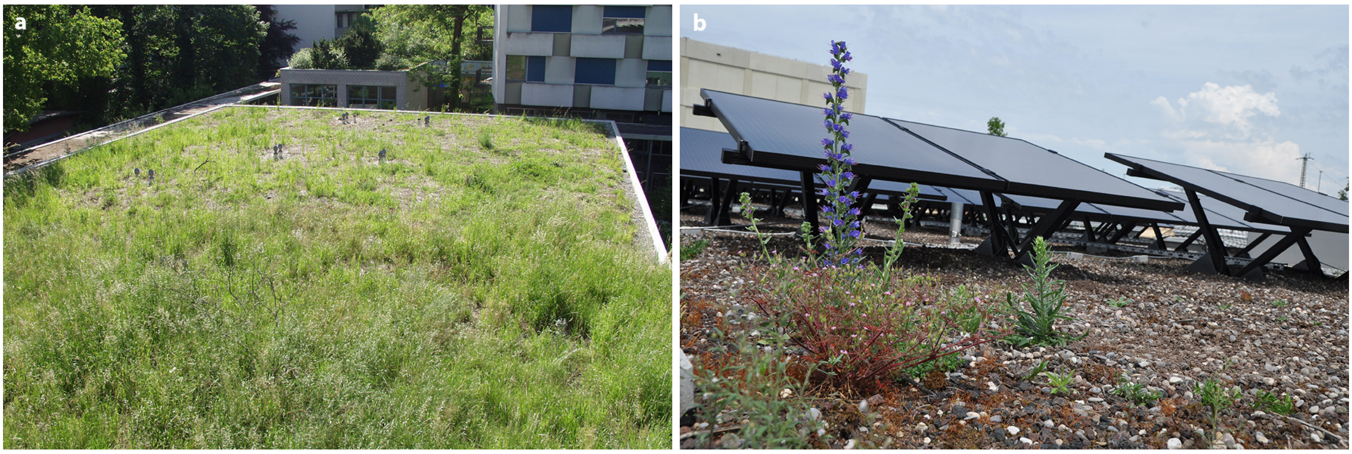

Fig. 2: Sites where *Erigone dentosa* was captured. **a.** Felix Platter Spital; **b.** Schulhaus Sandgruben with photovoltaic installations (Photos: Stephan Brenneisen)

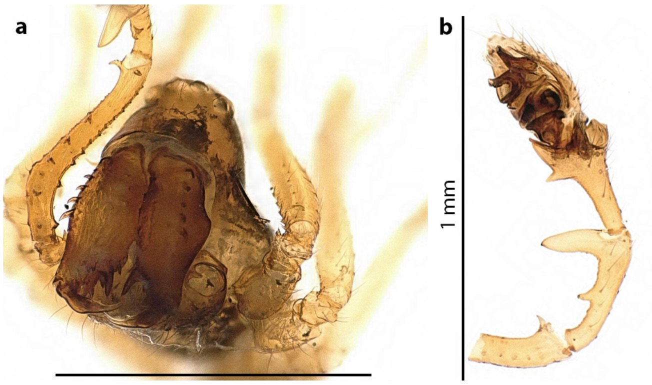

Fig. 3: *Erigone dentosa,* male. **a.** frontal view with the highly characteristic teeth on the chelicerae; **b.** left palp, retrolateral view

Dentition all over the body and especially of the male chelicerae clearly (Fig. 3a) distinguishes the species from all other representatives of the *psychrophila*-group.

A comprehensive discussion on the spread of this Nearctic spider species in Europe is given in Unruh (2020) and Kielhorn (2022) and a taxonomic discussion of the species can be found in Arco et al. (2019). The first discovery of the species in Europe dates back to the winter of 2012/2013 in a cemetery in Antwerp, Belgium (Kekenbosch & Baert 2013). The specimens from Oslo, Norway are presumed to have been imported with *Thuja* bushes (Oger 2022), and the ones from Germany are reported from a nursery (Unruh 2020). In Unruh (2020) it was questioned whether this species is able to establish itself outdoors. Our finding of it on two roofs would indicate that the species is able to colonise outdoor habitats.

Runcinia grammica **(C. L. Koch, 1837)**
SWITZERLAND: Basel, BVB tram depot Wiesenplatz, flat green roof, construction 2011, compost and crushed tiles on top of china reet, 10 cm, seeding: hay from a dry meadow (Reinacher Heide), 2000 m², 47.578121°N, 7.593456°E, Fig. 5, 1 ♂, 12.–25. Jun. 2018.
Determination. Levy (1973), Roberts (1998), Grismaldo & Achitte-Schmutzler (2020)

In Europe, *Runcinia grammica* is mainly known from the Mediterranean region, but it is also known from Africa and Asia. In Central Europe this species seems to be restricted to very warm and dry habitats (Bauer & Höfer 2017). The species is already known in the region around Basel: Bauer & Höfer (2017) found it in Weil am Rhein (Germany) on a ruderal area near railway tracks. A second record of the species in the surroundings of Basel is known from the "Petite Camarque Alsacienne" in Saint-Louis, France (Theo Blick, yellow pan, 1 ♀, 13. Aug. 1992, unpublished). There are only very few records of this species north of the Alps (not yet known in Austria). The three records from Germany and the record from Alsace were all made after 1990. Whether this indicates a northward spreading or it just means that the (possibly rare) species had never been caught before, remains unclear.

Endangered species on green roofs?
For Switzerland, there is no Red List for spiders. Nevertheless, the geographic and climatic conditions in the region of Basel are more or less the same as in the Upper Rhine Plain which, on the eastern side, forms part of the German state of Baden-Württemberg. Therefore, in Tab. 1, we compared our species

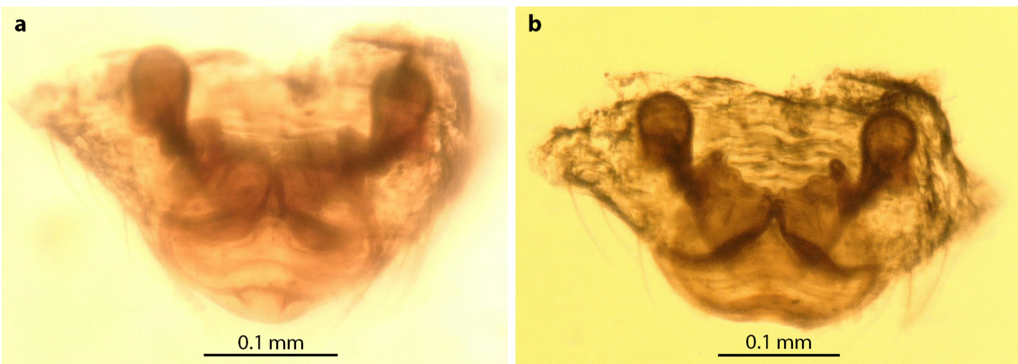

Fig. 4: *Erigone dentosa*, female. Epigyne and vulva in clove oil. **a.** ventral view; **b.** dorsal view

Fig. 5: Photo of the site, where *Runcinia grammica* was captured. Densely vegetated roof of the "Tramdepot Wiese" in Basel (Photo: Stephan Brenneisen)

list with the Red List of Baden-Württemberg (Nährig et al. 2003) and on a broader scale with that of Germany (Blick et al. 2016). Out of the 123 species caught on all the green roofs investigated, 26 are classified in some category of the red lists or are only recorded for the first time in Germany after the date of these lists. So more than a fifth of the species (21.1 %) are of special faunistic interest. To evaluate the true status of the species in the region, we compared our data with two published lists (Hänggi 1988, Brenneisen & Hänggi 2006) and five species lists of current comparable projects (all not yet published), some with several places (habitats) of investigation in Basel or its surroundings. If a species is mentioned in five to seven species lists, we presume it to be "established" in the region. Two to four is judged "rare" and if the species is mentioned for the first time in the region, it is given as "new".

Some of the species that are classified in the Red Lists are registered in our study in quite high numbers and on many roofs: *Attulus penicillatus* (>20 roofs), *Drassyllus praeficus* (10), *Steatoda albomaculata* (16) and *Zelotes exiguus* (>20). This indicates that these species seem to be well established, even if two of them *Attulus penicillatus* and *Steatoda albomaculata* were reported only "rarely" before. However, for both, there is a further note on its existence near Basel in Bauer & Höfer (2017). Moreover, *Attulus penicillatus* was already registered in five out of six investigated roofs in Brenneisen & Hänggi (2006).

According to the Nentwig et al. (2022) *Agyneta simplicitarsis* is "very rarely found". This is somewhat in contrast to the fact that in the region of Basel the species seems to be quite well distributed. We postulate that this has to do with the fact that *Agyneta simplicitaris* is mainly active in autumn and winter and thus is only caught in projects that last at least over the whole growing season. The frequency of recordings therefore may rather be due to methodological bias. Similar methodological bias may be true for the other regionally "established" species *Argenna subnigra, Drassyllus praeficus, Xerolycosa miniata, Xysticus acerbus* and *Zelotes exiguus.*

A special case is *Steatoda albomaculata*, one of the very abundant and frequent species of this investigation. The reason for its classification as "vulnerable" on the Red List of Baden-Württemberg (Nährig et al. 2003) does not seem to

Tab. 1: Species with a classification in the Red Lists of Baden-Württemberg (Nährig et al. 2003) and/or Germany (Blick et al. 2016) or species new to Germany since the most recent Red List published. Indicated are the numbers of males and females caught in our study and the estimated status of the species in the region around Basel (various published and unpublished data)

Species	Red List Baden-Würtemberg	Red List Germany	♂♂	♀♀	Region
Agyneta simplicitarsis	R Extremely rare	G endangered, status not clear	10	4	established
Argenna subnigra	V warning list		3	4	established
Attulus distinguendus	2 endangered	3 Vulnerable	1	.	rare
Attulus penicillatus	3 Vulnerable	2 endangered	375	314	rare
Cheiracanthium virescens	3 Vulnerable		3	18	rare
Drassyllus praeficus	V warning list		78	237	established
Gnaphosa rhenana		1 critically endangered	1	4	rare
Haplodrassus dalmatensis	2 endangered	V warning list	6	5	rare
Heliophanus auratus	V warning list	V warning list	.	1	rare
Heliophanus kochii		New: Schäfer & Krumm (2015)	1	8	rare
Hypsosinga albovittata	3 Vulnerable	V warning list	7	4	rare
Hypsosinga pygmaea	2 endangered	3 Vulnerable	2	.	new
Nematogmus sanguinolentus	2 endangered	3 Vulnerable	.	1	rare
Neottiura suaveolens	V warning list	G endangered, status not clear	1	.	new
Oxyopes lineatus		New: Bauer & Höfer (2017)	5	1	new
Prinerigone vagans	3 Vulnerable		82	17	new
Pseudomaro aenigmaticus	D Data deficient	G endangered, status not clear	.	1	rare
Runcinia grammica		R Extremely rare	1	.	rare
Scotina celans	V warning list		.	2	rare
Steatoda albomaculata	3 Vulnerable	G endangered, status not clear	1231	441	rare
Thomisus onustus	V warning list		1	.	rare
Walckenaeria alticeps	V warning list		2	.	rare
Xerolycosa miniata	V warning list		29	14	established
Xysticus acerbus	V warning list		26	12	established
Xysticus luctator	3 Vulnerable	V warning list	.	2	new
Zelotes exiguus	2 endangered	G endangered, status not clear	633	370	established

hold true for the region around Basel at least. There also exist old records of this species in the surroundings of Basel in the collection of the Natural History Museum of Basel.

For *Heliophanus kochii* and *Oxyopes lineatus* there are no entries in the Red Lists because the first recordings for Germany were only published later (Schäfer & Krumm 2015, Bauer & Höfer 2017), but both records are from the surroundings of Basel on the German side.

Finally, *Attulus distinguendus*, *Cheiracanthium virescens*, *Gnaphosa rhenana*, *Haplodrassus dalmatensis*, *Heliophanus auratus*, *Hypsosinga albovtttata*, *Hypsosinga pygmaea*, *Neottiura suaveolens*, *Oxyopes lineatus*, *Prinerigone vagans*, *Runcinia grammica*, *Scotina celans*, *Walckenaeria alticeps*, *Xysticus luctator* are species of special interest according to the Red Lists. Green roofs seem to have a certain potential as replacement sites of endangered habitats.

Neobionts on green roofs

Neobionts (species only recently recorded in a region) may be subdivided in two groups: 1) alien species originating from foreign continents and 2) species from southern regions (i.e. south of the Alps) that have shown a northward spreading during recent decades. The classification as "alien species" is in accordance with "Spiders of Europe" (Nentwig et al. 2022), while "northward spreading" is classified according to different publications. In our study we found representatives of both groups: four alien species and fourteen southern species (Tab. 2).

Four species are true alien species. One of these, *Ostearius melanopygius*, originally described as being from New Zealand (today it is thought to originate from South America (WSC 2022)) has been known in Europe since 1906. It was registered for the first time near London. Its spread in Europe was summarised in Růžička (1995). Even if widespread in Europe, its occurrence is rather scattered. We found it in seven sites on four buildings. The situation is totally different with *Mermessus trilobatus*. This species was first recorded in Germany in 1981 (Dumpert & Platen 1985) and then in southern and northern Switzerland in 1988 (Hänggi 1990). Today it can be found in every larger collection from any open habitat. Current overviews are given in Hirna (2017) and Narimanov et al. (2022). In our investigation, the species was found in 28 sites on 15 buildings. *Erigone autumnalis* was registered for the first time in Europe in southern Switzerland (Hänggi 1990, 1993). A good overview of its spread in Europe is given in Déjean & Danflous (2017). *Erigone dentosa* was only recorded a few years ago (Kekenbosch & Baert 2013). For details, see above.

Fifteen species seem to have enlarged their natural distribution from the Mediterranean northwards during recent decades (Blick et al. 2016, Nentwig et al. 2022). It is supposed that this is connected to climate warming, but could also be related to an augmentation of south–north traffic. Independent of the pathway of their appearance north of the Alps, it is obvious that especially the Upper Rhine Plain is a region with ecological conditions comparable to the ones south of the Alps.

Of special interest are the first records north of the Alps for *Erigone autumnalis* and *Robertus mediterraneus*. *Erigone autumnalis* was found on all four sites of the investigated building in Aarau (Telli) with 3 ♂♂ and 2 ♀♀ already in 2018, but much more in 2019, but also 1 ♂ in 2019 in one site in Basel (St. Jakobshalle). The single female of *Robertus mediterraneus* (Fig. 6) was caught on the green roof of the school building "Schoren" that was constructed only in 2017 (Fig. 7) with 10-15 cm of sandy gravel with compost and lava-pumice. The seeds stem from a nearby nature conservation area (Reinacher Heide). It will be of interest if this single female really represents a population of the species or if it is only a displaced specimen.

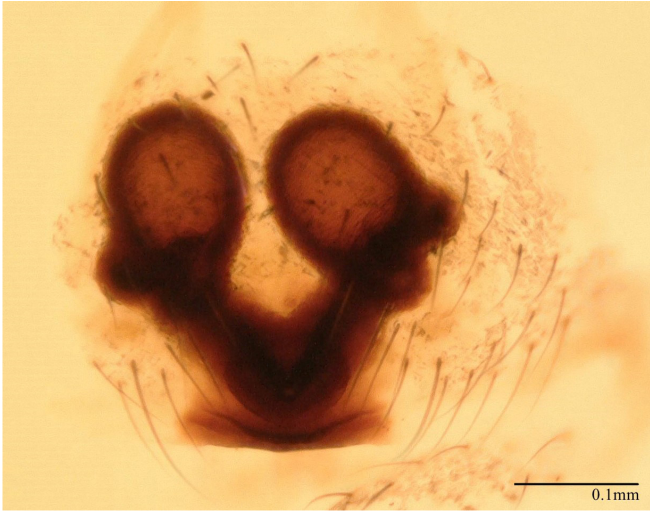

Fig. 6: *Robertus mediterraneus*, Epigyne and vulva, dorsal view, in clove oil

Fig. 7: School building Schoren, Basel, a green roof with a mixture of sandy gravel, compost, lava-pumice and wood, constructed in 2017. The site where *Robertus mediterraneus* was found for the first time north of the Alps (Photo: Stephan Brenneisen)

Further faunistic and taxonomic comments on some other species

Pardosa tenuipes

In Central Europe, *Pardosa tenuipes* was not distinguished from *Pardosa proxima* (C. L. Koch, 1847) for decades. It was only a few years ago that Isaia et al. (2018) gave clear criteria to separate the two species morphologically. Here we found *P. tenuipes* in 26 out of the 33 sites in Basel and Aarau (271 ♂♂, 147 ♀♀), mostly in quite high numbers. No *P. proxima* was found.

Dysdera erythrina s. l.

In the revision of the *Dysdera erythrina* species-complex, Řezáč et al. (2018) assigned all samples of *D. erythrina* from

Tab. 2: Neobiont spider species on green roofs in Basel and Aarau. Indicated are the numbers of males and females caught in our study and the estimated status of the species in the region around Basel (based on various published and unpublished data)

Species	Alien species	Spreading northwards	♂♂	♀♀	Region up to date
Collinsia inerrans		Blick et al. (2016)	2	2	rare
Cheiracanthium mildei		Blick et al. (2016)	.	1	established
Erigone autumnalis	Nentwig et al. (2022)		39	12	only this study
Erigone dentosa	Nentwig et al. (2022)		1 (3)	(1)	only this study
Icius subinermis		Blick et al. (2016)	.	1	established
Mermessus trilobatus	Nentwig et al. (2022)		117	43	established
Ostearius melanopygius	Nentwig et al. (2022)		11	14	established
Oxyopes lineatus		Bauer & Höfer (2017)	5	1	rare
Pholcus opilionoides		Nentwig et al. (2022)	6	5	in buildings
Prinerigone vagans		Blick et al. (2016)	82	17	rare
Pseudeuophrys lanigera		Nentwig et al. (2022)	87	55	synanthopic
Robertus mediterraneus		1. record north of the Alps	.	1	only this study
Runcinia grammica		new findings	1	.	only this study
Steatoda triangulosa		Nentwig et al. (2022)	1	.	established
Talavera aperta		Blick et al. (2016)	87	67	rare
Trachyzelotes pedestris		Blick et al. (2016)	2	2	established
Xysticus acerbus		Blick et al. (2016)	26	12	rare
Zodarion italicum		Blick et al. (2016)	17	14	established

Switzerland to *Dysdera kropfi* Řezáč, 2018 with the remark "Other material examined that may belong to this species (*erythrina/kropfi* morphotype but no karyological data available)". In contrast, all the German records are assigned to *D. erythrina*, as is the one from Freiburg im Breisgau. Geographically and ecologically Freiburg im Breisgau and Basel are very similar and quite often their species compositions are the same. Because the two species cannot be distinguished morphologically, we assigned our material to *D. erythrina* sensu lato.

Conclusions

As shown in the photos of some of the sites investigated (Figs. 1, 2, 5, 7, 8) habitats on green roofs may be quite diverse. However, all these habitats have in common the fact that the substrate is rather thin with a maximum thickness of 30 cm. Therefore, these habitats are limited in terms of water retention and the plants are unable to draw on water from greater soil depths with their roots during dry periods. Consequently, the vegetation density is often very low with open and bare areas, as for example in pioneer habitats such as riversides caused by river dynamics. A typical habitat type in the natural Upper Rhine valley used to be gravel and sand banks along the free running, meandering Rhine. The plant species compositions on green roofs also have similarities to rocky vegetations in mountainous areas with different soil cover depths or prairie landscapes (Brenneisen 2009). After the restructuring and canalization of the Rhine (and smaller tributaries) this habitat type has nearly disappeared. As our results on spiders on green roofs show (26 species on the red lists of Germany or Baden-Württemberg), there is, to a certain degree, the potential to create replacements of this lost habitat type, as was previously shown for ground beetles (Brenneisen 2009, Pétremand et al. 2018a).

Of course, all these green roofs are new habitats, built or at least installed only a few years ago, like natural pioneer habitats after a disturbance process. All these habitats have to be colonised in a first step and only later will a typical species community evolve. This may explain why four of the species are alien species with a high potential of colonising new

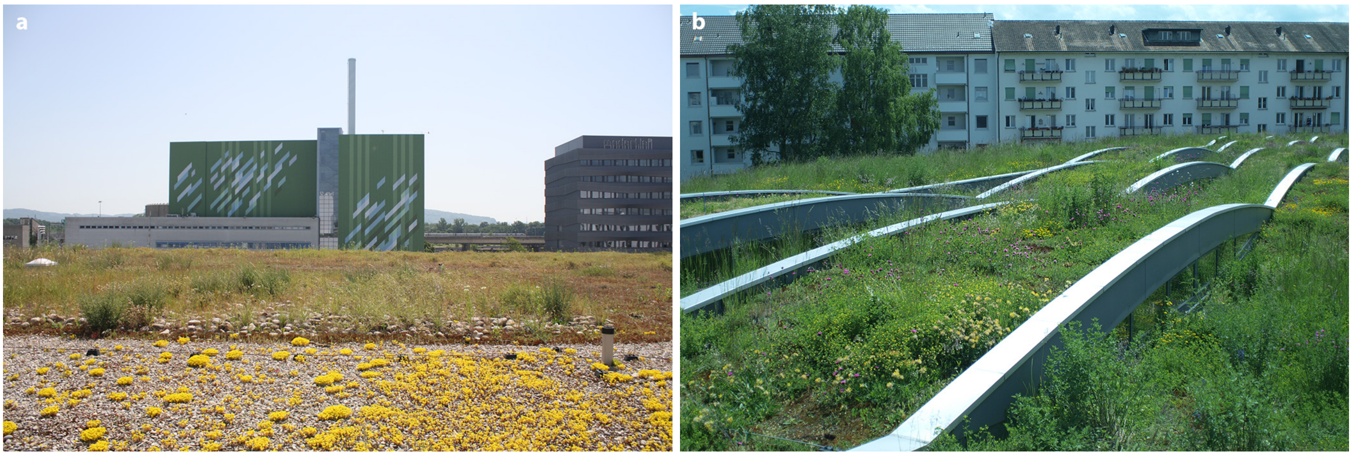

Fig. 8: Further habitat types on green roofs in Basel. **a.** Stücki Shopping Center, constructed to imitate some habitats on riverbanks; **b.** the green roof on the tram depot Wiesenplatz with higher vegetation density (Photos: Stephan Brenneisen)

habitats and 14 species, actually enlarging their distribution northwards, find new habitats on green roofs. It appears to us that the green roofs also may be very good stepping-stones for potentially invasive species as are, e.g. logistic and garden centers (Hänggi & Straub 2016). These findings can underline already known processes of invasive plant species being introduced into urban areas based on the numerous pioneer habitats created by human activities disturbing and opening surfaces. Most of the successful non-native colonisers are pioneer species.

With two years of observation of the different roofs we are not able to assess which effect is greater: roofs offering protection of endangered species or roofs as stepping-stones for new invaders that could eventually eliminate the endangered native species. Only a longer survey on different roofs will bring a clear answer, showing which species will become permanently established. Certainly, a milestone regarding how conservation goals can be achieved on green roofs with a special substrate construction is shown in Wollishofen/Zurich (Brenneisen 2006). Three green roofs that are older than 100 years reflect the species richness of an agricultural region of the early 20th century (Landolt 2001), stipulated to be protected by the canton with similar importance to conservation sites on the ground.

Acknowledgments
Thanks to the Federal Office for the Environment FOEN for financing the project "Ökofaunistische sowie vegetationstechnische Beurteilung und Optimierung von begrünten Dachflächen im Kontext der Biodiversitätsförderung im Siedlungsraum". Within this project we were able to contribute the determination of the spider species sampled in the pitfall traps. We thank Theo Blick for valuable comments on a draft of the manuscript and John Bennett for linguistic improvements.

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Appendix 1
Spider species list of pitfall trapping on 33 green roofs in Basel and Aarau (Switzerland) during the vegetation periods in 2018 and 2019. Nomenclature according to the World Spider Catalog (WSC 2022). Alphabetical arrangement of families (with number of species per family) and species within the families. Indicated are numbers of males, females and sum of both.

Taxon	♂	♀	ind
Agelenidae (4)			
Agelena labyrinthica (Clerck, 1757)	4	2	6
Allagelena gracilens (C. L. Koch, 1841)	1	.	1
Eratigena atrica (C. L. Koch, 1843)	.	1	1
Tegenaria domestica (Clerck, 1757)	.	1	1
Araneidae (5)			
Cercidia prominens (Westring, 1851)	.	1	1
Hypsosinga albovittata (Westring, 1851)	7	4	11
Hypsosinga pygmaea (Sundevall, 1831)	2	.	2
Hypsosinga sanguinea (C. L. Koch, 1844)	2	2	4
Larinioides sclopetarius (Clerck, 1757)	1	.	1
Cheiracanthiidae (2)			
Cheiracanthium mildei L. Koch, 1864	.	1	1
Cheiracanthium virescens (Sundevall, 1833)	3	18	21
Clubionidae (1)			
Clubiona neglecta O. Pickard-Cambridge, 1862	.	1	1
Dictynidae (2)			
Argenna subnigra (O. Pickard-Cambridge, 1861)	3	4	7
Dictyna arundinacea (Linnaeus, 1758)	1	1	2
Dysderidae (1)			
Dysdera erythrina (Walckenaer, 1802)	1	1	2
Gnaphosidae (12)			
Drassodes lapidosus (Walckenaer, 1802)	6	5	11
Drassodes pubescens (Thorell, 1856)	.	1	1
Drassyllus praeficus (L. Koch, 1866)	78	237	315
Drassyllus pumilus (C. L. Koch, 1839)	1		1
Drassyllus pusillus (C. L. Koch, 1833)	14	14	28
Gnaphosa rhenana Müller & Schenkel, 1895	1	4	5
Haplodrassus dalmatensis (L. Koch, 1866)	6	5	11
Haplodrassus signifer (C. L. Koch, 1839)	255	191	446
Trachyzelotes pedestris (C. L. Koch, 1837)	2	2	4
Zelotes apricorum (L. Koch, 1876)	.	1	1
Zelotes exiguus (Müller & Schenkel, 1895)	633	370	1003
Zelotes petrensis (C. L. Koch, 1839)	109	98	207
Hahniidae (1)			
Hahnia nava (Blackwall, 1841)	10	2	12
Linyphiidae (33)			
Agyneta fuscipalpa (C. L. Koch, 1836)	1	.	1
Agyneta rurestris (C. L. Koch, 1836)	2165	893	3058
Agyneta saxatilis (Blackwall, 1844)	.	1	1
Agyneta simplicitarsis (Simon, 1884)	10	4	14
Araeoncus humilis (Blackwall, 1841)	11	2	13
Bathyphantes gracilis (Blackwall, 1841)	2	2	4
Cnephalocotes obscurus (Blackwall, 1834)	1	.	1
Collinsia inerrans (O. Pickard-Cambridge, 1885)	2	2	4
Dicymbium brevisetosum Locket, 1962	1	.	1
Diplocephalus cristatus (Blackwall, 1833)	.	3	3
Erigone atra Blackwall, 1833	83	12	95
Erigone autumnalis Emerton, 1882	39	12	51
Erigone dentipalpis (Wider, 1834)	1563	276	1839
Erigone dentosa O. Pickard-Cambridge, 1894	1	.	1
Mermessus trilobatus (Emerton, 1882)	117	43	160
Metopobactrus prominulus (O. Pickard-Cambridge, 1873)	5	7	12
Micrargus subaequalis (Westring, 1851)	1	.	1
Microlinyphia pusilla (Sundevall, 1830)	4	3	7
Nematogmus sanguinolentus (Walckenaer, 1841)	.	1	1
Oedothorax apicatus (Blackwall, 1850)	2	3	5
Oedothorax fuscus (Blackwall, 1834)	7	6	13
Oedothorax retusus (Westring, 1851)	.	1	1
Ostearius melanopygius (O. Pickard-Cambridge, 1880)	11	14	25
Pelecopsis parallela (Wider, 1834)	211	573	784
Porrhomma microphthalmum (O. Pickard-Cambridge, 1871)	30	19	49
Porrhomma pygmaeum (Blackwall, 1834)	.	2	2
Prinerigone vagans (Audouin, 1826)	82	17	99
Pseudomaro aenigmaticus Denis, 1966	.	1	1
Saaristoa abnormis (Blackwall, 1841)	.	1	1
Tenuiphantes tenuis (Blackwall, 1852)	32	46	78
Tiso vagans (Blackwall, 1834)	14	8	22
Walckenaeria alticeps (Denis, 1952)	2	.	2
Walckenaeria vigilax (Blackwall, 1853)	1	.	1
Liocranidae (1)			
Scotina celans (Blackwall, 1841)	.	2	2
Lycosidae (17)			
Alopecosa cuneata (Clerck, 1757)	259	156	415
Alopecosa pulverulenta (Clerck, 1757)	6	2	8
Arctosa leopardus (Sundevall, 1833)	2	3	5
Arctosa lutetiana (Simon, 1876)	1	.	1
Aulonia albimana (Walckenaer, 1805)	6	3	9
Pardosa agrestis (Westring, 1861)	80	75	155
Pardosa hortensis (Thorell, 1872)	39	18	57
Pardosa palustris (Linnaeus, 1758)	246	169	415
Pardosa prativaga (L. Koch, 1870)	9	3	12
Pardosa pullata (Clerck, 1757)	2	4	6
Pardosa saltans Töpfer-Hofmann, 2000	.	1	1
Pardosa tenuipes L. Koch, 1882	271	147	418
Piratula hygrophila (Thorell, 1872)	2	.	2
Piratula latitans (Blackwall, 1841)	54	40	94
Trochosa ruricola (De Geer, 1778)	124	51	175
Trochosa terricola Thorell, 1856	1	.	1
Xerolycosa miniata (C. L. Koch, 1834)	29	14	43
Oxyopidae (1)			
Oxyopes lineatus Latreille, 1806	5	1	6
Philodromidae (1)			
Philodromus praedatus O. Pickard-Cambridge, 1871	.	1	1
Pholcidae (1)			
Pholcus opilionoides (Schrank, 1781)	6	5	11
Phrurolithidae (1)			
Phrurolithus festivus (C. L. Koch, 1835)	5	16	21

Taxon	♂	♀	ind
Pisauridae (1)			
Pisaura mirabilis (Clerck, 1757)	7	7	14
Salticidae (14)			
Attulus distinguendus (Simon, 1868)	1	.	1
Attulus penicillatus (Simon, 1875)	375	314	689
Euophrys frontalis (Walckenaer, 1802)	16	34	50
Evarcha arcuata (Clerck, 1757)	5	3	8
Heliophanus auratus C. L. Koch, 1835	.	1	1
Heliophanus cupreus (Walckenaer, 1802)	1	.	1
Heliophanus flavipes (Hahn, 1832)	7	9	16
Heliophanus kochii Simon, 1868	1	8	9
Icius subinermis Simon, 1937	.	1	1
Phlegra fasciata (Hahn, 1826)	598	503	1101
Pseudeuophrys lanigera (Simon, 1871)	87	55	142
Salticus scenicus (Clerck, 1757)	.	1	1
Talavera aequipes (O. Pickard-Cambridge, 1871)	17	6	23
Talavera aperta (Miller, 1971)	87	67	154
Segestriidae (1)			
Segestria bavarica C. L. Koch, 1843	1	.	1
Tetragnathidae (2)			
Pachygnatha clercki Sundevall, 1823	1	1	2
Pachygnatha degeeri Sundevall, 1830	208	192	400
Theridiidae (10)			
Asagena phalerata (Panzer, 1801)	979	280	1259
Enoplognatha latimana Hippa & Oksala, 1982	1	1	2
Enoplognatha thoracica (Hahn, 1833)	201	34	235
Episinus truncatus Latreille, 1809	.	1	1
Neottiura suaveolens (Simon, 1880)	1	.	1
Parasteatoda tepidariorum (C. L. Koch, 1841)	1	.	1
Phylloneta impressa (L. Koch, 1881)	.	1	1
Robertus mediterraneus Eskov, 1987	.	1	1
Steatoda albomaculata (De Geer, 1778)	1231	441	1672
Steatoda triangulosa (Walckenaer, 1802)	1	.	1
Thomisidae (11)			
Diaea dorsata (Fabricius, 1777)	1	.	1
Ozyptila atomaria (Panzer, 1801)	11	4	15
Ozyptila claveata (Walckenaer, 1837)	92	40	132
Ozyptila praticola (C. L. Koch, 1837)	6	5	11
Ozyptila simplex (O. Pickard-Cambridge, 1862)	22	28	50
Runcinia grammica (C. L. Koch, 1837)	1	.	1
Thomisus onustus Walckenaer, 1805	1	.	1
Xysticus acerbus Thorell, 1872	26	12	38
Xysticus cristatus (Clerck, 1757)	165	33	198
Xysticus kochi Thorell, 1872	1638	246	1884
Xysticus luctator L. Koch, 1870	.	2	2
Zodariidae (1)			
Zodarion italicum (Canestrini, 1868)	17	14	31
Total individuals	12492	5975	18467
Total species (123)			