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From the South and from the North? – *Quilnus marcosi* Heiss & Baena and *Aradus angularis* J. Sahlberg, two flat bug species new for Central Europe (Hemiptera, Heteroptera, Aradidae)

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Abstract

The flat bug fauna of Switzerland is still insufficiently studied. We describe the first records of *Aradus angularis* J. Sahlberg, 1886 and *Quilnus marcosi* Heiss & Baena, 2006 (Heteroptera: Aradidae) in Switzerland from a burnt forest area in the canton Valais. These are also the first records for Central Europe. With these new records, the number of Aradidae species recorded in Switzerland increases to 21, and in the canton Valais to 16. A cantonal record list of aradid species in Switzerland and photographs of the two recently new recorded species are provided. The pyrophilous *A. angularis* shows a disjunct distribution pattern, disconnected from its known distributional range from Fennoscandia to Northeast China, which suggests that the species is a relict of the Ice Age in Central Europe. In contrast, the sub-Mediterranean *Q. marcosi* seems to have expanded its distributional range to the north-east or has previously gone unnoticed in Switzerland. The host plants of *Q. marcosi* include *Pinus nigra* and *P. sylvestris*.

Zusammenfassung

Die Rindenwanzen der Schweiz sind noch ungenügend erforscht. Wir beschreiben den ersten Nachweis von *Aradus angularis* J. Sahlberg, 1886 und *Quilnus marcosi* Heiss & Baena, 2006 (Heteroptera: Aradidae) für die Schweiz, von einer Waldbrandfläche im Kanton Wallis. Diese beiden Nachweise sind zugleich die ersten für Mitteleuropa. Dadurch erhöht sich die Zahl der für die Schweiz bekannten Aradidenarten auf 21, für das Wallis auf 16. Eine kantonale Liste der Aradidenarten der Schweiz und Photos der neu gemeldeten Arten werden vorgestellt. Der pyrophile *A. angularis* zeigt ein, von seinem bekannten Verbreitungsgebiet von Fennoskandinavien bis nach Nordost-China, disjunktes Vorkommen. Dies lässt vermuten, dass es sich bei der Art in Mitteleuropa um ein Eiszeitrelikt handelt. Im Kontrast dazu sieht es so aus, als dass die sub-mediterrane *Q. marcosi* ihr Verbreitungsgebiet nach Nordosten ausdehnt oder sie bisher in der Schweiz übersehen wurde. Das Wirtsbaumspektrum von *Q. marcosi* umfasst *Pinus nigra* und *P. sylvestris*.

Introduction

Flat bugs (Heteroptera: Aradidae) represent the most species-rich family of saproxylic Hemiptera, besides Achilidae and Derbidae (both Fulgoromorpha) (Gossner and Damken 2018). All aradids feed on the hyphae of wood-decomposing fungi, with only a few exceptions, such as *Aradus cinnamomeus* Panzer, 1806, which sucks on living pines. The bodies of juveniles as well as of adults are strongly widened and flattened, with the upper

side featuring many pointed excrescences, humps and warts. Most species are highly specialized, living on specific decomposing fungi of certain woody plants, hidden under the bark or in the wood (Heiss and Péricart 2007). Some rather black-coloured species show an adaptation to forest fires, being able to rapidly detect burnt deadwood infested by a particular host fungi, e.g. *Aradus lugubris* Fallén, 1807 on *Daldinia loculata* (Lév.) Sacc. (Xylariaceae) (Wikars 2001). Their hidden way of life and the low amount of deadwood, in particular large dimensions, in Central European forests, explains the relatively few records of most flat bug species in this region (Gossner et al. 2007).

In the Palaearctic region, 241 species and nine subspecies from 28 genera of flat bugs are known to occur (Aukema and Rieger 2001, Aukema et al. 2013). Of these, 31 species, of which one is divided in two subspecies, of the four genera *Aneurus*, *Aradus*, *Calisius* and *Mezira* have been recorded in Central Europe (Günther and Schuster 2000, Heiss and Péricart 2007, Aukema et al. 2013), and 18 species, one comprising two subspecies, of this subset have been observed in Switzerland (Table 1). Due to losses of older collections, in particular that of Frey-Gessner (Anonymous 1866), and to unclear author names, historical records sometimes cannot be verified. Furthermore, some records are very questionable, such as *Aradus annulicornis* Fabricius, 1803 commented as the "most common Aradidae species in Switzerland" (Frey-Gessner 1864). In addition, a qualitative investigation on aradids in Switzerland has not been conducted so far. Based on that, the knowledge on the Aradidae of Switzerland is still very limited irrespective of the canton. However, 17 of the 19 known aradid species were also found after 1990 (Table 1). The record list for the canton Valais alone comprises 14 species and thus can be considered a hotspot of Aradidae diversity in Switzerland.

In this study, we present records of two species new to Central Europe, sampled in a forest stand in the canton Valais that was heavily affected by wild fire on 300 ha in 2003 (Wohlgemuth et al. 2005). The species *Aradus angularis* J. Sahlberg, 1886 was sampled during a post-fire invertebrate succession survey ten years after the fire. *Quilnus marcosi* Heiss & Baena, 2006 was sampled during a field excursion in 2017, 14 years after the fire.

Table 1. Cantonal list of Swiss records of Aradidae. The information refers to Heiss and Péricart (2007), supplemented by [1] = Records of the Swiss Federal Research Institute WSL (det. Heckmann), [2] = Wyniger (1999), Wyniger and Burckhardt (2003), [3] = Heckmann and Blöchlinger (in prep.), [4] = Di Giulio et al. (2000), [5] = Göllner-Scheiding (1988), [6] = Simonet (1954), [7] = present study, [8] = leg. det. coll. MMG, [9] = Records of the Swiss Federal Research Institute WSL (det. Grimm), [10] = Records of the Swiss Federal Research Institute WSL (det. Jenser), [11] = Records of the Swiss Federal Research Institute WSL (det. Stöcki); [12] = Hollier (2012); Canton = license plate abbreviations of cantons are used. ! = Occurrence after 1990 confirmed. ? = no evidence after 1990, with the year of the last record, if known. Older bibliographical references are not included in this table because many museum records (Entomological Collection of the Muséum d' histoire naturelle de Genève MHNG, Entomological Collection of the Muséum d' histoire naturelle de Lyon MHNL, Entomological Collection of the Swiss Federal Institute of Technology Zurich ETHZH) have been verified by Heiss and Péricart (2007) and some of them are references to these older bibliographical quotations. Many data on the cantonal occurrences in Heiss and Péricart (2007) do not include the dates of the records, and thus the differentiation into historical, older and current evidence is not possible in many cases.

Species	Canton	Current
Aneurus (Aneurodes) avenius (Dufour, 1833)	BL[2] BS[2] GE[12] SO[9] TI[1,2]	!
Aneurus (Aneurus) laevis (Fabricius, 1775)	AG[10] GE[6, 12] SO[9] TG[3] TI VD	!
Aradus angularis J. Sahlberg, 1886	VS[7]	!
Aradus aterrimus Fieber, 1864	GE VS[1]	!
Aradus betulae (Linnaeus, 1758)	TI[8] VS	!
Aradus betulinus Fallén, 1807	GL[1] GR SG[1] VS	!
Aradus cinnamomeus Panzer, 1806	GE GR LU[4] SO VD VS ZH[1]	!
Aradus conspicuus Herrich-Schaeffer, 1835	BE SO[9] TI VD VS	!
Aradus corticalis (Linnaeus, 1758)	GE[12] GR VD VS	!
Aradus crenaticollis R.F. Sahlberg, 1848	GL TI VS	!
Aradus depressus depressus (Fabricius, 1794)	AG BE[11] BL GE GL GR SH SG SO TG TI VS	!
Aradus krueperi Reuter, 1884	GE[12]	
Aradus lugubris Fallén, 1807	GR TI VS[1]	!
Aradus obtectus Vásárhelyi, 1988	GR SG VS	!
Aradus pallescens frigidus Kiritshenko, 1913	GR VS	!
Aradus pallescens pallescens Herrich-Schaeffer, 1840	GE VS	!
Aradus reuterianus Puton, 1875	VS	!
Aradus ribauti Wagner, 1956	VS	!
Aradus truncatus Fieber, 1860	GE GR	? 1974
Aradus versicolor Herrich-Schaeffer, 1835	AG[10] BE GE[12] SH SO SZ[5] TI VD ZH[8]	!
Quilnus marcosi Heiss & Baena, 2006	VS[7]	!

Methods

Sampling area

The sampling area is located within a large area of burnt forest in the Swiss Central Alps near Leuk (canton Valais; 46°20'N, 7°39'E) along a south-facing slope ranging from 800 to 2200 m a.s.l. close to the upper timber line (Fig. 1). The climate is continental with cold winters and dry summers (Zumbrunnen et al. 2009). Mean annual temperature decreases from 8.6°C at 640 m a.s.l. to 5.2°C at 1500 m a.s.l., while annual precipitation ranges from 600 mm at 640 m a.s.l. to 1000 mm at 1500 m a.s.l. (1961–1990) (Aschwanden et al. 1996). The wildfire (arson) occurred on 13 August 2003 and burnt 300 ha. The burnt area encompasses a gradient in vegetation ranging from a xerothermic mixed forest of oak (*Quercus pubescens* Willd.) and Scots pine (*Pinus sylvestris* L.) at 800–1200 m a.s.l., to spruce (*Picea abies* (L.) H.Karst.) at 1200–1800 m a.s.l., to larch (*Larix decidua* Mill.) mixed with woodland pasture at 1800–2000 m a.s.l. The forest is homogeneous within each vegetation type, but forest density and canopy coverage decrease with increasing altitude. Small gaps of former pasture activity and rock outcrops shape the forest structure at high altitudes (Wohlgemuth et al. 2008).

Sampling of the specimens

Aradus angularis was found during post-fire invertebrate succession surveys carried out by the Swiss Federal Research Institute WSL in 2004, 2005, 2006, 2008 and 2013 (e.g. Moretti et al. 2010). In these surveys true bugs were sampled using Combi-Traps (Fig. 1C), a yellow water pan (funnel) combined with a window trap, with two plexiglass screens at right angles to avoid the influence of wind direction, and one pitfall trap (13 cm diameter) at each trapping site (for details, see Duelli et al. 1999). Eighteen traps of each type were set along transects at three distinct altitudes (six traps per type and per altitudes at 1200, 1450, and 1700 m a.s.l.), and in three distinct areas: A) unburnt area, with ca. 150 m distance from the margin of the burnt area, B) burnt margin, within the burnt area, ca. 50 m from the forest margin, and C) a central burnt area within the burnt area, ca. 250 m from the forest margin. Along each transect, two trap sites per area were set, for a total of 6 trap sites per transect and 18 trap sites in total. During each sampling year, the traps were

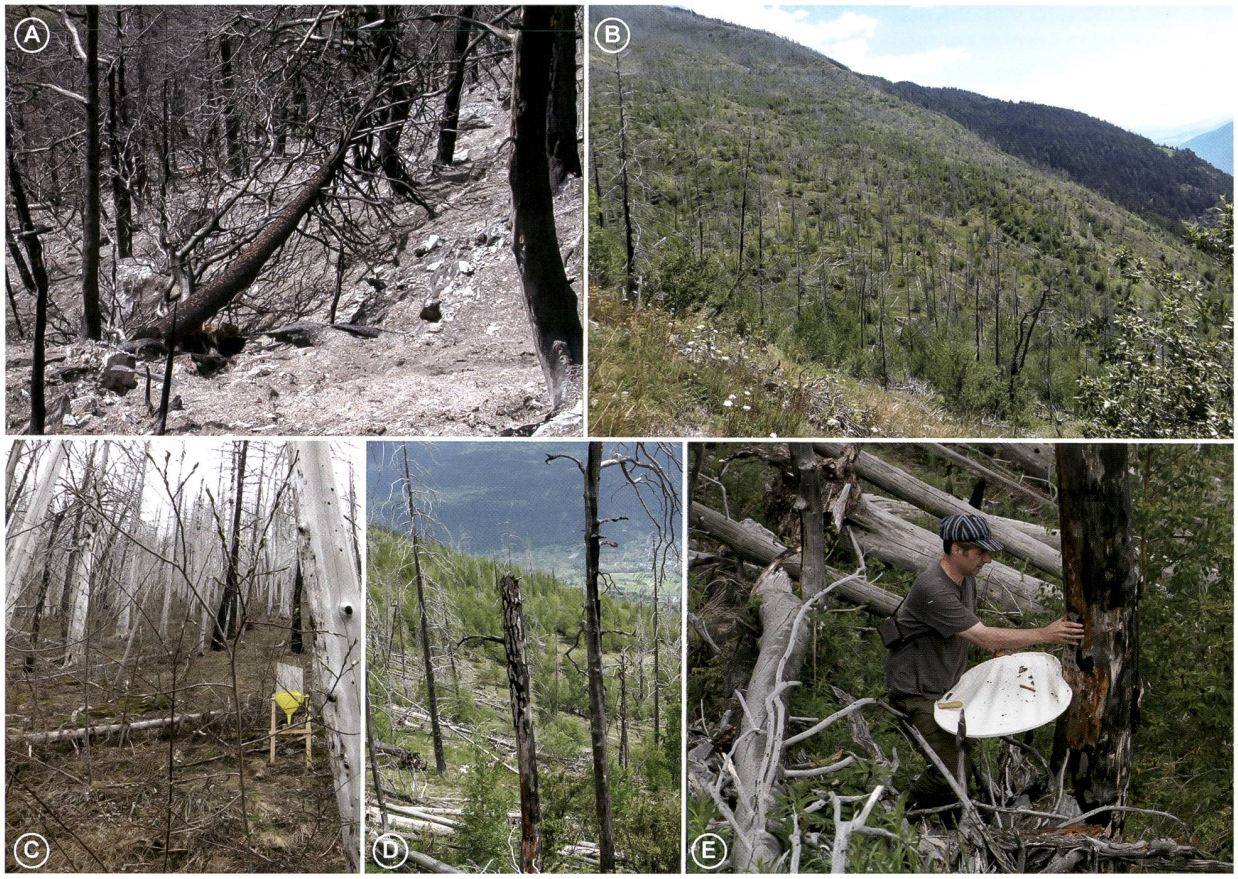

Figure 1. Photographs of the burnt site in Leuk, Valais, Switzerland: (**A**) Detail of the forest in 2003, one month after the fire; (**B**) Overview in August 2013 and (**C**) Detail of the site incl. Combi-trap in April 2013 (*Aradus angularis* J. Sahlberg, 1886 was sampled in June 2013); (**D**) Surrounding and (**E**) detail of the burnt pine tree (*Pinus sylvestris*) on which *Quilnus marcosi* Heiss & Baena, 2006 was detected in 2017 under one of a few remaining bark pieces. Photo credits: **A**: Marco Moretti, **B, E**: Beat Wermelinger, **C**: Martin Obrist, **D**: Martin M. Gossner.

emptied weekly from mid-April to early September. The insects were conserved in 70% alcohol.

During an excursion on 1 June 2017 to the burnt area two snags of burnt *Pinus sylvestris* trees were checked for Aradidae, one at 1480 m a.s.l. and the other at 1670 m a.s.l.

Results

During the post-fire invertebrate succession surveys by the WSL, two aradid species were recorded for the first time in Central Europe. *Aradus angularis* J. Sahlberg, 1886 occurred at a distance of 2177 km from the closest known record in Fennoscandia, and *Quilnus marcosi* Heiss & Baena, 2006 occurred 278 km from the closest record in southern France.

First detections and diagnoses

Aradus angularis J. Sahlberg, 1886

VS, Leuk, Thel, forest fire area, 1730 m a.s.l., 46°20'05"N, 7°39'28"E, 1 ♂ in Combi-trap, 19 June 2013. Voucher specimen is stored in the collection of R. Heckmann, Konstanz.

The species differs from other smaller, very dark species of the genus by its elongated body, almost-parallel outer margins of the wings and very thin antennas (Fig. 2A). To confirm identification of the specimen, the genitalia were dissected: The paramere has a typical distal basal tooth, distinct for *angularis*. Furthermore the 9th tergite shows a pointed shape, as shown in Heiss and Péricart (2007).

Quilnus marcosi Heiss & Baena, 2006

VS, Leuk, Thel, forest fire area, 1480 m a.s.l., 46°19'56"N, 7°38'51"E, 1 ♂, 1 juv., below one of a few remaining bark pieces on a sun-exposed burnt *Pinus sylvestris* snag, with a diameter at breast height of 35 cm (Fig. 1D, E). 1 June 2017, leg., det. M.M. Gossner, 19 June 2013. Voucher specimens are stored in the private collection of MMG, Fronreute, Germany.

The species (Fig. 2B) differs from other larger *Quilnus* species by rounded apical corners of the pronotum, the shorter second antennal segment and the structure of the genitalia (paramere, parandria, tergit IX), as shown in Heiss and Péricart (2007) and Heiss (2010).

Discussion

The records of the two new species increase the number of flat bug species in Switzerland to 21 species, with canton Valais being the most species-rich canton with 16 species. The frequent fires in south-facing regions, such as Valais and Grisons, as well as Ticino, which contribute to a large amount of deadwood, combined with warm and

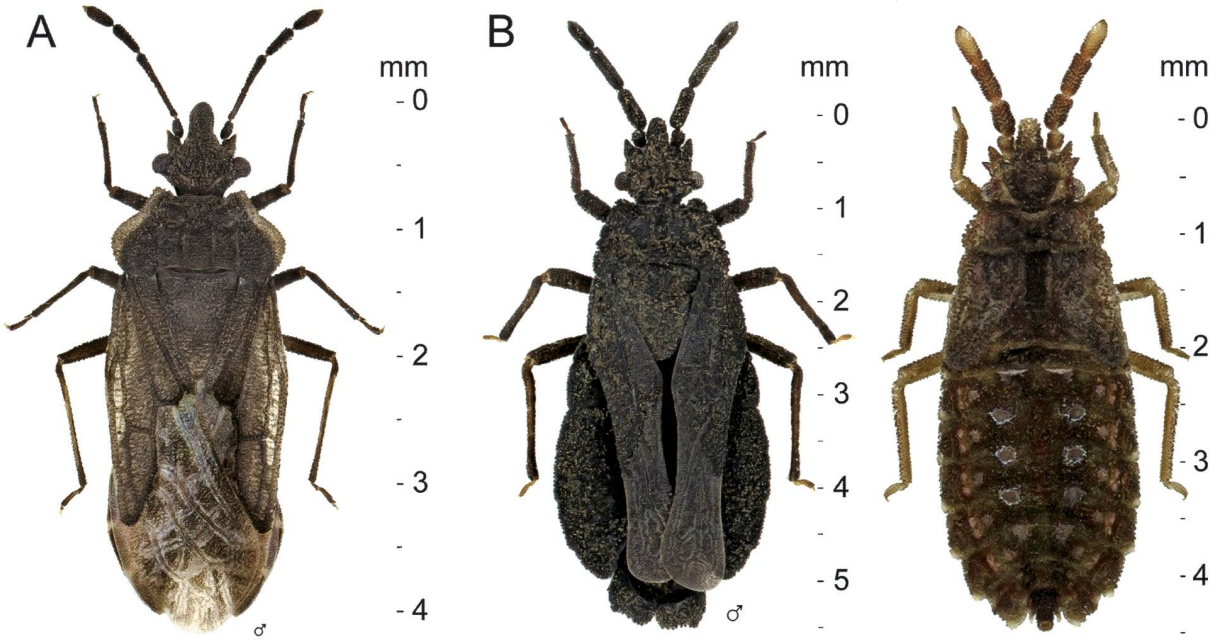

Figure 2. Two flat bug (Aradidae) species new to Central Europe, sampled in the burnt forest site in Leuk, Valais, Switzerland. (**A**) Male of *Aradus angularis* J. Sahlberg, 1886, sampled with a "Combi-trap" at 1730 m a.s.l. in June 2013 (sampling period 21 May to 23 June), leg. MM, det. coll. RH. Characteristic for the species are the size, the very thin antennae and the elongated body with the almost parallel outer margins of the wings and the form of the male genital structures. (**B**) Stenoptere male and juvenile of *Quilnus marcosi* Heiss & Baena, 2006, sampled under the bark of a burnt pine (*Pinus sylvestris*) tree at 1480 m a.s.l. on 1 June 2017, leg. det. coll. MMG. Characteristic for the species within the genus are the small size, the rounded apical corners of the pronotum and the form of the male genital structures. Photo credits: Gerhard Strauß.

dry climatic conditions, might be a main reason for such high diversity of Aradidae in Switzerland. Although the aradids are not well studied across cantons in Switzerland, data on saproxylic beetles also support the idea of Valais and Ticino being hotspots of saproxylic species diversity (Chittaro and Sanchez 2016, Sanchez et al. 2016). In the German federal states of Baden-Württemberg and Bavaria, 18 and 16 aradid species have been identified, respectively, which means that Switzerland, which is the same size but is not as well studied, already exceeds the number of species in Baden-Württemberg and Bavaria (Simon et al. 2018).

The record of *Aradus angularis* J. Sahlberg, 1886 in Switzerland is remarkable. In Europe, the species is distributed in Fennoscandia (Finland, Sweden) and European Russia (Fig. 3), but also occurs further east in Siberia and Mongolia (Heiss and Péricart 2007). More recently, it was also found in Northeast China (Bai et al. 2010). The vastly disconnected, rather disjunct occurrence in Switzerland at high altitude (Figs 3, 4) suggests that the species might be a relict of the last Ice Age. These relicts are cold-adapted species originating from the arctic or high alpine regions, which dispersed to lower elevation and to the south during cold periods and survived in higher elevations or "cooling holes" during later warmer periods (Hewitt 1999, Habel and Assmann 2010). Other examples of such Ice Age relicts among Heteroptera are the Corixidae *Arctocorisa carinata* (C. Sahlberg, 1819) (Jansson 1986), the Lygaeidae *Geocoris lapponicus* Zetterstedt, 1838 (Péricart 1998), and the Saldidae *Micracanthia fennica* (Reuter, 1848) (Günther and Strauß 2006).

Aradus angularis lives on dead burnt conifer trees, in particular *Picea* (Helioevaara and Vaisanen 1983), a tree species also found in the sampling area. It is listed as vulnerable in the Red Lists of Sweden and Finland (Gärdenfors 2000, Rassi et al. 2001). In Sweden and Finland the species has been found on charred tree trunks up to three years after forest fires (Helioevaara and Vaisanen 1983, Pettersson and Nilsson 1986, Heiss and Péricart 2007, Hagglund et al. 2015, Heikkala et al. 2017) (Fig. 4) and

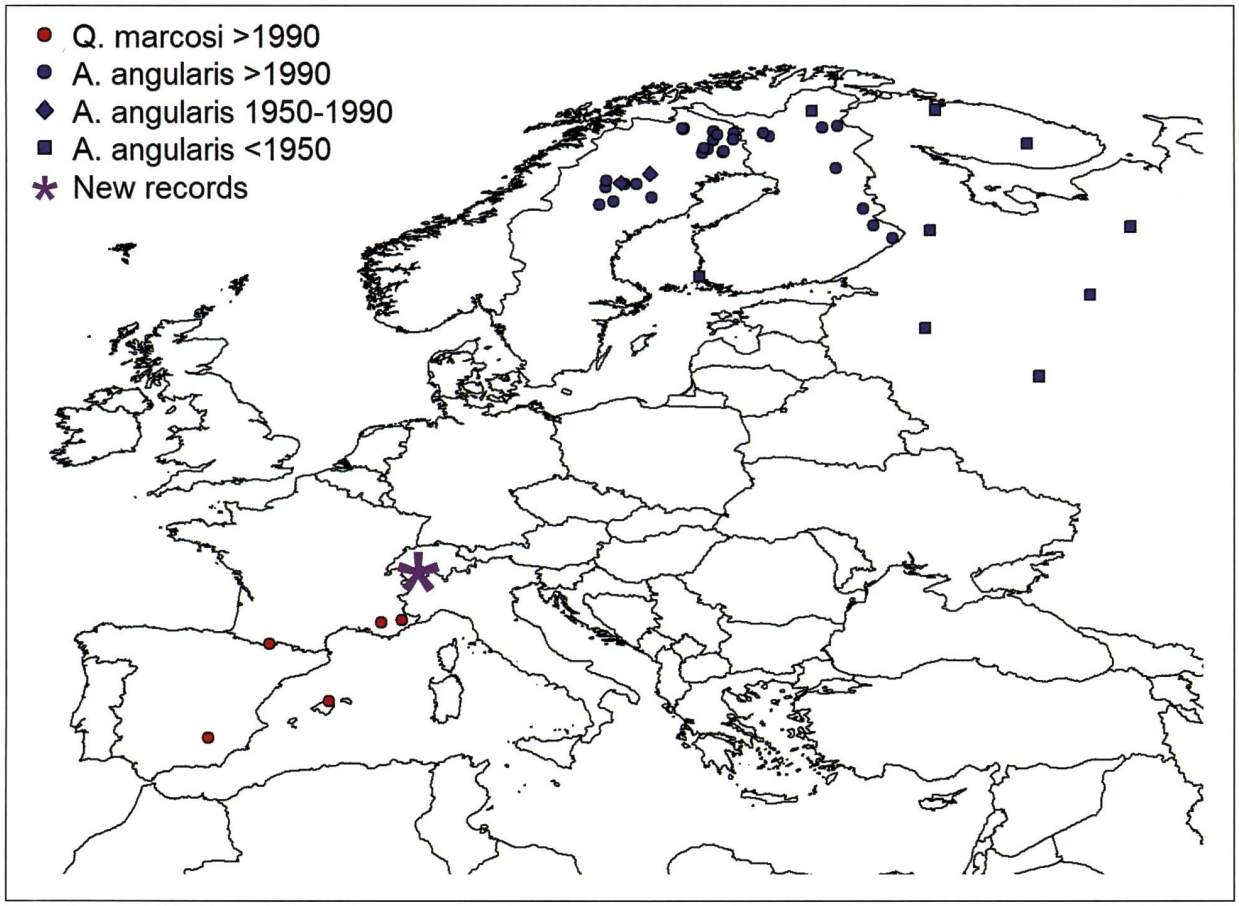

Figure 3. Records of *Aradus angularis* J. Sahlberg, 1886 (blue, n=46) and *Quilnus marcosi* Heiss & Baena, 2006 (red, n=7) in Europe, and new records of both species in Switzerland (star). Data are based on Heiss and Péricart (2007), Brustel (2009), Heiss (2010), Esser (Mallorca, unpubl., leg. Esser, det. coll. MMG) and the website of the Muséum national d'histoire naturelle Paris (https://science.mnhn.fr/institution/mnhn/collection/eh/item/eh18974?lang=en_US) for *Q. marcosi* and Reuter (1900), Helioevaara and Vaisanen (1983), Pettersson and Nilsson (1986), Lammes and Rinne (1990), Roth and Coulianos (2014), Hagglund et al. (2015), Heikkala et al. (2017), Heikkala (pers. com.), Martikainen (pers. com.), Artportalen Sveden (https://artfakta.artdatabanken.se/taxon/100379) and Kirishenko (1951) for *A. angularis*. Please note that data points in the European part of Russia represent the centre of each Oblast in which the species has been recorded.

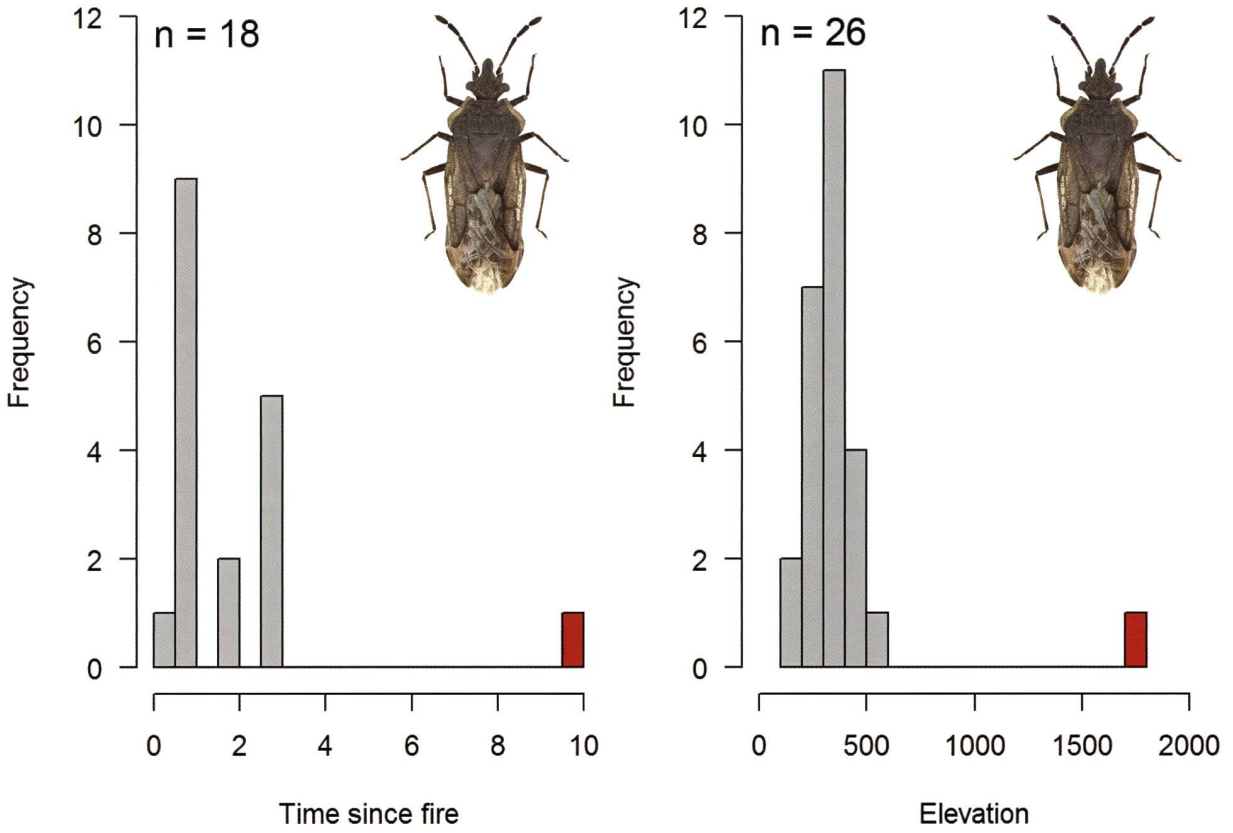

Figure 4. Frequency of occurrences of *Aradus angularis* J. Sahlberg, 1886 with respect to time since fire (left) and elevation (right), based on previous records in Fennoscandia (grey) and the new record in Switzerland (red). Please note that data were available for a subset of records only.

therefore is classified as a pyrophilous species by Wikars (1992, 1997). It is assumed that the pyrophilous Aradidae depend on pioneer fire-related ascomycete fungi that arrive early on competition-free substrates but are rapidly outcompeted by other fungi (Wikars 1997). The host fungi of *A. angularis* remains unknown. Surprisingly, we found only a single specimen of this species, 10 years after the fire, although sampling started in the year after the fire and continued two, three and five years after the fire occurred. This finding does not support the classification as a pyrophilous species, at least not as an obligatory one. In contrast, several individuals of another pyrophilous species, *Aradus lugubris* Fallén, 1807, and two pyrophilous longhorn beetle species (Pradella et al. 2010) were caught in the year after fire, in the same trap where *A. angularis* was captured, and at several other sampling sites. This suggests that the trapping method is suitable for catching pyrophilous species. It is still unclear how pyrophilous species survive during periods without forest fires. They might persist hidden in old burnt forests or in matrix forests with a large amount of deadwood (Saint-Germain et al. 2008), or they might extend their diet to other fungi that are not dependent on fire. Alternatively, being generally highly mobile species, the pyrophilous specimen reported here might have dispersed from a nearby burnt forest stand, such as that in Visp (21 km distance), where a large intensive forest fire occurred in 2011, and become caught in the trap. Similar to our observations regarding flat bug species, tens of individuals of one carabid (ground beetle) species (*Pterostichus quadrifoveolatus* Letzner, 1852), which is pyrophilous according to Wikars (1997), was found in the burnt forest in Leuk in 2013, while other pyrophilous beetles were only found in the first years after fire (Pradella et al. 2010). This suggests that some species are obligatory pyrophilous, while others might have a higher flexibility in terms of feeding or habitat requirements.

The record of *Quilnus marcosi* Heiss & Baena, 2006 is less surprising, as it has already been detected 279 km away in southern France in the West Alps (Heiss 2010). *Quilnus marcosi* has a sub-Mediterranean distributional range, expanding to the mountain range of the Alps. The species seems to be rare, as it was discovered only eleven years ago and not more than seven sites of occurrences of this species are known so far (Fig. 3). All previous records have described occurrences in southern Europe, including Spain and France. Thus, the present record might show its range expansion to Central Europe or a general wider distribution for the first time. Heiss (2010) already suggested that this species might further spread to the north and east, in particular with climate warming. However, Heiss (2010) predicted only colonisation of

dead *Pinus nigra*, within its disjunct distributional range from the Iberian Peninsula south of the Alpine mountain range up to the relict site at the eastern border of the Alps in Austria. The present record is the second one from *Pinus sylvestris*, following a record from Vallée du Rioumajou (Hautes-Pyrénées) (Brustel 2009). As a larva was also found in the tree in the present study, it is likely that this tree species can also be used as a host, which would allow further spread within the distributional range of *P. sylvestris*. The host fungi of *Q. marcosi* is the polyporous *Antrodia xantha* (Fr.) Ryvarden, 1973, which occurs on several *Pinus* species (Brustel 2009). There are no indications that *Q. marcosi* is associated with burnt deadwood. Thus, the large supply of deadwood resources after forest fires most likely promotes the occurrence of this species, as has been shown for other Aradidae species (Seibold et al. 2014).

Conclusions

The overall high number of flat bug species that have been recorded previously in Valais, Switzerland (Heiss and Péricart 2007) and the two recent species records suggests that this region may be a hot spot of flat bug diversity in Central Europe. This is also supported by other taxa that depend on deadwood such as saproxylic beetles (Chittaro and Sanchez 2016, Sanchez et al. 2016). The canton Valais has an unexpected long fire history (see Gimmi et al. 2004) and burnt areas and hotspots similar to the study area Leuk might exist in the region. The large amount of deadwood created by frequent forest fires most likely generates suitable habitats for pyrophilous as well as non-pyrophilous species. We strongly encourage entomologists to conduct a qualitative and even standardized quantitative assessment (see Gossner et al. 2007, Marchal et al. 2013, Morkel 2017) of aradids across Switzerland to evaluate the diversity distribution of this highly specialised saproxylic family with many endangered species.

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