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Distribution, biology and habitat of the rare European osmiine bee species *Osmia* (*Melanosmia*) *pilicornis* (Hymenoptera, Megachilidae, Osmiini)

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Abstract

Osmia pilicornis is distributed from western temperate Europe to western Siberia, where it exclusively occurs in open-structured, mesophilous and mainly deciduous woodland below 1000 m a.s.l. In Central Europe, its peak activity ranges from the last third of March to the first third of June. Due to its rarity and its low population densities over most of its range, the biology of *O. pilicornis* was only fragmentarily known. The discovery of six nests in the course of the present study revealed that females of *O. pilicornis* have a unique nesting behaviour among the osmiine bees: they gnaw their nests in dead wood with the aid of their strong mandibles, which have a peculiar chisel-like shape hypothesized to be an adaptation to the species' specialized nesting behaviour. All six nests were in dead fallen branches of different tree and shrub species and of varying wood hardness. The nesting branches had a diameter of 1.5–6.1 cm, lay on sun-exposed ground and were largely hidden under vegetation. The nests contained one to three linearly arranged brood cells. Both cell partitions and nest plug were built from chewed leaves harvested from *Fragaria vesca*. *Osmia pilicornis* was identified as a new host of the chrysidid wasp *Chrysura hirsuta*, and the ichneumonid wasp *Hoplocryptus confector* developed in its nests. Microscopical analysis of scopal pollen loads of collected females revealed that pollen is mainly collected from three plant taxa, i.e. *Pulmonaria* (Boraginaceae), Fabaceae (e.g. *Lathyrus*, *Vicia*) and Lamiaceae (e.g. *Ajuga*, *Glechoma*). On flowers

of *Pulmonaria*, which is the most important pollen host over most of the species' range, the females use specialized bristles on their proboscis to brush pollen out of the narrow corolla tube, they almost exclusively exploit pollen-rich flowers in the early red stage and they often steal pollen from still closed flowers by forcefully opening buds. On their search for females, males of *O. pilicornis* patrol flowers of *Pulmonaria* in a rapid flight regularly interrupted by short resting periods on the ground. Females are grasped for copulation both during flower visits and in flight between the flowers. The wide spectrum of semi-open mesophilous woodland types colonized by *O. pilicornis* suggests that dead fallen branches and a rich spring flora in combination with a rather warm but not xeric microclimate are the only requisites needed by the species. As the great majority of woodland habitats currently occupied by *O. pilicornis* in Central Europe owe their origin to human forest use, the recent decline of *O. pilicornis* in many regions of Europe may have been caused by changes in woodland management practices leading to closed and dark forests not suitable as habitats for this specialized bee species.

Keywords

Apiformes, *Chrysura hirsuta*, dead wood, *Hoplocryptus confector*, *Pulmonaria*, nesting behaviour, open-structured woodland

Introduction

Osmia pilicornis Smith is a member of the large holarctic subgenus *Melanosmia* represented by 12 species in Europe (Müller 2016). Most of the European *Melanosmia* species are adapted to colder climates and typically occur in mountainous habitats, often exhibiting an alpine, boreoalpine or boreal distribution (Tkalců 1983, Rightmyer et al. 2010, Müller 2016). *Osmia pilicornis*, whose distribution area ranges from western over central and eastern temperate Europe to western Siberia, belongs to those few European *Melanosmia* species, which are restricted to lower elevations. Its early appearance in spring and its exclusive occurrence in mainly mesophilous woodland habitats, however, suggests a moderate preference for colder climates revealing its affiliation to *Melanosmia*.

Osmia pilicornis is regarded as a rare bee species over most of its range (Westrich 1989, Amiet et al. 2004, Westrich et al. 2008, Falk and Lewington 2015). In several European countries, it is listed on regional or national red lists since its populations have declined in many regions in recent decades (Amiet 1994, Winter 1994, Dathe and Saure 2000, Saure 2005, Westrich et al. 2000, 2008, Van der Smissen 2001, Theunert 2002, Mandery et al. 2003, Burger et al. 2004, Burger 2005, Straka 2005, Tischendorf et al. 2009, Esser et al. 2010, Earwaker 2012). Changes in woodland management practices are assumed to be a major cause of its decline, resulting in a lack of suitable food plants and nesting sites (Earwaker 2012, 2014). Given the threatened status of *O. pilicornis* in parts of its European range, knowledge of the species' requirements for nesting sites, host plants and habitat characteristics is needed to aid in its conservation.

The preference of *Osmia pilicornis* for the flowers of *Pulmonaria* (Boraginaceae) as pollen hosts has been known for a long time (Stoeckhert 1933, Westrich 1989, Müller

1995, Amiet et al. 2004, Ebmer 2010), as has the presence of specialized bristles on the female proboscis, which are used to brush pollen out of the narrow *Pulmonaria* corolla tubes (Müller 1995). In contrast, the nesting biology of *O. pilicornis* is virtually unknown. While masticated leaves ("leaf pulp") have recently been identified as nest building material (Westrich 2010), the nesting sites are still enigmatic. Depending on the author, *O. pilicornis* was assumed to burrow in stony ground (Wallis 1886), to nest in empty snail shells (Friese 1911, Banaszak and Romasenko 2001), to gnaw burrows in dead wood (Wallis 1886, Perkins 1891), to nest in old tree stumps or branches lying on the ground (Blüthgen 1919, Stoeckhert 1933, Chambers 1949), to build brood cells under loose bark (Amiet et al. 2004) or to colonize preexisting insect borings in dead wood (Earwaker 2014, Falk and Lewington 2015). While the assumption that *O. pilicornis* nests in the ground or in snail shells appears to be unlikely and is probably due to misidentifications with similar species, all the other literature records clearly suggest dead wood as nesting substrate. However, as no nests in dead wood have ever been described in detail, the question remains open whether the females of *O. pilicornis* excavate their own burrows, build their brood cells under loose bark or nest in insect borings.

In the present publication, we describe nesting site, nest architecture and nesting behaviour of *Osmia pilicornis* based on the recent discovery of several nests in Germany and Austria. In addition, we report on a hitherto unknown host-parasitoid relationship between *O. pilicornis* and a chrysidid wasp, investigate host-plant spectrum and flower-visiting behaviour based on both analysis of female pollen loads and field observations and describe the mating strategies of the males. Furthermore, we present a comprehensive distribution map and characterize phenology and habitat of *O. pilicornis* focussing on Central Europe.

Methods

To elucidate the distribution of *Osmia pilicornis*, we conducted a comprehensive literature study, gathered unpublished records from European entomological collections and retrieved distributional data from several public databases. Numerous additional records were provided by bee researchers all over Europe. For details see Acknowledgments and Suppl. material 1, which contains a complete list of all distributional data.

To evaluate the phenology of *Osmia pilicornis* in Central Europe, all records were considered that could be assigned to sex and an exact date. Central Europe is defined here as the area that comprises Austria, Czech Republic, Germany, Hungary, Poland, Switzerland, Slovakia and Slovenia.

Field work was mainly conducted in southern Germany near Crailsheim (Baden-Württemberg) from 12 April to 15 May 2015 and from 10 April to 30 May 2016. Additional study sites were near Ernstbrunn (Niederösterreich) in northeastern Austria and near Flaach (Zürich) and Schaffhausen (Schaffhausen) in northern Switzerland, where field work was done in April and May 2016. The four study sites differed in the *Pulmonaria* species available for *Osmia pilicornis*: the first contained only *P. mollis*

Wulfen ex Hornemann, the second and third only *P. officinalis* Linné and the fourth only *P. obscura* Dumortier.

To uncover the pollen-host preferences of *Osmia pilicornis*, the scopal pollen contents of 52 female specimens collected at 49 different localities in Austria (n=18), Germany (n=16), Switzerland (n=13) and the Czech Republic (n=5) from 1903 to 2013 as well as the pollen provisions of three brood cells originating from two nests were microscopically analysed following the method of Müller (2015).

Flowers of *Pulmonaria* change their colour from red to blue during anthesis, which lasts about five to eight days (Oberrath et al. 1995, Oberrath and Böhning-Gaese 1999). This colour change, which takes place approximately in the middle of anthesis, is caused only by aging and thus independent of pollination (Süssenguth 1936, Oberrath et al. 1995). To investigate whether females of *Osmia pilicornis* discriminate between *Pulmonaria* flowers in the early red and the late blue stage, we counted flower visits on red and blue flowers of *P. mollis* on a plot of 15×15 m on six days during ten intervals each lasting from 0.5 to 2.5 h. Counting occurred during two periods from 7 to 10 May 2016 and from 20 to 21 May 2016. After each interval, the total number of red and blue flowers of all plant individuals that were visited by the female bees was determined. To compare the nectar quantity contained in *Pulmonaria* flowers of the red and the blue stage, we determined the nectar amount in 33 red and 33 blue flowers of *P. mollis* with 10 µl microcapillaries. The flowers for nectar quantification were collected on the same day in early morning before the onset of insect activity. To compare the pollen quantity contained in *Pulmonaria* flowers of the red and the blue stage, we determined the pollen amount in 20 red and 20 blue flowers each of *P. obscura* and *P. officinalis*. As a proxy for the pollen amount we estimated the proportion of the thecal surface that was covered by pollen (to the nearest 10%) separately for each of the ten thecae of a flower and averaged the ten percentages to get an average degree of thecal pollen coverage for each flower. For both *Pulmonaria* species, the flowers were collected on the same day between 11 and 12 am, stored in open eppendorf tubes and slit the following morning for pollen quantification. To investigate the proportion of already dehisced vs. still closed anthers in flowers of the late bud stage, we opened 20 buds of *P. officinalis*.

Pulmonaria is distylous with two floral morphs, which occur on separate plants and differ in the relative height of anthers and stigma and the size of the pollen grains (Olsen 1979; Fig. 27, 28). The ratio of plants with longistylous and brevistylous flowers often deviates from 1:1 within the same population and may vary between different populations (Brys et al. 2008). To investigate whether females of *Osmia pilicornis* prefer one of the two floral morphs, the morph of each *P. mollis* plant growing on the 15×15 m study plot was determined after the female flower-visiting behaviour was recorded (see above).

To take photos, video sequences and photomicrographs, we used a Canon EOS 70D with 150 mm macro lens and macro flashlights, a Camcorder Panasonic HC V777 and a digital microscope Keyence VHX-2000, respectively. For statistical analyses, SPSS 22.0.0.2 for Macintosh OS X (SPSS Inc., Chicago, IL, USA) was used.

Results

Distribution

Osmia pilicornis occurs from western, central and eastern temperate Europe eastwards to the Kemerovo region in western Siberia (Fig. 1). It inhabits a rather narrow belt between 44.5° and 62.5° northern latitude, extending from 3.5° western to 87.5° eastern longitude (Table 1). It is distributed from sea level up to about 950 m a.s.l., with the highest records all lying below 1000 m a.s.l. It has been recorded so far from (west to east) southern Great Britain, northern France, Belgium, western and northern Switzerland, Luxembourg, Germany, Denmark, Austria, southern Sweden, Czech Republic, Slovenia, Hungary, Slovakia, Poland, Romania, Lithuania, southern Finland, Latvia, Belarus, Ukraine and Russia (southern North-West district, Central district, Wolga district, southern Ural district, southwestern Siberia district). Wu (2006) reports *O. pilicornis* from the Taihang mountains in Hebei province in northeastern China, which is about 2600 km to the east of the easternmost records of *O. pilicornis* in western Siberia. This record appears to be doubtful and needs verification as already demanded by Ebmer (2010).

Phenology in Central Europe

Osmia pilicornis emerges early in spring (Fig. 2). Its appearance coincides with that of other early bee species, such as *Andrena bicolor* Fabricius, *Anthophora plumipes* (Pallas), *Eucera nigrescens* Pérez, *Osmia bicolor* (Schrank) and *Osmia bicornis* (Linné). In Central Europe, the earliest records are 22 February for males and 18 March for females. Males have their peak activity from the last third of March to the first third of May and occasionally fly until mid May. The latest male record in Central Europe is 17 May. Females have their peak activity from the first third of April to the first third of June and occasionally fly until the end of July. The latest female record in Central Europe is 4 August. While the males emerge only a few days before the females, their flight period is roughly one month shorter, indicating that the females have a distinctly longer average life span than the males.

Nesting biology

Nesting site

Six nests of *Osmia pilicornis* were discovered in 2015 and 2016. Five nests were found on a 0.8 ha large and about five years old clear-cutting in a former spruce plantation with numerous plants of *Pulmonaria mollis* near Crailsheim (Baden-Württemberg) in southern Germany (10.11°E 49.18°N, 450 m a.s.l., Fig. 42). One nest was detected in a recently thinned, very light and oak-dominated deciduous forest with large stands

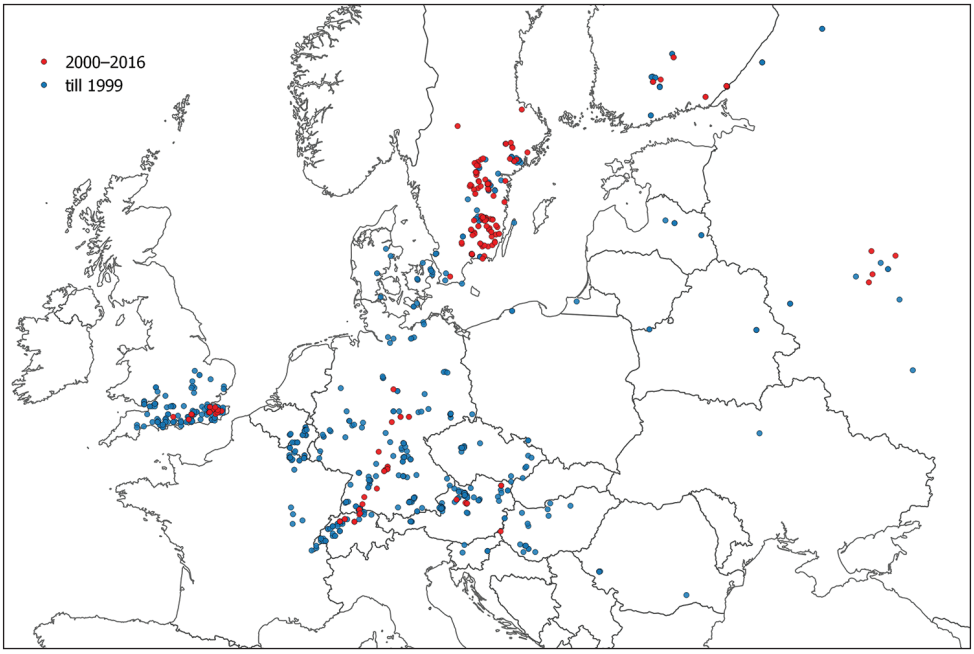


Figure 1. Distribution of *Osmia pilicornis*. Records east of the Ural mountains are not shown.

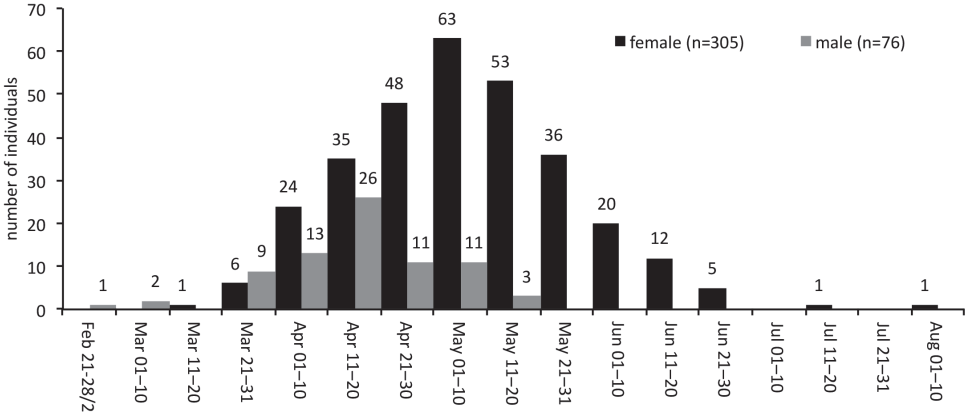


Figure 2. Phenology of *Osmia pilicornis* in Central Europe. Central Europe is defined here to comprise Austria, Czech Republic, Germany, Hungary, Poland, Switzerland, Slovakia and Slovenia.

of *Pulmonaria officinalis* near Ernstbrunn (Niederösterreich) in northeastern Austria (16.35°E 48.59°N, 330 m a.s.l., Fig. 44).

All six nests were burrows excavated by the female bees in dead branches lying on sun-exposed ground (Table 2, Figs 3–11). One branch contained two separate nests built by two females (nesting site 1), another branch also contained two nests, which, however, were probably constructed by the same female (nesting site 3), and

Table 1. Southern-, northern- western- and easternmost as well as highest records of *Osmia pilicornis*. Only one record per country is given for the southernmost, northernmost and highest records.

Locality		Source
southernmost records	Romania, Călărași, Fundulea, 26.511E, 44.464N	Aftene (1995)
	Slovenia, Črni Vrh, Pasja ravan, 14.229E, 46.098N	A. Gogala (personal communication)
	Hungary, Baranya, Mecsek, Remete-árok, 18.217E, 46.118N	M. Sarospataki (personal communication)
	Switzerland, Genève, Dardagny, 5.949E, 46.177N	database of Centre Suisse de Cartographie de la Faune (CSCF)
	France, Côte-d'Or, Reulle-Vergy, 4.905E, 47.181N	M. Aubert and G. Le Goff (personal communication)
northernmost records	Russia, Karelia, Kondopozhskiy rayon, Tivdiya, 33.961E, 62.561N	J. Paukkunen (personal communication)
	Finland, Western Finland, Korpilahti, Korospohja, 25.732E, 61.917N	J. Paukkunen (personal communication)
	Sweden, Uppsala, Brändäng, 17.482E, 60.447N	A. Nilsson (personal communication)
westernmost records	United Kingdom, Devon, 3.630W, 50.743N	database of Global Biodiversity Information Facility (GBIF)
	United Kingdom, Wales, Castell Coch, 3.247W, 51.534N	database of Global Biodiversity Information Facility (GBIF)
easternmost records	Russia, Kemorovo, Tashtagol district, Kaz, 87.542E, 53.108N	T. Levchenko (personal communication)
	Russia, Kemerovo, Karakan Mountains, 86.932E, 54.364N	T. Levchenko (personal communication)
highest records	Slovenia, Črni Vrh, Pasja ravan, 970m a.s.l.	A. Gogala (personal communication)
	Germany, Baden-Württemberg, Swabian Jura, Obernheim, 950m a.s.l.	Westrich (2010, personal communication)
	Switzerland, Bern, La Neuveville, Neuve Métairie, 860m a.s.l.	database of Centre Suisse de Cartographie de la Faune (CSCF)
	Austria, Salzburg, Hinterwinkl near Ebenau, 700m a.s.l.	M. Schwarz (personal communication)

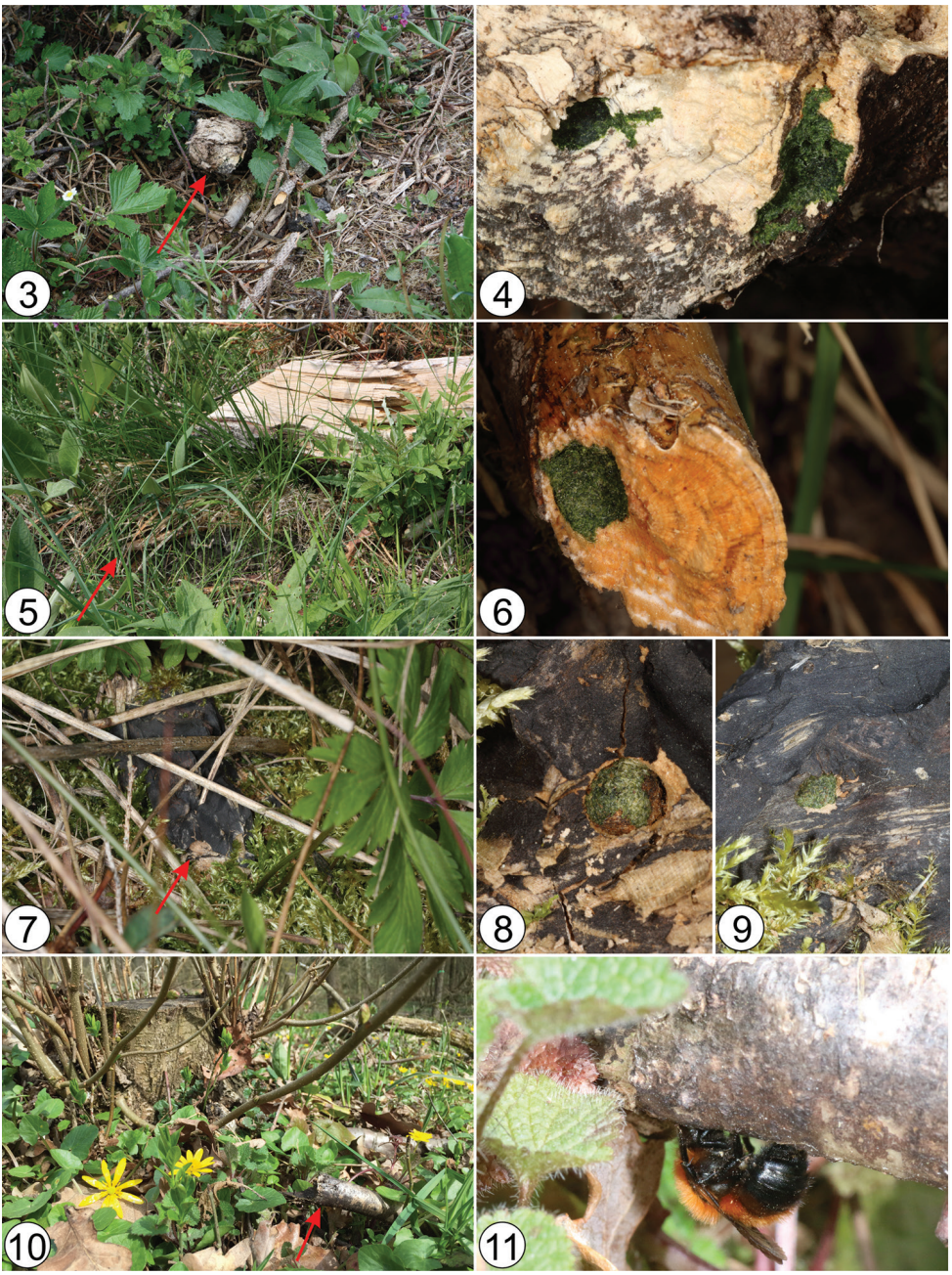
two branches contained one nest each (nesting sites 2 and 4). The branches selected as nesting sites had a length of 7.5–85 cm and a diameter of 1.5–6.1 cm, were largely hidden under vegetation and belonged to four different tree or shrub species. The females started to gnaw the nest burrows either in the apical area of branch fracture (n=4), on the side of the branch (n=1) or on the underside of the branch about 10 cm above ground (n=1). The nest entrances were exposed to south-southwest (n=3), southeast (n=1) or northeast (n=1). The hardness of the nesting wood varied from very hard (n=2) and moderately hard (n=1) to soft (n=1).

Nest architecture

The nests of *Osmia pilicornis* were composed of i) a burrow tunelled out by the female bee, ii) a varying number of brood cells each delimited towards the nest entrance by a

Table 2. Characteristics of six nests of *Osmia pilicornis* discovered in Germany (nesting sites 1–3) and Austria (nesting site 4). The hardness of the wood is indicated by the following categories: very hard = impossible to scratch the wood with the fingernail; moderately hard = possible to scratch the wood with the fingernail, but impossible to burrow a hole with the finger; soft = possible to burrow a hole with the finger.

Nesting site no	Species of branch	Length and diameter of branch	Hardness of wood	Degree of concealment of branch	Wood infesting fungi	Nest no	Location of nest entrance	Direction of nest entrance	Number of brood cells
1	*Fraxinus excelsior*	85 cm × 6.1 cm	very hard	hidden under vegetation except for the apical 9 cm	*Hypoxylon rubiginosum* (Xylariaceae), *Xylaria hypoxylon* (Xylariaceae), *Phanerochaete* spec. (Phanerochaetaceae)	1	apical area of fracture	SSW	3
						2	apical area of fracture	SSW	2
2	*Picea abies*	18 cm × 1.5 cm	very hard	almost completely hidden under vegetation except for the apicalmost part	Corticiaceae spec.	3	apical area of fracture	SSW	1
3	*Salix* spec.	7.5 cm × 3.5 cm	soft	almost completely hidden under vegetation except for the apicalmost part		4	apical area of fracture	SE	2
						5	side of branch about 3.5cm behind apical area of fracture	NE	1
4	*Corylus avellana*	25 cm × 2.5 cm	moderately hard	hidden under vegetation except for the apical 5 cm		6	underside of branch about 2 cm behind apical area of fracture and 10 cm above ground	-	unknown



Figures 3–11. Nesting sites of *Osmia pilicornis* in dead fallen branches (see Table 2): **3–4** Nesting site 1 with nests 1 and 2 in a branch of *Fraxinus excelsior* **5–6** Nesting site 2 with nest 3 in a branch of *Picea abies* **7–9** Nesting site 3 with nests 4 and 5 in a branch of *Salix* spec. **10–11** Nesting site 4 with nest 6 in a branch of *Corylus avellana*.

cell partition, iii) a (facultative) empty space ("vestibule") of varying length in front of the outermost cell and iv) a nest plug that closed the nest at the front end (Figs 12–14). There was no basal wall that sealed the nest burrow against the rear end.

The excavated burrows consisted of a short entrance part, which was 6–7 mm long and 5–6.4 mm wide, and a main part, which ran in longitudinal direction of the branch and contained the brood cells. The main part deviated from the entrance part by an angle of 90–140°. Depending on the number of brood cells, the total length of the burrows was 1.7–3.2 cm. The burrow and cell walls were neither lined with glandular secretions nor with leaf pulp except for a small area of less than 15 mm^2 in the rearmost brood cell of nest 4, which was covered by a thin layer of leaf pulp. In nest 3, the gnawing female obviously met a preexisting burrow of the cerambycid beetle *Molorchus minor* (Linné) running in longitudinal direction of the branch and adopted it as part of her own burrow by broadening its diameter from 2.8 mm to 5.7 mm (Fig. 13).

The nests contained one (n=2), two (n=2) or three (n=1) linearly arranged brood cells. Brood cell number could not be assessed in one nest as the nesting branch disappeared in the course of the study for unknown reasons. The brood cells had a length of 9.7–12.4 mm and a maximal width of 5.4–6.5 mm. They were widest in the centre and slightly constricted at both ends. The cell partitions were one-layered and had a width of 1–1.25 mm along the burrow wall.

Three out of five nests contained a vestibule between the outermost cell partition and the nest plug measuring 4–6 mm in length. In the other nests, no vestibule was developed; instead, the outermost cell partition was part of the nest plug.

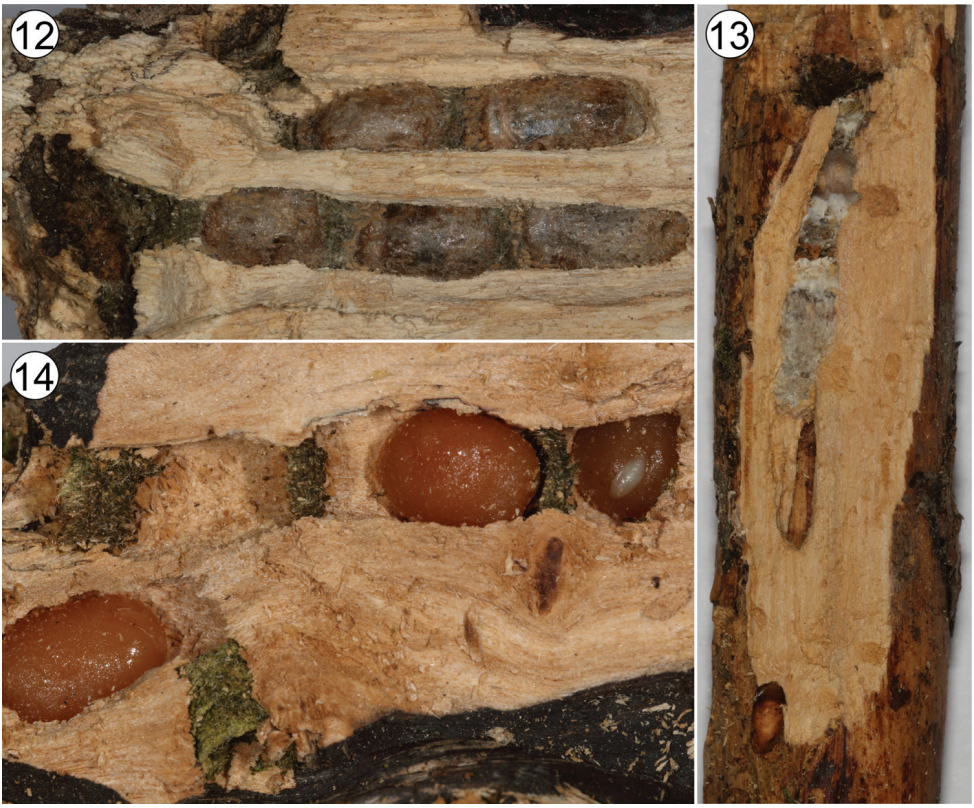
The nest plugs measured 3–7.5 mm in length. They were multi-layered and consisted of 2–4 and 1–2 mm thick walls, which were built immediately behind each other. The nest plugs were flush with the nest entrance (n=3) or recessed by 2.5–3.5 mm (n=2).

Both cell partitions and nest plug exclusively consisted of leaf pulp. At nesting sites 1–3, females of *Osmia pilicornis* were repeatedly observed to collect leaf material from *Fragaria vesca* Linné (Fig. 19).

Female nesting behaviour

The females of *Osmia pilicornis* gnawed their nests in dead wood exclusively with the aid of their mandibles (Figs 15, 16, Suppl. material 2). At nesting site 1, the female was repeatedly observed to burrow for a period of 10–15 sec, before she left the nest for a short circular flight of 1–1.5 m diameter, during which she dropped the carved wood chips that she had held in her mandibles. Occasionally, the female pushed the wood chips with her legs backwards out of the nest. It took about 10 min from the start of carving at the surface of the very hard *Fraxinus* branch until head and mesosoma had disappeared within the substrate, indicating a remarkably high speed of tunneling.

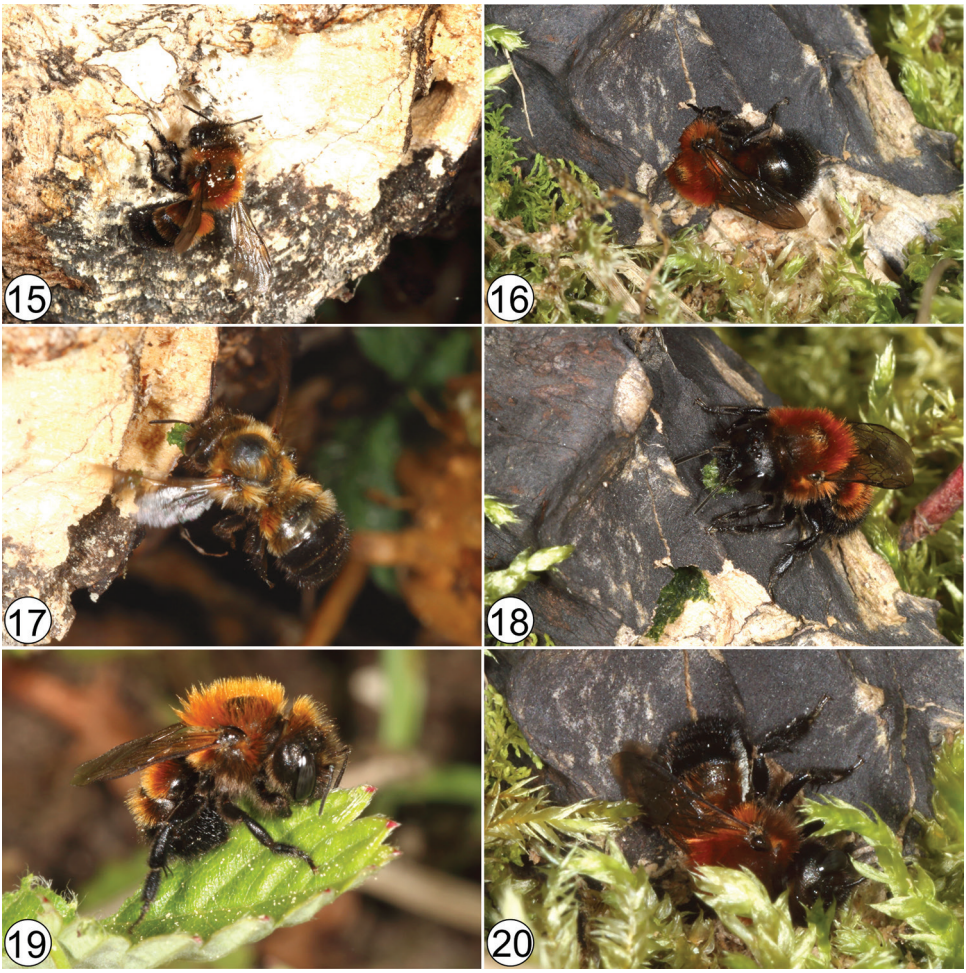
The shape of the female mandible of *Osmia pilicornis* differs from that of closely related *Osmia* (*Melanosmia*) species, such as *O. inermis* or *O. parietina* (Figs 21–26).



Figures 12–14. Opened nests of *Osmia pilicornis* in dead branches (see Table 2): **12** Nests 1 and 2 with three and two brood cells, respectively, each containing a cocoon spun by the *O. pilicornis* larva **13** Nest 3 with one brood cell containing a cocoon spun by the *O. pilicornis* larva; at the bottom a pupa of *Molorchus minor* (Cerambycidae) **14** Nests 4 and 5 with two and one brood cell, respectively, each containing a larval provision; an empty vestibule is present between the outermost cell partition and the nest plug in nest 4, while the cell partition is part of the nest plug in nest 5.

In *O. pilicornis*, the mandible has a much broader and distinctly more inflated base, is relatively shorter, has less diverging margins and is apically only slightly curved inwards giving it a more compact and chisel-shaped appearance. In addition, the uppermost mandibular tooth is more prominent being as large as the medial tooth so that the apices of all mandibular teeth are almost at the same height forming a regular three-toothed apical edge.

The female of nest 1 needed 25 foraging flights to provision a single brood cell. This female spent 0.6–19.9 min for one provisioning flight (mean 8.7 min, n=25) and remained 10–105 sec within the nest to deposit nectar and pollen (mean 48 sec, n=25). The female of nest 4 returning from a provisioning flight entered the nest head first to regurgitate nectar before she came out, turned around at the nest entrance and entered the nest metasoma first to comb pollen out of the scopa (Fig. 20, Suppl. material 3). The first phase lasted about 25 sec (n=2), suggesting that the regurgitation of nectar



Figures 15–20. Nesting behaviour of *Osmia pilicornis* (see Table 2): **15–16** Females of nests 1 and 4 tunneling out burrows in dead branches **17–18** Females of nests 2 and 4 transporting small leaf fragments of *Fragaria vesca* to build brood cell partitions and nest plug **19** Female harvesting nest-building material on a leaf of *Fragaria vesca* **20** Female of nest 4 returning from a foraging flight with pollen-filled metasomal scopa.

and the deposition of pollen require a similar amount of time. Turning at the nest entrance was not observed at nest 1. Here, there was probably enough space within the burrow allowing the female to turn inside the nest. At nest 1, the last provisioning flight took place at 7:27 pm (temperature 22 °C) and the first provisioning flight the subsequent day at 8:49 am (nesting site in full sunlight), indicating a remarkably long daily activity of more than 10.5 h under favourable conditions.

The females harvested leaf material of *Fragaria vesca* with their mandibles (Fig. 19). They transported it as small leaf fragments rather than as masticated pellets back to

Figures 21–26. Female mandibles of three closely related *Osmia* (*Melanosmia*) species; left=mandible in front view, right=mandible from below: **21–22** *O. pilicornis* **23–24** *O. inermis* **25–26** *O. parietina*. Figures are not to scale.

their nest (Figs 17, 18, Suppl. material 4). As cell partitions and nest plug were built mainly from masticated leaves, the leaf fragments were probably chewed to leaf pulp during their processing inside the nest. The collection of leaf pulp by the female of nest 1 lasted 5–155 sec per flight including flight time (mean 27 sec, n=21) and its processing inside the nest 5–355 sec (mean 75 sec, n=21).

Brood parasites

A female of the chrysidid wasp *Chrysura hirsuta* (Gerstaecker) was observed to visit nest 1 on 11 May 2015 three times in succession (Fig. 37). During the first visit, the wasp lurked at a distance of 2 cm from the nest entrance during 19 min, before she entered the nest headfirst and left it a few seconds later backward. During the second visit, the wasp intruded the nest again headfirst, backed out and immediately entered the nest a second time, but now backward, thereby possibly laying an egg into the brood cell; after about 15 sec she reappeared at the nest entrance and flew away. During the third visit, the wasp was collected for identification. Similarly, females of *C. hirsuta* were repeatedly observed in the close neighbourhood of nest 6 on four days from 2 to 21 April 2016. In contrast to nest 1, however, *C. hirsuta* was not observed to approach or enter the nest.

Five out of the six brood cells of nests 1–3 discovered in 2015 were parasitized, suggesting a high pressure exerted by brood parasites on *Osmia pilicornis*. In all three cells of nest 1, including the cell that was entered by *Chrysura hirsuta* (see above), females of the ichneumonid wasp *Hoplocryptus confector* (Gravenhorst) developed. A female of the same ichneumonid species emerged from the rear cell of nest 2, while the front cell contained inside the larval cocoon of *O. pilicornis* a cocoon with a dead chrysidid wasp larva most probably of *C. hirsuta*. The only unparasitized cell was the single cell of nest 3, in which a male of *O. pilicornis* developed.

As a possible further brood parasite we noticed a single triungulin larva of *Meloe violaceus* Marsham (Meloidae) adhering to the body of a male of *Osmia pilicornis*.

Host plants

Pollen hosts

The microscopical analysis of 52 pollen loads originating from 49 different localities in Central Europe revealed that *Osmia pilicornis* is polylectic harvesting pollen from the flowers of at least eight plant families (Table 3). However, pollen of the three families Boraginaceae, Fabaceae and Lamiaceae strongly dominated constituting 93.5% of the total pollen grain volume. Pollen of all other plant families was recorded in small percentages only. By far the most important pollen host was *Pulmonaria* (Boraginaceae); its pollen represented 58.6% of the total pollen grain volume and was recorded in 35 (67.3%) out of 52 loads, 22 of which were pure *Pulmonaria* pollen loads. The importance of *Pulmonaria* is also revealed by the finding that the larval provisions of three brood cells of nests 4 and 5 exclusively consisted of *Pulmonaria* pollen. The second most important pollen was of the *Lathyrus-Vicia*-type (Fabaceae), which unites the morphologically very similar pollen of the closely related genera *Lathyrus* and *Vicia*; this pollen type constituted 14.8% of the total pollen grain volume and was found in 15 (28.8%) loads. The third most important

Table 3. Pollen composition of female pollen loads of *Osmia pilicornis*. n=52 pollen loads from 49 different localities in Austria (n=18), Germany (n=16), Switzerland (n=13) and Czech Republic (n=5).

Plant family	Plant genus/subfamily or pollen type	% pollen grain volume	number of loads (%) with this pollen type	number (%) of pure loads
Boraginaceae	*Pulmonaria*	58.6	35 (67.3)	22 (42.3)
	Symphytum	2.8	4 (7.7)	0 (0)
Fabaceae	*Lathyrus-Vicia*-type	14.8	15 (28.8)	4 (7.7)
	Anthyllis	0.5	1 (1.9)	0 (0)
	Trifolium	0.1	1 (1.9)	0 (0)
	Lotus	0.1	1 (1.9)	0 (0)
	Hippocrepis	0.1	1 (1.9)	0 (0)
	other	2.0	3 (5.8)	0 (0)
Lamiaceae	tricolpate type	13.9	13 (25.0)	0 (0)
	hexacolpate type	0.6	1 (1.9)	0 (0)
Asparagaceae	*Polygonatum*	2.1	3 (5.8)	0 (0)
Rosaceae	*Rubus*	1.9	1 (1.9)	1 (1.9)
Caprifoliaceae	*Lonicera*	0.8	1 (1.9)	0 (0)
Asteraceae	*Taraxacum*	0.3	2 (3.8)	0 (0)
Violaceae	*Viola*	0.2	1 (1.9)	0 (0)
unknown		1.2	2 (3.8)	1 (1.9)

pollen was tricolpate pollen of Lamiaceae represented by 13.9% of the total pollen grain volume and recorded in 13 (25.0%) loads. At our study sites, representatives of all these three main hosts were exploited by females of *O. pilicornis* for pollen, i.e. three *Pulmonaria* species (*P. mollis*, *P. obscura* and *P. officinalis*), *Lathyrus vernus* (Linné) Bernhardi as well as *Ajuga reptans* Linné and *Lamium purpureum* Linné. In addition, pollen harvesting was also ascertained at the flowers of *Glechoma hederacea* Linné, a Lamiaceae species with hexacolpate pollen grains.

Female flower-visiting behaviour

Females of *Osmia pilicornis* used the specialized brush of hooked bristles on their proboscis to remove pollen from the narrow *Pulmonaria* corolla tubes (Fig. 34). Although the action of the mouthparts could not directly be seen as flower-visiting females pressed their head tightly against the small tube entrance, distinct back and forth movements of head and body during flower visitation as well as the conspicuous white coloured *Pulmonaria* pollen that stuck to the black mouthparts after the females had withdrawn them from the flower clearly indicate that the flowers of both the longistylous and the brevistylous morph were brushed out with the aid of the bristled proboscis (Suppl. material 5). Careful examination of video sequences revealed that females removed the pollen from the proboscis in flight with the forelegs immediately after having left the flower (Fig. 33). Flower visits to brevistylous flowers resulted in substantial amounts of pollen sticking to

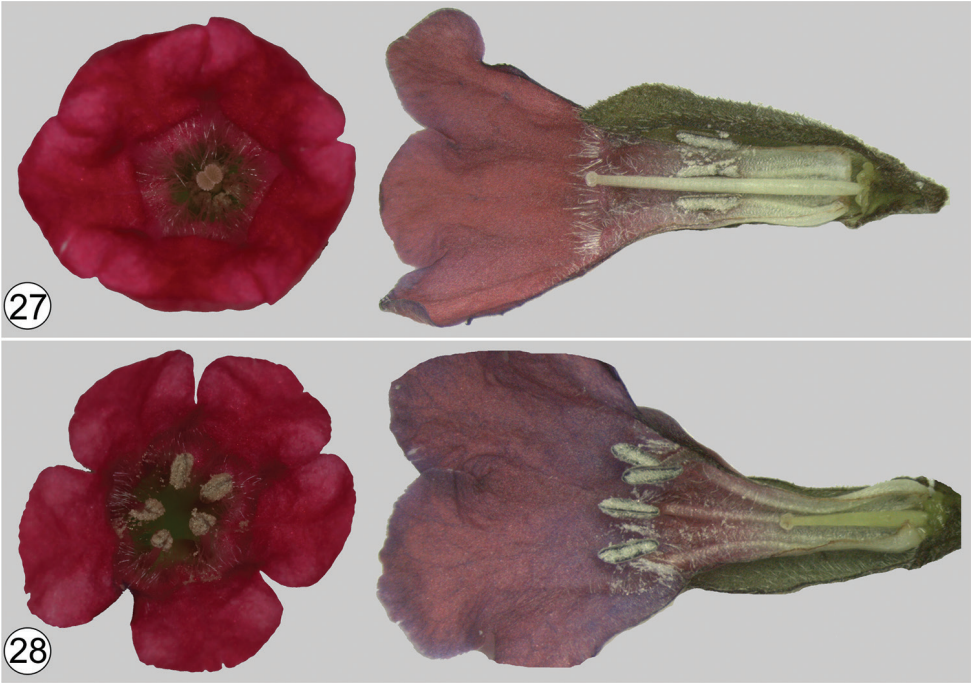
the lower half of the face, suggesting that both the bristled proboscis and the facial pilosity were involved in pollen collection from this flower morph (Fig. 32). Pollen collection on flowers of Lamiaceae also involved the facial pilosity. Females visiting flowers of *Ajuga reptans* and *Glechoma hederacea* pressed their forehead against the anthers while head and body performed rapid up and down movements, which led the pollen to pass over from the anthers to the facial pilosity (Fig. 35, Suppl. material 6). Pollen was removed from the facial pilosity again by stroking movements of the forelegs.

Of a total of 478 flower visits by *Osmia pilicornis* females on *Pulmonaria mollis*, 458 were on red and 20 on blue flowers, revealing a distinct preference of the female bees for the earlier red flower stage (chi-square goodness-of-fit test, χ^2=435.6 df=1, p<0.001; Figs 29, 30). 10.9% of the 458 red flowers visited by the female bees were still in the late bud stage. Here, the females forcefully opened the closed flowers with the aid of head and mouthparts before they harvested pollen and nectar (Fig. 31). The same behaviour could also be observed in several females exploiting flowers of *P. obscura* and *P. officinalis*. Bud-exploiting females were repeatedly observed to visit the same bud twice or three times in direct succession only interrupted by a short hovering flight in front of the bud. This suggests that the loading capacity of the pollen-harvesting bristles of the proboscis was not sufficient to completely empty the flower bud with a single visit, but that the females had first to remove the pollen sticking to their proboscis before landing again to harvest the remaining pollen.

Flowers of *Pulmonaria mollis* in the red stage contained on average 1.65 µl nectar per flower, which did not significantly differ from the quantity of nectar in flowers of the blue stage averaging 2.06 µl per flower (Mann-Whitney U test, U=531.0, p=0.86, n=33 red and blue flowers each). The filling degree of the anthers with pollen (measured as average degree of thecal pollen coverage, see Methods) was 64% in red and 8% in blue flowers of *P. obscura* and 67% in red and 9% in blue flowers of *P. officinalis*, revealing a substantial difference in the pollen quantity available in the two flower stages (Mann-Whitney U tests, U=6.5 and U=17.5, p<0.001, n=20 red and blue flowers each for both species). In 3 out of 20 *P. officinalis* flowers opened in the late bud stage all five anthers were still closed, whereas in 12 buds all anthers and in 5 buds part of the anthers had dehisced, indicating that most flowers in the late bud stage can already be exploited for pollen.

Females of *Osmia pilicornis* exploited both longistylous and brevistylous flowers (Figs 27, 28). During the first observation period (see Methods), they exhibited a preference for brevistylous flowers (chi-square goodness-of-fit test, χ^2=14.7 df=1, p<0.001), while no difference in the proportion of visits to longistylous and brevistylous flowers was found during the second observation period (chi-square goodness-of-fit test, χ^2=0.65, df=1, p=0.42).

Females of *Osmia pilicornis* regularly interrupted their foraging on *Pulmonaria mollis* to land on the ground for short periods varying in duration from 15 to 270 sec. During these resting periods, the mouthparts were constantly moved back and forth (Fig. 36, Suppl. material 7). Careful examination of video sequences revealed droplets

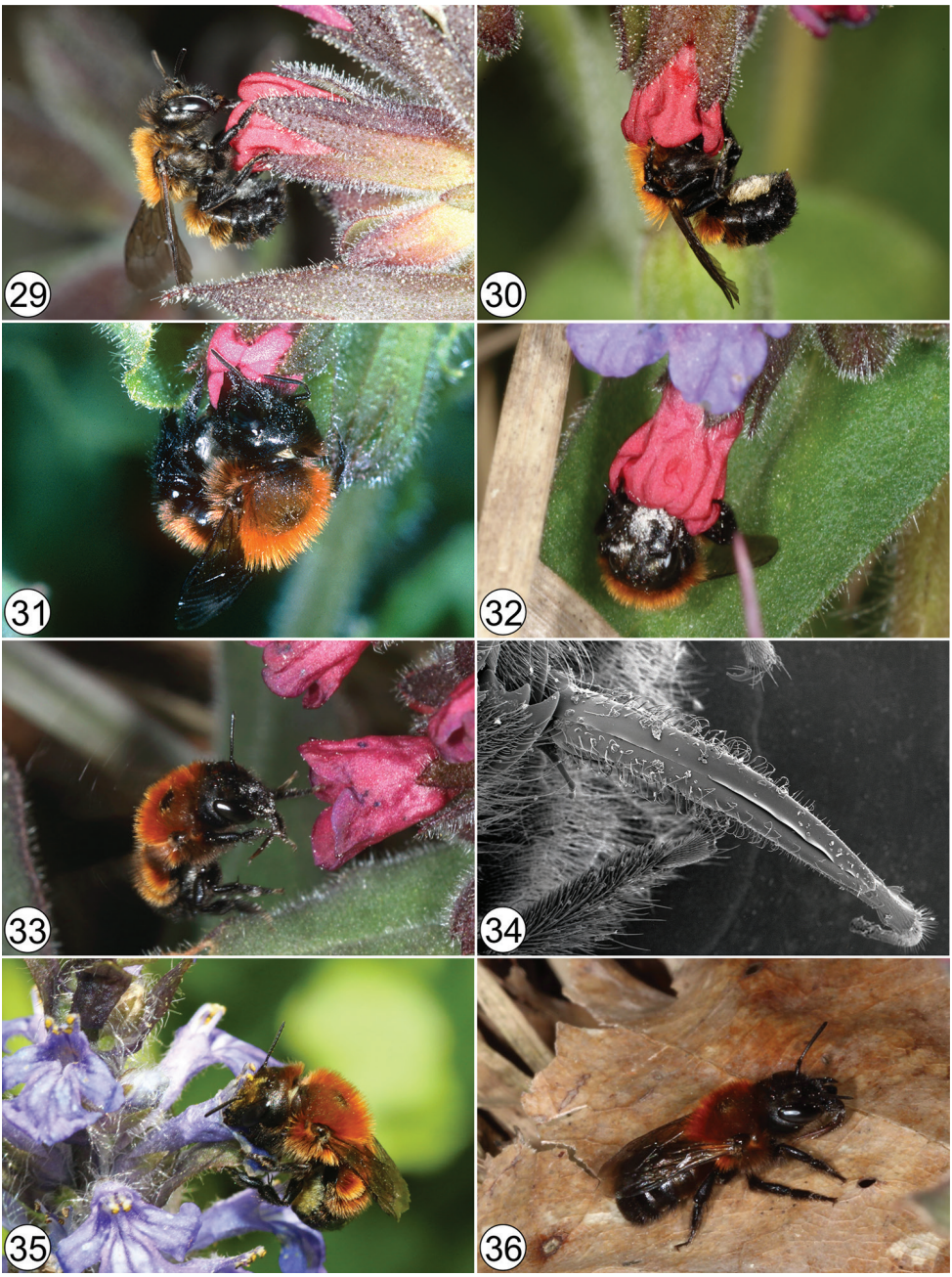


Figures 27–28. Floral morphs of *Pulmonaria mollis* in top and lateral view: **27** Longistylous flower with anthers deeply hidden within the floral tube **28** Brevistylous flower with anthers located at the entrance of the floral tube.

of a fluid on the mouthparts, suggesting that this behaviour served to thicken the collected nectar.

Male mating strategy

On their search for females, males of *Osmia pilicornis* patrolled flowers of *Pulmonaria* in a rapid flight, which was regularly interrupted by short resting periods at sunny spots on or near the ground, such as fallen leaves, flexed grass blades or tree stumps (Fig. 38). These resting periods lasted from 10 to 40 sec. In one case a male returned to his resting place every 5-7 min at least ten times in succession, which suggests that this male patrolled along a more or less fixed circular route. The males occasionally discontinued their patrolling flights to suck nectar on flowers of *Pulmonaria* (Fig. 39). Males were never observed to search for females at or near nests, suggesting that (potential) nesting sites do not serve as rendezvous places for the two sexes. Three copulations were observed: in two cases the male grabbed the female during her visit to a *Pulmonaria* flower, in another case the male grasped the female in flight immediately after she had left a *Pulmonaria* flower. In all three cases the pair fell on the ground, where the copulation was completed within 50 to 80 sec (Fig. 40).



Figures 29–36. Flower-visiting behaviour of *Osmia pilicornis*: **29–30** Females collecting pollen on flowers of *Pulmonaria mollis* in the early red stage **31** Female forcefully opening a bud of *Pulmonaria obscura* **32** Female collecting pollen on brevistylous flower of *Pulmonaria mollis* **33** Female removing pollen sticking to the bristled proboscis with her forelegs **34** Specialized pollen-harvesting bristles on the galeae of the female proboscis **35** Female collecting pollen on flower of *Ajuga reptans* **36** Female moving her proboscis back and forth, thereby probably thickening the collected nectar.

Figures 37–41. Brood parasites and male mating strategy of *Osmia pilicornis*: **37** Female of the chrysidid wasp *Chrysura hirsuta* lurking near nest of *O. pilicornis* **38** Male resting on flexed grass blades lying on the ground **39** Male sucking nectar on flower of *Pulmonaria mollis* **40** Pair separating after copulation on the ground **41** Male with well visible hairs along the posterior margin of the antennae.

Habitat

During the study period, *Osmia pilicornis* was observed at nine different localities in Germany, Austria and Switzerland. At six further localities, where we recorded the species after 1990, its presence could not be confirmed. All localities including the unconfirmed ones were open-structured, deciduous woodland sites rich in dead wood between 330 and 650 m a.s.l. on rather nutrient-rich soil with a well developed layer of herbaceous spring flowers (Figs 42–47). More specifically, we found the species along forest edges (n=5) and broad forest tracks (n=3), on clear-cuttings and clearings (n=4) and in thinned forests (n=2) and coppiced woodland (n=1).

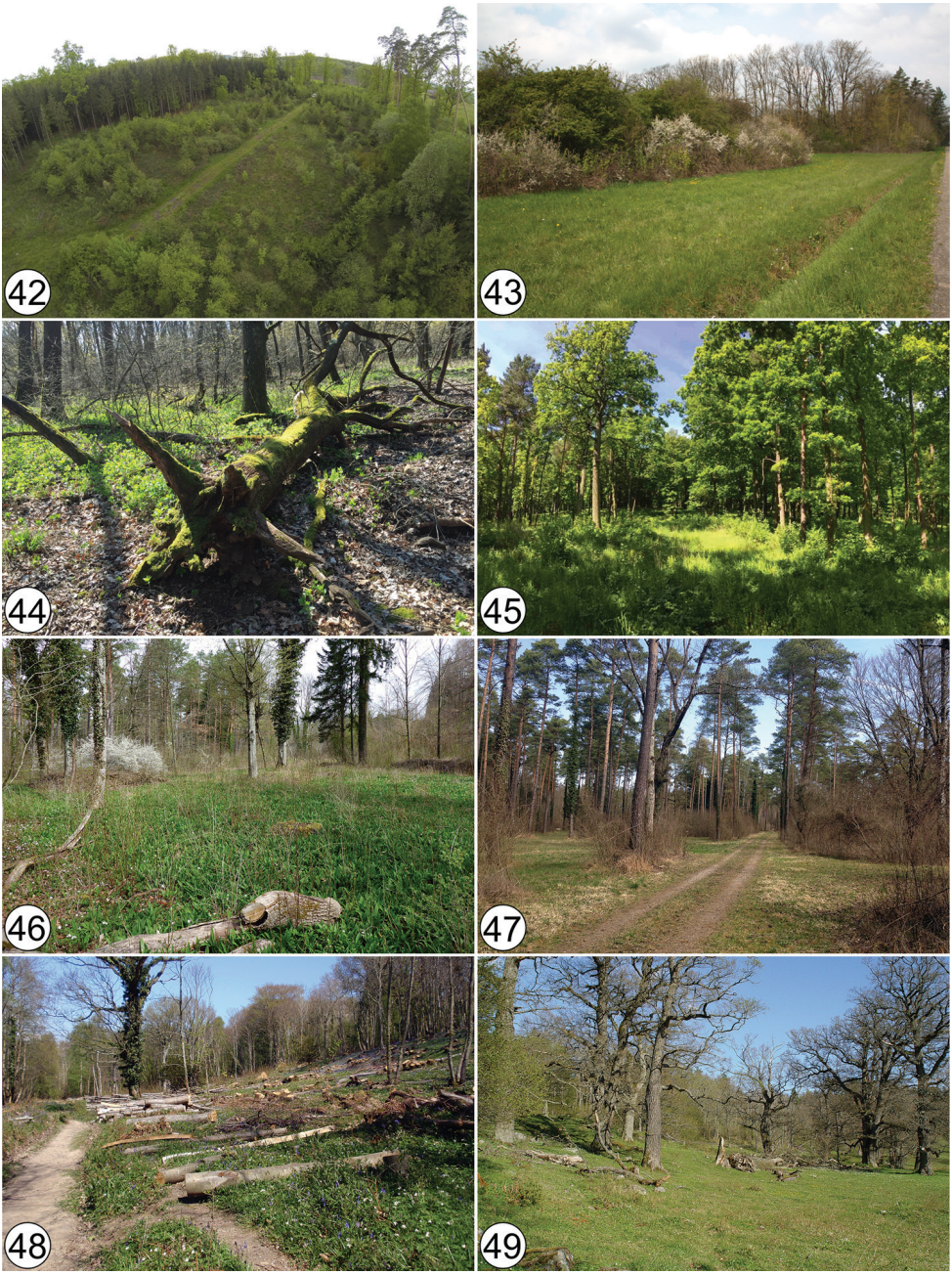
The maximal number of individuals of *Osmia pilicornis* recorded at the same locality and date was three females and two males, while at most localities only one or two individuals were simultaneously observed, indicating very low population densities at the study sites.

Discussion

Nesting biology of *Osmia pilicornis*

Our discovery of six nests at two localities in Germany and Austria built by at least five different bee individuals clearly show that females of *Osmia pilicornis* gnaw their nest burrows in dead wood. Thus, our findings contradict the assumption that *O. pilicornis* constructs its brood cells under loose bark (Amiet et al. 2004) or within preexisting insect borings (Earwaker 2014, Falk and Lewington 2015), but instead confirm observations in Britain from the nineteenth century that *O. pilicornis* burrows in dead wood (Wallis 1886, Perkins 1891). Our findings also explain why the repeated attempts to establish *O. pilicornis* in trap nest composed of drilled borings in dead wood or hollow stems all have failed (R. Earwaker personal communication, R. Prosi and A. Müller unpublished data).

Interestingly, the female mandibular shape of *Osmia pilicornis* differs from that of other *O.* (*Melanosmia*) species. Compared with closely related species that also use leaf pulp as nest building material but exclusively nest in preexisting cavities such as *O. inermis* (Zetterstedt) or *O. parietina* Curtis (Frey-Gessner 1880, Priesner 1981, Westrich 1989, Else and Edwards 1996, Hicks 2009, A. Müller unpublished data), the mandibles of *O. pilicornis* are relatively shorter, more compact and apically less curved resulting in a chisel-like shape that appears to be well suited to tunnel out burrows in dead wood. In addition, the distinctly broader and more inflated mandibular base suggests the presence of strong mandibular muscles, which might provide the needed strength to burrow even in hard wood. We thus hypothesize that the peculiar mandibular shape in females of *O. pilicornis* is an adaptation to the species' specialized nesting behaviour.



Figures 42–49. Habitats of *Osmia pilicornis*: **42** Clear-cutting in southern Germany west of Crailsheim **43** Forest edge in southern Germany northeast of Crailsheim **44** Coppiced woodland in northeastern Austria near Ernstbrunn **45–47** Thinned forests in northeastern Austria near Ernstbrunn (**45**) and in northern Switzerland near Flaach (**46**, **47**) **48** Clear-cutting in southern England near Battle in East Sussex (photo R. Earwaker) **49** Pasture in semi-open, oak-dominated woodland in middle Sweden near Sparreholm in Södermanland (photo A.L. Nilsson).

All six nests were in dead branches, which had a diameter of 1.5–6.1 cm, lay on the ground and were largely hidden under vegetation. A nest found by Chambers (1949) was also in a broken branch and we often observed females that searched for suitable nesting sites flying close to the ground and patrolling 2-10 cm thick branches. Nest-searching females were also repeatedly seen to fly or crawl under vegetation or grass tussocks. Thus, dead branches of moderate diameter lying on the ground and partly hidden by vegetation appear to represent the typical nesting site of *Osmia pilicornis.* The discovery of a nest of *O. pilicornis* in a tree stump by Blüthgen (1919), however, suggests that dead wood other than broken branches might occasionally also serve as nesting site.

The six nests were carved out in dead branches of *Fraxinus excelsior* Linné, *Picea abies* (Linné) Karsten, *Salix* spec. and *Corylus avellana* Linné. The nest detected by Blüthgen (1919) was in a stump of *Fagus sylvatica* Linné and Chambers (1949) assumed the nesting branch he found to probably originate from *Quercus*. The different kinds of wood selected as nesting substrate indicate that *Osmia pilicornis* is flexible in its choice of wood for nesting. A similar flexibility was observed with respect to the direction of the nest entrance and the hardness of the nesting wood. The nest entrances were directed from northeast to south-southwest and both hard and soft wood was used as nesting substrate.

The nests of *Osmia pilicornis* discovered in the course of our study contained only one to three brood cells, which is in line with Chambers (1949), who reported two cells for the nest he discovered. Thus, the construction of few-celled nests appears to be a typical trait of *O. pilicornis*. As females of osmiine bees usually lay up to 20 eggs during their lifetime under natural conditions (Raw 1972, Hawkins 1975, Correia 1981, Haeseler 1982, Müller 1994), a female of *O. pilicornis* is expected to construct a number of nests in several branches during her flight period.

In all nests the main part of the nesting burrow, which harboured the brood cells and ran in longitudinal direction of the branch, deviated from the short entrance part by an angle of 90-140°. This suggests that the females gnawed into the wood until they reached a sufficient depth to continue their tunneling in longitudinal direction, which possibly might have been less labour intensive than gnawing perpendicular to the wood fibers.

We identified leaves of *Fragaria vesca* as material to construct both cell partitions and nest plug. Interestingly, Westrich (2010) observed a female of *Osmia pilicornis* collecting leaf pulp on the same plant species, suggesting that *Fragaria vesca* might play a prominent role as source of nest-building material.

Nesting biology of *Osmia* (*Melanosmia*)

The nesting biology of *Osmia* species of the subgenus *Melanosmia* is diverse (Cane et al. 2007, Müller 2016, and references therein). While the majority of species construct cell partitions, nest plug or entire brood cells with leaf pulp as *O. pilicornis*,

others combine leaf pulp with wood fibers, pith, mud, sand grains or small pebbles, or exclusively use mud as nesting material, sometimes under addition of small pebbles. Although information on the nesting sites is available only for about 50 of the 135 *O.* (*Melanosmia*) species (Cane et al. 2007, Müller 2016, and references therein), most species appear to nest in preexisting cavities, such as insect borings in dead wood, hollow stems, holes and fissures in stones and walls, abandoned nests of other aculeates or deserted galls. Others attach their brood cells to the underside of stones, hide them among dense vegetation and litter or excavate their own burrows in the ground. So far, only two *O.* (*Melanosmia*) species are reported to occasionally gnaw burrows in dead wood. The Nearctic *O. bucephala* Cresson was observed to tunnel out burrows in a maple tree (Packard 1868) and the Holarctic *O. nigriventris* (Zetterstedt) was found to nest in burrows in bark and decaying wood, which were at least partly excavated by the female bees (Frey-Gessner 1881, Friese 1911, Amiet et al. 2004). However, at least the former species also colonizes preexisting burrows in dead wood or trap nests (Krombein 1967, Sheffield et al. 2003), suggesting a considerable intraspecific flexibility in nest site selection. To the best of our knowledge, excavation of burrows in dead wood is unknown in osmiine bees other than *Melanosmia*. Thus, the nesting behaviour of *O. pilicornis*, which constructs its brood cells most probably exclusively in self excavated burrows in dead wood, appears to be unique among both *Melanosmia* and the Osmiini, contributing a further facet to the astonishingly diverse nesting biology of the osmiine bees.

Brood parasites

No brood parasites have been recorded for *Osmia pilicornis* so far. However, Blüthgen (1919) found larvae of *Meloe* beetles (Meloidae) adhering to the body of several specimens of *O. pilicornis* as we did in the present study, suggesting that these parasitic beetles might occasionally develop in nests of *O. pilicornis*. However, as osmiine bees have never been recorded as hosts of Central European *Meloe* species (Lückmann and Niehuis 2009), the beetle larvae might have used *O. pilicornis* simply for dispersal.

Our observation of *Chrysura hirsuta* approaching, entering or flying in close neighbourhood of nests of *Osmia pilicornis* as well as the discovery of a dead chrysidid wasp larva inside a brood cell of nest 2 clearly reveals that *O. pilicornis* is a host of this chrysidid wasp species. *Chrysura* species are metaparasitoids of osmiine bees (Krombein 1967, Morgan 1984, Kunz 1989). After eclosion, their larvae attach to the body of the feeding bee larva with their mandibles and start devouring its host only after the latter has eaten the entire food provision and spun a cocoon. In the literature, several osmiine bee species are mentioned as hosts of *C. hirsuta*. However, not all of these records seem to be reliable as they are either based on personal communication rather than direct observation by the authors, are not detailed enough to judge their reliability or rely on the mere coocurrence of wasp and bee at the same place. Three osmiine bee species are confirmed hosts since *C. hirsuta* has been reared from their nests: *Hoplitis*

(*Alcidamea*) *tuberculata* (Nylander) (Trautmann 1918), *Osmia* (*Melanosmia*) *inermis* (Zetterstedt) (Xambeu in Buysson 1891, Evans 1896 as *Osmia parietina*, Maneval in Berland and Bernard 1938, Morgan 1984, Falk and Lewington 2015) and *Osmia* (*Melanosmia*) *xanthomelana* (Kirby) (Trautmann 1918, Enslin 1920). Given their close relatedness with some of the above hosts and their main occurrence in mountainous or northern regions where *C. hirsuta* has its main distribution (Kunz 1989), the following species are probably also hosts of *C. hirsuta*, although no proof for the wasp's development within their nests exists: *Osmia* (*Melanosmia*) *nigriventris* (Zetterstedt) (Zetterstedt in Berland and Bernard 1938, Trautmann 1927, Stoeckhert 1933, Paukkunen et al. 2014), *Osmia* (*Melanosmia*) *parietina* Curtis (Smith in Trautmann 1927, Dalla Torre in Berland and Bernard 1938, Falk and Lewington 2015) and *Osmia* (*Melanosmia*) *uncinata* Gerstäcker (Forsius in Trautmann 1927, Falk and Lewington 2015). Possible further hosts are *Hoplitis* (*Anthocopa*) *villosa* (Schenck) (Maneval in Berland and Bernard 1938), *Osmia* (*Helicosmia*) *aurulenta* (Panzer) (Benoist in Berland and Bernard 1938) and *Osmia* (*Metallinella*) *brevicornis* (Fabricius) (Trautmann 1927). Although the authors report that *C. hirsuta* has been reared from nests of these latter three species, the evidence is ambiguous as these records are either not based on direct observation by the authors or lack necessary additional information. *Chelostoma florisomne* (Linné) was also supposed to be a host of *C. hirsuta* (Berland and Bernard 1938) as the chrysidid wasp was observed to fly in the vicinity of its nests in dead wood (Frey-Gessner 1887). However, as *H. tuberculata* nested in the same dead wood as *C. florisomne* according to the author, *C. hirsuta* probably parasitized the former species. In summary, the above list of confirmed, probable and possible hosts includes numerous *Melanosmia* species, suggesting that species of this subgenus are the main hosts of *C. hirsuta*. Our new finding that *C. hirsuta* also attacks the nests of *O. pilicornis* supports this assumption.

In four brood cells of *Osmia pilicornis* in nest 1 and 2 the ichneumonid wasp *Hoplocryptus confector* developed. Hosts of this parasitoid wasp are mainly stem-nesting aculeate hymenopterans (Schwarz 2007 and references therein). As the wasp is known to parasitize species of both osmiine bees and chrysidid wasps, it remains unclear whether *O. pilicornis* served as host or whether the wasps developed as hyperparasitoids on the larvae of *Chrysura hirsuta*.

Host plants

Pollen hosts

In this study, *Pulmonaria* (Boraginaceae) was identified as the most important pollen host of *Osmia pilicornis* in Central Europe, supporting earlier findings by other authors (Stoeckhert 1933, Westrich 1989, Müller 1995, Amiet et al. 2004, Ebmer 2010). *Pulmonaria* is also an important pollen source of *O. pilicornis* outside Central Europe (Arnold 1902, Benoist 1931, Moczar 1956, Papp 1965, Kuznetsova 1990, T.

Levchenko and L.A. Nilsson personal communication) and might therefore be considered as the species' main host across most of its range. This assumption is supported by the presence of a specialized morphological adaptation facilitating the exploitation of *Pulmonaria* flowers, i.e. numerous hooked bristles on the female proboscis, which are specifically used to brush pollen out of the narrow *Pulmonaria* corolla tubes (Müller 1995, this study). Interestingly, *Pulmonaria* is lacking on the British Isles and British populations of *O. pilicornis* primarily rely on the pollen of two Lamiaceae species, i.e. *Ajuga reptans* and *Glechoma hederacea* (Chambers 1949, Beavis 2010, Earwaker 2014, Falk and Lewington 2015). Here, the specialized pollen-harvesting bristles seem to be without any function. As the phenologies of *Pulmonaria* and *O. pilicornis* are not fully congruent in continental Europe, where the flowering period of *Pulmonaria* usually covers only about the first half of the bee's flight period, females of *O. pilicornis* have to exploit other pollen hosts later in the season. This again clearly indicates that *O. pilicornis* is not entirely dependent on *Pulmonaria* and that its populations might thrive also in the absence of the species' main host. Nevertheless, the Central European populations of *O. pilicornis* seem to be linked to localities with large *Pulmonaria* stands, which suggests that the efficient harvesting of *Pulmonaria* pollen in early spring facilitated by the specialized pollen harvesting device may provide a substantial advantage that might tie the bee to *Pulmonaria*. On the other hand, the apparently exclusive occurrence of *O. pilicornis* at localities where *Pulmonaria* is present might be an artefact since bee researchers use to search for this rare bee species at places with large *Pulmonaria* stands. In fact, in Sweden populations of *O. pilicornis* exist at localities where *Pulmonaria* is absent (L.A. Nilsson and L. Norén personal communication). To date, the question must remain open whether Central European populations of *O. pilicornis* only occur at places with *Pulmonaria* stands or whether this rare bee has simply been overlooked at *Pulmonaria* free woodland sites.

Major pollen hosts of *Osmia pilicornis* other than *Pulmonaria* are several species of Fabaceae and Lamiaceae. The analysis of female pollen loads (Table 3) in combination with literature records and personal communication from bee researchers reveals that the most important pollen host genera of European populations of *O. pilicornis* are among the Fabaceae *Lathyrus* (Stoeckhert 1933, Westrich 1989, T. Levchenko and L.A. Nilsson personal communication) and *Vicia* (Westrich 1989, T. Levchenko personal communication) and among the Lamiaceae *Ajuga* (Stoeckhert 1933, Chambers 1949, Westrich 1989, Beavis 2010, Earwaker 2014, Falk and Lewington 2015, this study) and *Glechoma* (Earwaker 2014, this study). Additional albeit apparently only secondary pollen host genera of the Fabaceae are *Anthyllis* (Table 3), *Hippocrepis* (Stoeckhert 1933, Westrich 1989, Table 3), *Lotus* (Table 3) and *Trifolium* (T. Levchenko personal communication, Table 3) and of the Lamiaceae *Lamium* (this study) and *Salvia* (Westrich 1989). Pollen of other plant taxa seems to have only a minor significance for *O. pilicornis*. Confirmed pollen sources other than *Pulmonaria* and species of Fabaceae and Lamiaceae are *Lonicera* (Caprifoliaceae; Table 3), *Polygonatum* (Asparagaceae; Benoist 1931, Table 3), *Potentilla* (Rosaceae; Westrich 1989), *Rubus* (Rosaceae; L.A. Nilsson personal communication, Table 3), *Symphytum* (Boraginace-

ae; L.A. Nilsson personal communication, Table 3), *Taraxacum* (Asteraceae; Table 3) and *Viola* (Violaceae; Wallis 1886, Friese 1911, Benoist 1931, Chambers 1949, Elfving 1968, Table 3). Most of these latter pollen host genera occur at woodland sites reflecting the bee's exclusive habitat.

Female flower-visiting behaviour

Flower visiting females of *Osmia pilicornis* exhibited a distinct preference for *Pulmonaria* flowers in the earlier red stage and only occasionally visited flowers in the later blue stage. As both stages were found to offer nectar in similar quantities, the near exclusive exploitation of flowers in the red stage is most likely due to differences in the amount of pollen. In fact, flowers in the red stage contained much more pollen than flowers in the blue stage, which were usually almost devoid of pollen due to their older age and the putatively higher number of flower visits they already had experienced. The forceful opening of *Pulmonaria* flower buds seems to be a regular behaviour as it could be observed in numerous females exploiting three different *Pulmonaria* species at three localities. Undoubtedly, this behaviour is highly adaptive as it enables the females to collect large quantities of pollen within a short period of time.

Our results on the proportion of longistylous and brevistylous flowers visited by females of *Osmia pilicornis* are ambiguous. The females preferred brevistylous over longistylous flowers during the first observation period, but exhibited no preference for one of the two floral morphs during the second observation period. We hypothesize that this incongruency might possibly be due to *Anthophora plumipes*, which was common at the study site during the first but entirely lacked during the second observation period. Like *O. pilicornis*, females of *A. plumipes* are morphologically adapted to remove pollen out of the narrow *Pulmonaria* flower tubes (Müller 1995). Since *O. pilicornis* and *A. plumipes* are among the few flower visitors that can efficiently exploit longistylous flowers for their deeply hidden pollen, longistylous flowers should be more attractive to these two species due to their higher standing crop of pollen compared to brevistylous flowers, which can be exploited for pollen by a larger proportion of flower visitors. Thus, the numerous females of *A. plumipes* that visited the *Pulmonaria* flowers earlier in the season might possibly have preferentially emptied longistylous flowers, thereby indirectly forcing the few females of *O. pilicornis* to exploit a larger proportion of brevistylous flowers. Later in the season, when *A. plumipes* was no longer present, a higher proportion of unemptied longistylous flowers was available for *O. pilicornis* resulting in a more balanced visitation rate of longistylous and brevistylous flowers.

Females of *Osmia pilicornis* collected pollen on nototribic flowers of the Lamiaceae with the aid of their facial pilosity. In contrast to numerous other bee species, which are equipped with a specialized pollen-collecting apparatus on clypeus and/or frons to harvest pollen on nototribic flowers (Müller 1996, Rightmyer et al. 2011), the facial hairs of *O. pilicornis* are not specialized and correspond in length, density and shape to those of other *O.* (*Melanosmia*) species, such as *O. inermis* or *O. parietina*, which

do not harvest pollen from Lamiaceae but instead exploit mainly Fabaceae (Westrich 1989, Müller 2016).

In summary, females of *Osmia pilicornis* are highly adapted to efficiently collect pollen in several respects. On flowers of *Pulmonaria*, they use specialized bristles on the proboscis to brush pollen out of the corolla tubes, they almost exclusively exploit pollen-rich flowers in the red stage and they often steal pollen from still closed flowers by forcefully opening buds. On flowers of Lamiaceae, they remove pollen from the nototribic flowers by applying a specialized behaviour that involves the facial pilosity.

Male mating strategy

Although still only fragmentarily known, the mating strategy of the males of *Osmia pilicornis* seems to correspond to that of other osmiine bee species, such as *Hoplitis zandeni* (Teunissen and Van Achterberg) or *Osmia spinulosa* (Kirby). In these two species, both of which nest in empty snail shells (Müller 1994, Müller and Mauss 2016), the males also patrol flowers of the female host plants in a fast flight along more or less fixed circular routes regularly interrupted by short resting periods on the ground. As in *O. pilicornis*, they do not search for females at potential nesting sites, probably since the habitat of the former species contains huge numbers of empty snail shells making nest localization difficult and the females of the latter species exhibit strict pollen specialization making female detection straightforward. A similar discrepancy in the probability of finding females at *Pulmonaria* flowers and the widely scattered and inconspicuous nesting sites, respectively, might be the reason why flowers seem to serve as exclusive rendezvous places for the two sexes of *O. pilicornis*. In fact, the amount of dead fallen branches was often large in habitats occupied by *O. pilicornis* making it almost impossible for the males to localize nests. As the males of *O. pilicornis* were not observed to defend their flight routes against conspecifics as for example in *O.* (*Melanosmia*) *maritima* Friese (Haeseler 1982), their mating strategy might be best described as scramble competition polygyny (Thornhill and Alcock 1983).

The males of *Osmia pilicornis* are characterized by numerous long hairs along the entire posterior margin of their antennae (Fig. 41). The function of this specialized pilosity, which is unique among osmiine bees and gave *O. "pilicornis"* its species epithet, is unknown. As these hairs are absent in the female sex, they might possibly help in the perception of the females or play a role during copulation or courtship.

Habitat

Our observations confirm other authors, who assume *Osmia pilicornis* to be strongly restricted to woodland habitats (Stoeckhert 1933, Westrich 1989, Amiet et al. 2004, Falk and Lewington 2015). This clear habitat preference, which appears to be valid across the species' entire range (Figs 48, 49), may primarily be explained by the need

for dead fallen branches as nesting sites. *O. pilicornis* never colonizes closed and dark forests but instead exhibits an exclusive preference for semi-open, sunny, rather warm and deciduous woodland habitats rich in dead wood below 1000 m a.s.l. The fact that the species usually colonizes mesophilous rather than xeric woodland is probably due to its need of a rich supply of pollen hosts flowering in early spring, which requires nutrient-rich edaphic conditions. The spectrum of open-structured woodland types colonized by *O. pilicornis* is surprisingly wide and ranges from clearings and clear-cuttings over forest edges and forest tracks to thinned and coppiced woodland, suggesting that dead fallen branches and a rich spring flora in combination with a rather warm microclimate are the only requisites needed by the species. Interestingly, the majority of woodland habitats currently colonized by *O. pilicornis* in Central Europe owe their origin to human forest use. This raises the question about the primary habitats of the species in Europe in prehistoric times. We hypothesize that the primary habitats of *O. pilicornis* were either windfalls or woodland sites kept open by the former grazing megafauna (A. Nilsson personal communication, Bunzel-Drüke et al. 2008).

Populations of *Osmia pilicornis* at our study sites were remarkably small and often contained only single individuals. Such low population densities seem to be typical for *O. pilicornis* throughout its range. Of 516 records of *O. pilicornis* that could be assigned an exact date and contained information on individual numbers (see list of all distributional data in the Suppl. material 1), 91.1% had 1-2 individuals, 7.7% 3-5 individuals and 1.2% 6-11 individuals recorded at the same locality and date. The highest number of females simultaneously observed at the same site was 7 and the highest number of males was 10. These overall very low population densities are probably not due to food limitation as *Pulmonaria* often occurs in large stands and *O. pilicornis* is able to collect pollen from a variety of plant taxa. Nor do they seem to be explained by special characteristics of the wood used for nesting as *O. pilicornis* was found to nest in dead branches of different species and of varying hardness. Instead, we hypothesize that a high pressure by brood parasites might possibly be an important reason contributing to the low population densities. In fact, five out of the six brood cells of nests 1-3 were found to be parasitized. A high brood-parasite pressure would also explain why the females of *O. pilicornis* construct nests that contain only few brood cells, thereby possibly reducing the risk to loose all progeny after a brood parasite has detected a nest.

Conservation

Populations of *Osmia pilicornis* have regressed in many regions of Europe over the last decades resulting in the species' inclusion in numerous regional or national red lists (Amiet 1994, Winter 1994, Dathe and Saure 2000, Saure 2005, Westrich et al. 2000, 2008, Van der Smissen 2001, Theunert 2002, Mandery et al. 2003, Burger

et al. 2004, Burger 2005, Straka 2005, Tischendorf et al. 2009, Esser et al. 2010, Earwaker 2012). In our study, *O. pilicornis* was no longer found at six out of 15 localities, although the former were still colonized 3-25 years ago, supporting its status as a declining and threatened species. Although this recent decline is poorly understood, changes in woodland management practices might be an important reason, in particular the abandonment of the area-wide but little intensive former human forest use, which led to the closed and dark forests now prevailing in most regions of Central Europe at lower elevations. Due to the species' overall rareness and low population densities, its widely scattered and often highly localized occurrence and the reported recent declines, current Central European populations of *O. pilicornis* need regular monitoring and deserve protection. Measures to conserve and foster *O. pilicornis* should focus on the preservation of the semi-open structure and the rich supply of dead wood in currently colonized woodland habitats as well as the new creation of such habitats by thinning or clearing of woodland on nutrient-rich soils at warm but not xeric sites, preferentially in close neighbourhood to existing populations of *O. pilicornis*.

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Supplementary material 1

List of distributional data of *Osmia pilicornis*

Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller

Data type: distributional data

Supplementary material 2

Female of *Osmia pilicornis* gnawing nesting burrow

Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller

Data type: species data

Supplementary material 3

Female of *Osmia pilicornis* provisioning brood cell
Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller
Data type: species data

Supplementary material 4

Female of *Osmia pilicornis* constructing nest plug
Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller
Data type: species data

Supplementary material 5

Female of *Osmia pilicornis* collecting pollen on *Pulmonaria mollis*
Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller
Data type: species data

Supplementary material 6

Female of *Osmia pilicornis* collecting pollen on *Ajuga reptans*
Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller
Data type: species data

Supplementary material 7

Female of *Osmia pilicornis* thickening nectar
Authors: Rainer Prosi, Heinz Wiesbauer, Andreas Müller
Data type: species data

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Four new species of *Rhogadopsis* Brèthes from NW China (Hymenoptera, Braconidae, Opiinae)

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Abstract

Four new species of the genus *Rhogadopsis* Brèthes, 1913 (Hymenoptera, Braconidae, Opiinae) are reported from Shaanxi province (NW China). The new species (*R. aciculifera* **sp. n.**, *R. cracentata* **sp. n.**, *R. longivena* **sp. n.**, and *R. moniliata* **sp. n.**) and two newly recorded species for Shaanxi and Ningxia provinces (*R. mediocarinata* (Fischer, 1963) and *R. pratellae* (Weng & Chen, 2005), respectively) are keyed and fully illustrated. *Rhogadopsis mediocarinata* (Fischer, 1963) is a new combination.

Keywords

Rhogadopsis, new species, new record, new combination, Shaanxi, Ningxia, key

Introduction

The large subfamily Opiinae (Braconidae), with nearly 2,000 valid species according to Yu et al. (2012), is a common group containing generally small (2–5 mm) parasitoid wasps of mainly mining or fruit-infesting dipterous larvae. It has a worldwide distribution and the world fauna has been reviewed by Fischer (1972, 1977, 1986, 1987).

Li et al. (2013) supplied a key to the genera of Opiinae in China, including *Rhogadopsis* Brèthes, and listed six species mainly for Hunan province. In the review of the Opiinae of China (Chen and Weng 2005) the genus was not recognized and the examination of the types by the second author was necessary to list the *Rhogadopsis* species among the newly described species in *Opius* Wesmael, 1835 s.l. Despite the general scope of the latter review there have been no species of *Rhogadopsis* found in NW China. Recent collecting in Shaanxi (especially the Qinling Mountains) and Ningxia resulted in a large collection of Opiinae and included several species of *Rhogadopsis*. In this paper we give the first results of the survey.

Material and methods

The specimens were either collected by Malaise trap or by using a sweep net and directly preserved in 70% alcohol. The specimens were chemically treated with a mixture of xylene + alcohol 96% and amylacetate, respectively (AXA-method; van Achterberg 2009; van Achterberg et al. 2010). For identification of the subfamily Opiinae, see van Achterberg (1990, 1993); for identification of the Chinese genera, see Li et al. (2013); for references to the Opiinae, see Yu et al. (2012).

Morphological terminology follows van Achterberg (1988, 1993), including the abbreviations for wing venation. Measurements are taken as indicated by van Achterberg (1988): for the length and the width of a body part the maximum length and width is taken, unless otherwise indicated. The length of the mesosoma is measured from the anterior border of the mesoscutum to the apex of the propodeum and of the first tergite from the posterior border of the adductor to the medio-posterior margin of the tergite.

Observations and descriptions were made with an Olympus SZX11 stereomicroscope and fluorescent lamps. Photographic images were made with the Keyence VHX-5000 digital microscope. The specimens are deposited in the collections of the Northwest University (NWUX) at Xi'an and of the Naturalis Biodiversity Center (RMNH) at Leiden.

Taxonomy

***Rhogadopsis* Brèthes, 1913**

Figs 1–62

Rhogadopsis Brèthes, 1913: 44; Shenefelt, 1975: 1212; Wharton, 1987: 66 (synonymy with subgenus *Lissosema*); Li et al., 2013: 147 (as valid genus). Type species (by monotypy): *Rhogadopsis miniacea* Brèthes, 1913 [examined].

Lissosema Fischer, 1972: 359. Type species (by original designation): *Opius parvungula* Thomson, 1895 [examined].

Diagnosis. Propodeum with a medio-longitudinal carina anteriorly (Figs 4, 14, 26, 36); vein m-cu of fore wing gradually merging into 2-CU1 and linear with vein 2-M, rarely angulate; vein 1r-m of hind wing less oblique and 0.7–1.0 times as long as vein 1-M; mandible triangular and with narrow ventral carina; occipital carina remaining separate from hypostomal carina ventrally; precoxal sulcus usually present and crenulate; anterior groove of metapleuron nearly always crenulate; veins CU1b and 1-SR of fore wing medium-sized; dorsope absent.

Biology. Parasitoids of Agromyzidae.

Key to species of *Rhogadopsis* from NW China

1 Medio-posterior depression of mesoscutum absent (Figs 26, 36); ventral half of posterior groove of pronotal side sometimes smooth (Fig. 35) **2**

– Medio-posterior depression of mesoscutum present (Figs 4, 14, 46), but sometimes only point-like impressed; ventral half of posterior groove of pronotal side crenulate (Figs 13, 45) **3**

2 Vein r of fore wing long and slender, at least 5 times longer than wide medially (Fig. 24); pronotum coarsely and densely crenulate posteriorly (Fig. 25); first tergite without long median carina (Fig. 27); [face strongly punctate and tricoloured laterally; clypeus about twice as wide as high hardly protruding ventrally; first metasomal tergite parallel-sided; vein m-cu rather angled with 2-CU1] ..... ***R. longivena* sp. n.**

– Vein r of fore wing short and at most about twice as long as wide (Fig. 34); posterior groove of pronotum smooth or finely and sparsely crenulate (Fig. 35); first tergite with long median carina (Fig. 37); [propodeum largely smooth; setose part of ovipositor sheath about 0.7 times length of first tergite; clypeus about twice as wide as high, thin apically and evenly protruding; head brownish yellow anteriorly; posterior groove of pronotal side at least dorsally smooth] ..... ***R. mediocarinata* (Fischer, 1963)**

3 Mesoscutum of ♀ brownish yellow (Figs 55–56), of ♂ with brownish yellow or brown stripes; vein r of fore wing slenderer and about 3 times longer than its medial width (Fig. 54); area in front of notauli rugose (Fig. 55); metasoma of ♀ with yellow bands (Fig. 53; of ♂ mainly dark brown); vein 1-SR of fore wing 0.4–0.5 times as long as vein 1-M (Fig. 54); vein 3-SR 1.5–1.6 times as long as vein 2-SR; first metasomal tergite distinctly widened apically (Fig. 57); [apical half of parameres yellow; setose part of ovipositor sheath 0.6–0.7 times hind tibia and about 2.5 times as long as hind basitarsus (entire exserted sheath about 4 times (= equal to hind tibia)); vein 1r-m of hind wing 0.8–1.0 times as long as vein 1-M; ovipositor sheath lamelliform basally and glabrous] ..... ***R. pratellae* (Weng & Chen, 2005)**

– Mesoscutum black or dark chestnut brown (Figs 4, 14, 46); vein r of fore wing wider and about twice as long as its medial width or less (Figs 12, 44); area in front of notauli smooth or punctate (Figs 13, 45); metasoma of ♀

without distinct yellow bands (Figs 11, 43); vein 1-SR of fore wing 0.3–0.4 times as long as vein 1-M (Figs 2, 12, 44); [apical half of parameres dark brown, brown or yellowish; length of eye 3.2–3.3 times temple in dorsal view] **4**

4 Medially second and third tergites longitudinally rugulose-striate or aciculate (Fig. 5); vein r of fore wing about twice as long as wide (Fig. 2); first metasomal tergite distinctly widened apically (Fig. 5) ..... ***R. aciculifera* sp. n.**

– Medially second and third tergites smooth (Figs 15, 47); vein r of fore wing about as long as wide (Figs 12, 44); first tergite less widened apically (Figs 15, 47); [vein 3-SR 1.7–2.0 times as long as vein 2-SR] **5**

5 Setose part of ovipositor sheath 0.2 times hind tibia and slightly shorter than hind basitarsus (Fig. 21); third and fourth antennal segments of ♀ rather slender (Fig. 16); first metasomal tergite elongate, 1.7–1.9 times longer than its apical width (Fig. 15); hind femur slenderer, 4.5–4.7 times as long as wide (Fig. 21); vein m-cu of fore wing gradually merging into vein 2-CU1 (Fig. 12) ..... ***R. cracentata* sp. n.**

– Setose part of ovipositor sheath 0.5–0.7 times hind tibia and about twice as long as hind basitarsus (Fig. 44); third and fourth antennal segments of ♀ robust (Fig. 52); first metasomal tergite rather stout, 1.2–1.4 times longer than its apical width (Fig. 47); hind femur wider, about 3.7 times as long as wide (Fig. 50); vein m-cu of fore wing rather angled with vein 2-CU1 .... ***R. moniliata* sp. n.**

***Rhogadopsis aciculifera* Chen & van Achterberg, sp. n.**
http://zoobank.org/81C62748-36DC-49BD-ADD6-78BF0030A075
Figs 1–10

Type material. Holotype, ♀ (NWUX), "NW **China**: **Shaanxi**, Liping Nat. For. P., MT1+2, c. 1495 m, 22.vi.-4.ix.2015, 32°47'33"N, 106°39'52"E, JL. Tan & C. v. Achterberg".

Diagnosis. Among the Chinese species of *Rhogadopsis* with the second and third metasomal tergites striate or aciculate the new species can be separated as follows: from *R. dimidia* (Chen & Weng, 2005) by having a medio-posterior depression of the mesoscutum (absent in *R. dimidia*), length of eye about 2.5 times temple in dorsal view (about 7 times) and basal half of notauli largely smooth (crenulate). *Rhogadopsis sculpta* (Chen & Weng, 2005) has the second and third tergites partly superficially striate, a medio-posterior depression of the mesoscutum and the anterior half of the notauli present on the mesoscutal disc, but has vein 2-SR+M of fore wing slightly shorter than vein m-cu or subequal (distinctly shorter than vein m-cu in *R. aciculifera*). *Rhogadopsis tabidula* (Weng & Chen, 2005) and *R. sculpturator* Li & van Achterberg, 2013, are similar but the new species has the anterior half of the notauli impressed (absent or as a shallow impression on mesoscutal disc in both species), hind femur and tibia similarly

Figure 1. *Rhogadopsis aciculifera* sp. n., female, holotype, habitus lateral.

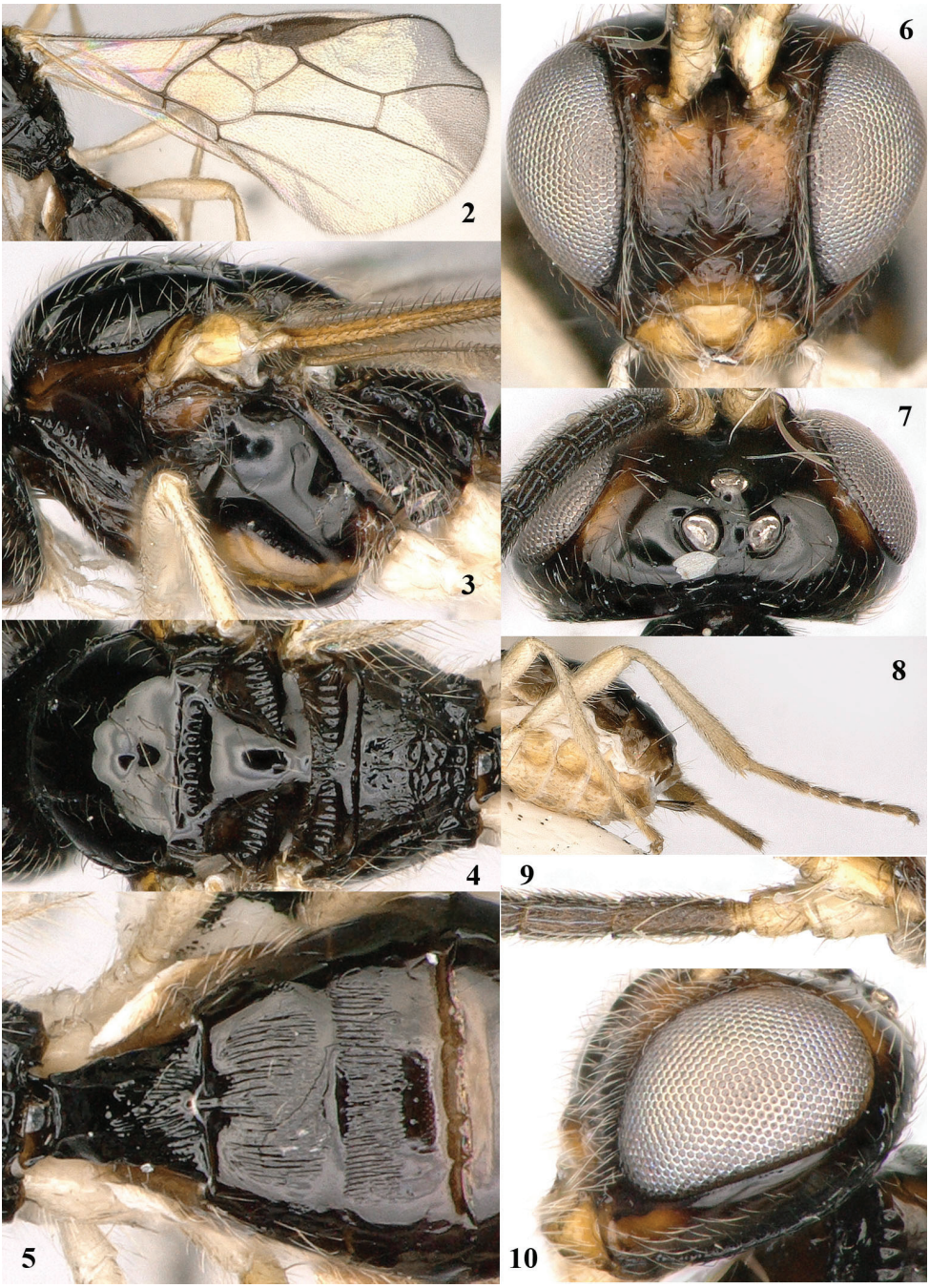
ivory as the hind coxa (hind femur and tibia yellow, different from pale hind coxa), vein r of fore wing about twice as long as wide (about as long as wide) and the propodeum without distinct costulae (with distinct costulae).

Description. Holotype, ♀, length of body 3.1 mm, of fore wing 3.4 mm.

Head. Antenna incomplete, with 16 segments remaining; third segment 1.6 times as long as fourth segment, length of third and fourth segments 3.6 and 2 times their width, respectively (Fig. 9); maxillary palp as long as height of head, labial palp segments slender; occipital carina rather far separated from hypostomal carina and dorsally absent; hypostomal carina narrow; length of eye in dorsal view 2.6 times temple; frons shallowly depressed, smooth and setose; face setose, with weak medial elevation, remotely and finally punctate (Fig. 6); width of clypeus 2.1 times its maximum height and 0.5 times width of face; clypeus rather flat, straight and thin ventrally (Figs 6, 10); hypoclypeal depression medium-sized (Fig. 6); malar suture wide; length of malar space 0.7 times as long as basal width of mandible; mandible triangular and with long carina (Fig. 10).

Mesosoma. Length of mesosoma 1.4 times its height; dorsal pronope large, deep and nearly round; pronotal side glabrous, mainly smooth and only medio-anteriorly crenulate; epicnemial area finely crenulate; precoxal sulcus medium-sized and crenulate (Fig. 3), remain removed from anterior and posterior margins of mesopleuron; remainder of mesopleuron smooth; pleural sulcus smooth; anterior groove of metapleuron crenulate; anterior half of notauli present on disc and smooth; mesoscutum largely glabrous, but setose along notaulic courses and laterally; medio-posterior depression of mesoscutum large and round (Fig. 4); scutellar sulcus wide and crenulate; scutellum slightly convex medially, smooth and glabrous; anterior half of propodeum with medio-longitudinal carina and smooth anteriorly, sparsely rugose medially and posteriorly (Fig. 4).

Wings. Fore wing (Fig. 2): pterostigma elliptical; 1-R1 ending at wing apex and 1.4 times as long as pterostigma; r:3-SR:SR1 = 8:58:92; 2-SR:3-SR:r-m = 30:49:19; r



Figures 2–10. *Rhogadopsis aciculifera* sp. n., female, holotype. **2** wings **3** mesosoma lateral **4** mesosoma dorsal **5** first-third metasomal tergites dorsal **6** head anterior **7** head dorsal **8** hind leg **9** base of antenna **10** head lateral.

widened; 1-M and SR1 slightly curved; m-cu and cu-a far postfurcal; 1-SR 0.35 times as long as 1-M; first subdiscal cell closed, CU1b medium-sized; apical 0.3 of M+CU sclerotized. Hind wing (Fig. 2): M+CU:1-M:1r-m = 39:20:19; cu-a slightly curved; m-cu vaguely indicated.

Legs. Length of femur, tibia and basitarsus of hind leg 4.4, 8.4 and 7.5 times as long as wide, respectively; especially hind femur with long setae (Fig. 8).

Metasoma. Length of first tergite 1.3 times its apical width, its surface moderately convex and striate, medially with some grooves and minute punctures, dorsal carinae united subbasally (Fig. 5); second (as third) tergite largely striate, with pair of large basal depressions; following tergites smooth; length of setose part of ovipositor sheath 0.05 times fore wing and 0.2 times hind tibia, entire visible sheath 0.09 times fore wing (Fig. 8).

Colour. Black; palpi, metasoma ventrally and legs except dark brown hind tarsus (but basal half of basitarsus yellow) pale yellow or ivory; clypeus and face dorsally orange brown (Fig. 7); mandible (except black teeth), tegulae and veins at base of wings yellow; pterostigma and veins (except basal veins) dark brown; wing membrane subhyaline.

Distribution. China (Shaanxi).

Biology. Unknown.

Etymology. From "acicula" (Latin for "small pin"), because of the longitudinally rugulose-striate or aciculate second and third metasomal tergites (similar to the fine grooves made with a small pin), and "fera" (Latin for "carry, bear").

Rhogadopsis cracentata **Tan & van Achterberg, sp. n.**
http://zoobank.org/35BE7207-87FA-48B5-8F7B-BADE474ABD19
Figs 11–22

Type material. Holotype, ♀ (NWUX), "NW. **China**: **Shaanxi**, Xunyangba, Ningshan, c. 1300 m, 24.vi.2014, 33°33'N 108°32'E, Jiangli Tan, NWUX". Paratypes: 1♂ (NWUX), same data as holotype; 1♀ (RMNH), id., but 2.vi.2014; 1♀ (NWUX), "NW China: Shaanxi, Liping Nat. For. P., c. 1500 m, 16.vi.2011, 32°50'N 106°31'E, Jiangli Tan"; 1 ♂ (RMNH), "NW China: Shaanxi, Baolongyu, Qin[ling] Mt[s], c 1000 m, 10.vi.2015, 34°03'N 108°09'E, Jiangli Tan, NWUX"; 1♀ (NWUX), "NW China: Shaanxi, along the road from Huangbaiyuan to Taibai, 33°49'8.56"N, 107°39'38.64"E, 17.vii.2015, Jiangli Tan & Qingqing Tan"; 1♀ (NWUX), "NW China: Shaanxi, Nangong Mt. N.G., 32°14'52"N, 109°4'10"E, c. 2250 m, 10.vi.2016, Qingqing Tan".

Diagnosis. The new species is close to *R. moniliata* sp. n., for the differences see the diagnosis of this species. It shares with *R. infernalis* (Fischer, 1966) from the Philippines the first tergite about 1.5 times as long as wide apically, antenna of ♂ with 35–37 segments and a rather short temple (eye 3.2–4.0 times as long as temple in dorsal view, not twice, as is mentioned in the original description, in the paratype examined). *Rhogadopsis infernalis* has the third antennal segment about twice as long as

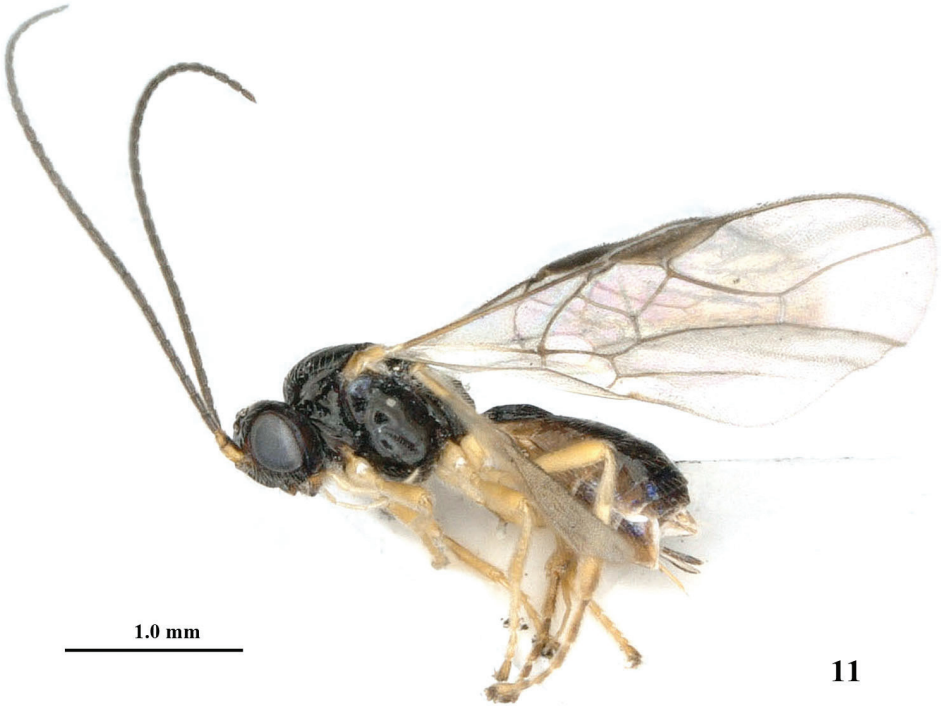


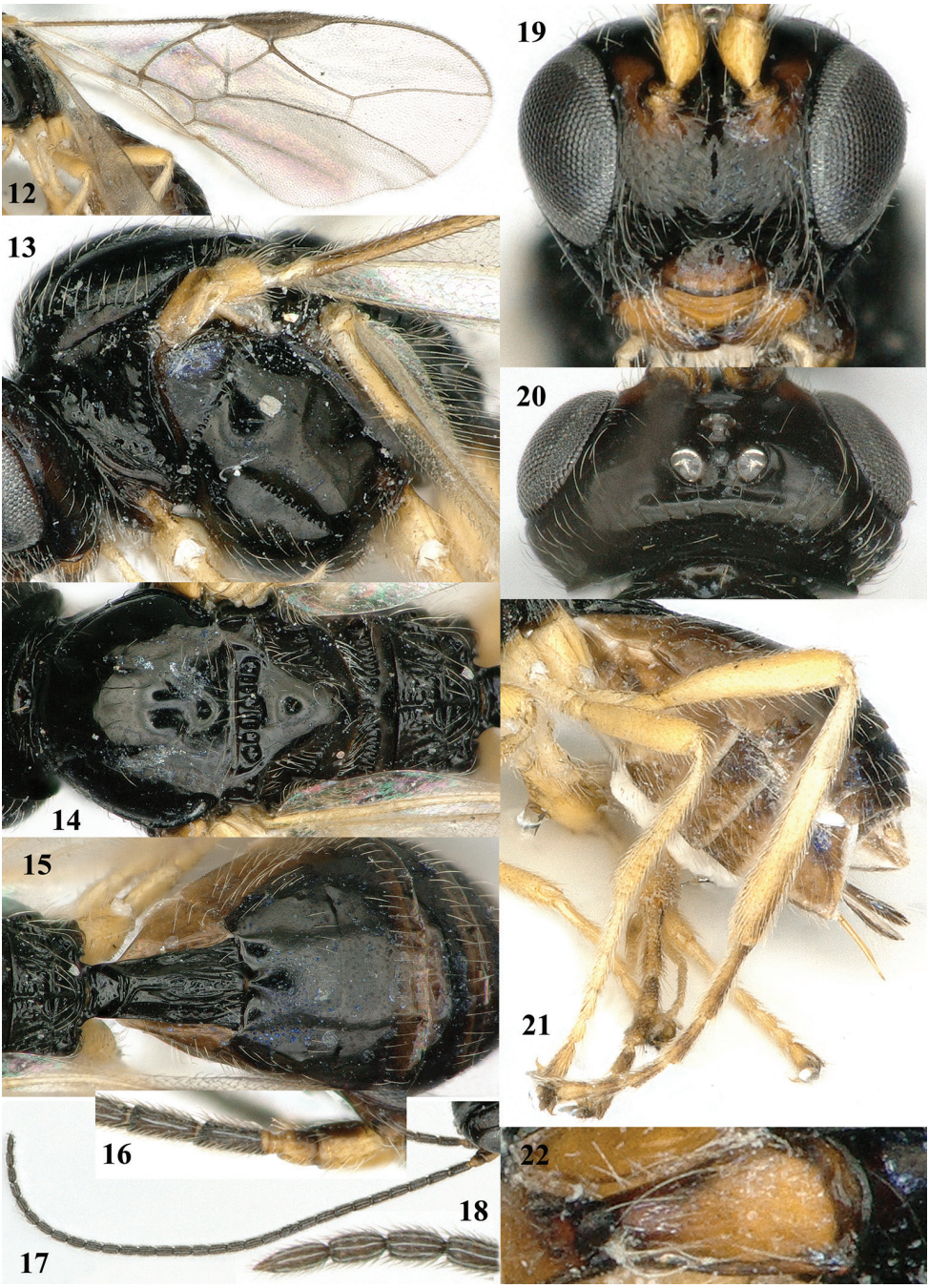
Figure 11. *Rhogadopsis cracentata* sp. n., female, holotype, habitus lateral.

wide (about 3 times in *R. moniliata*), the propodeum with some superficial rugae (with complete median carina and costulae), the precoxal sulcus short (long) and the hind femur 3 times as long as wide (about 4.5 times). The length of the ovipositor sheath of *R. infernalis* is unknown because the type series consists of only males.

Description. ♀, length of body 3.1 mm, of fore wing 3.6 mm.

Head. Antenna with 32 segments and 1.1 times as long as fore wing; third segment 1.2 times as long as fourth segment, length of third, fourth and penultimate segments 3.0, 2.6 and 2.0 times their width, respectively (Figs 16, 18); maxillary palp as long as height of head, labial palp segments slender; occipital carina separated from hypostomal carina and dorsally absent; hypostomal carina wide; length of eye in dorsal view 3.7 times temple; frons shallowly depressed, smooth and glabrous, laterally somewhat elevated; face smooth except punctulation, medially slightly elevated (Fig. 19); width of clypeus 1.7 times its maximum height and 0.5 times width of face; clypeus convex, punctate and protruding, slightly curved and thin ventrally (Fig. 19); hypoclypeal depression medium-sized (Fig. 19); malar suture present; length of malar space as long as basal width of mandible; mandible triangular and with narrow ventral carina (Fig. 22).

Mesosoma. Length of mesosoma 1.4 times its height; dorsal pronope large and wide elliptical; pronotal side glabrous, mainly smooth and only crenulate posteriorly and medio-anteriorly; epicnemial area crenulate; precoxal sulcus narrow and mainly



Figures 12–22. *Rhogadopsis cracentata* sp. n., female, holotype. **12** wings **13** mesosoma lateral **14** mesosoma dorsal **15** first-third metasomal tergites dorsal **16** base of antenna **17** antenna **18** apex of antenna **19** head anterior **20** head dorsal **21** hind leg **22** mandible lateral.

crenulate (Fig. 13), remain removed from anterior and posterior margins of mesopleuron; remainder of mesopleuron smooth; pleural sulcus smooth; anterior groove of metapleuron crenulate; notauli present on disc as shallowly depression; mesoscutum largely glabrous, but sparsely setose posteriorly and along notauli; medio-posterior depression of mesoscutum rather deep and round (Fig. 14); scutellar sulcus medium-sized and crenulate; scutellum slightly convex medially, smooth and glabrous, but setose posteriorly and laterally; propodeum with complete medio-longitudinal carina and smooth anteriorly and medially (Fig. 14).

Wings. Fore wing (Fig. 12): pterostigma wide elliptical; r widened and short; 1-R1 ending at wing apex and 1.5 times as long as pterostigma; r:3-SR:SR1 = 5: 69: 100; 2-SR:3-SR:r-m = 18:34:10; 1-M and SR1slightly curved; cu-a postfurcal; first subdiscal cell closed, CU1b short; apical 0.3 of M+CU sclerotized. Hind wing: M+CU:1-M:1r-m = 10:10:6; cu-a straight; m-cu nearly absent.

Legs. Length of femur, tibia and basitarsus of hind leg 4.6, 8.0, 4.7 times as long as wide, respectively; especially hind femur with long setae (Fig. 21).

Metasoma. Length of first tergite 1.7 times its apical width, its surface moderately convex medially, finely rugose, dorsal carinae united and with short median carina (Fig. 15); second tergite smooth, with pair of large basal depressions; following tergites smooth; length of setose part of ovipositor sheath 0.06 times fore wing and 0.2 times hind tibia, entire visible sheath 0.07 times fore wing (Fig. 21).

Colour. Black; clypeus, scapus and pedicellus (except dark brown dorsal side), legs (but hind tarsus and apex of hind tibia brown dorsally), tegulae and veins of base of wing yellow; mandible yellowish brown (except its blackish teeth); palpi ivory; metasoma and ventrally mainly brown; ovipositor sheath, pterostigma and veins (except basal veins) dark brown; wing membrane subhyaline.

Variation. Length of body 2.7–3.3 mm, of fore wing 3.1–3.7 mm; antennal segments of ♀ 31(3) or 32(2) and of ♂ 35(1) or 37(1), length of hind femur 4.5–4.7 times its width; length of first tergite 1.7–1.9 times its apical width, length of setose part of ovipositor sheath 0.06 times fore wing and its visible part 0.07–0.10 times fore wing. Parameres of ♂ brown or apical half yellowish.

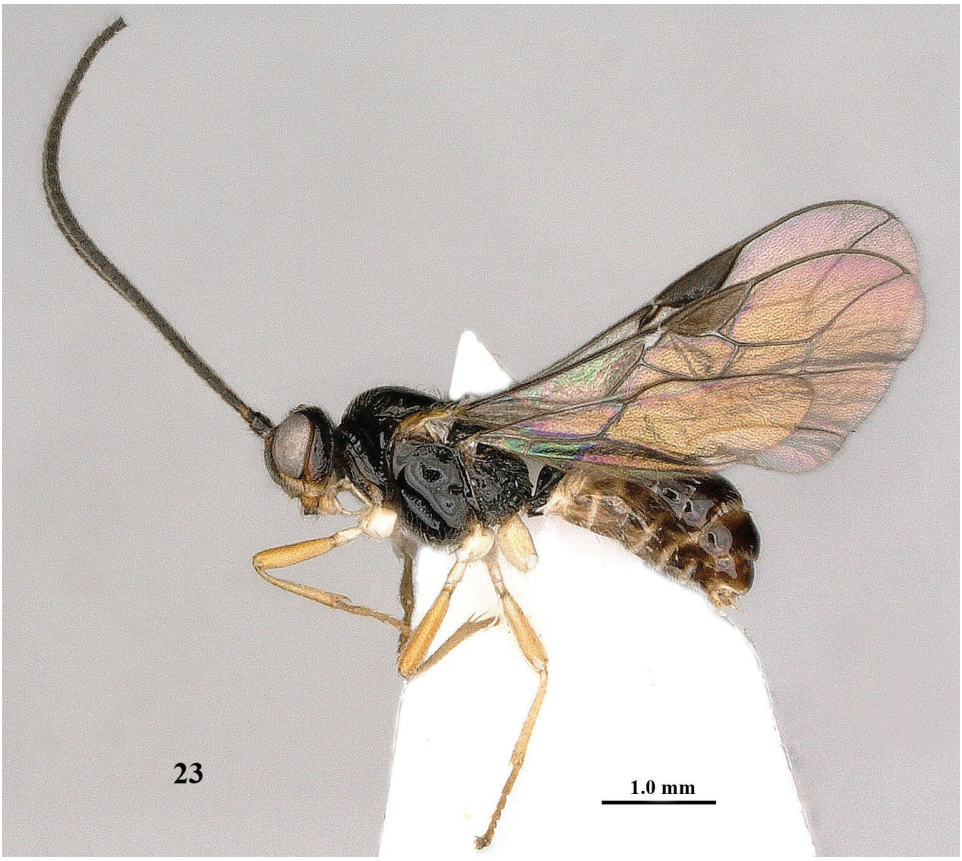
Distribution. China (Shaanxi).

Biology. Unknown.

Etymology. From "cracentis" (Latin for "slender") because of the slender first metasomal tergite.

Rhogadopsis longivena **Chen & van Achterberg, sp. n.**
http://zoobank.org/BBCD7F03-B6CC-45FA-A018-D543BEA6F3CF
Figs 23–32

Type material. Holotype, ♂ (NWUX), "NW **China**: **Shaanxi**, Liping Nat. For. P., MT1+2, c. 1495 m, 22.vi.-4.ix.2015, 32°47'33"N, 106°39'52"E, JL. Tan & C. v. Achterberg".

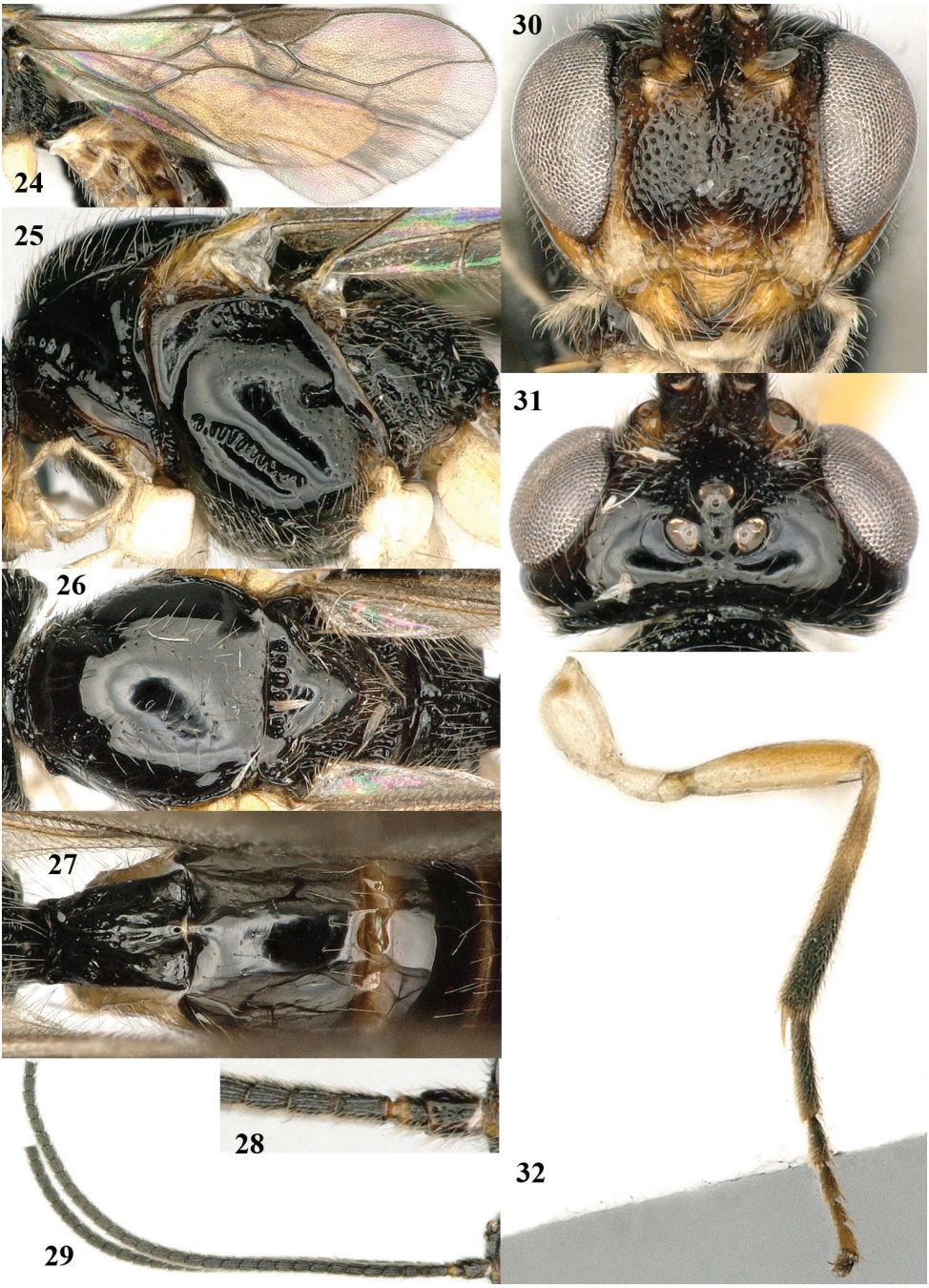


Figures 23. *Rhogadopsis longivena* sp. n., female, holotype.

Diagnosis. The combination of an absence of the medio-posterior depression of the mesoscutum (Fig. 26), the first metasomal tergite without a long median carina (Fig. 27) and vein r of the fore wing long and slender (at least 5 times longer than wide; Fig. 23) makes this species easy to separate from other known species.

Description. Holotype, ♂, length of body 4.4 mm, and of fore wing 4.2 mm.

Head. Antenna incomplete, 34 segments remaining, third segment 1.3 times as long as fourth segment, length of third, fourth and penultimate segments 2.0, 1.9 and 1.8 times their width, respectively (Figs 28–29); maxillary palp 1.3 times as long as height of head; labial palp segments slender; occipital carina rather far separated from hypostomal carina and carina dorsally absent; hypostomal carina narrow; length of eye in dorsal view 3.1 times temple; frons shallowly depressed, smooth and setose, laterally punctate and setose; face setose, with weak medial elevation, medially remotely and laterally densely punctate (Fig. 30); width of clypeus 2.1 times its maximum height and 0.5 times width of face, clypeus moderately convex, straight and thin ventrally (Fig. 30); hypoclypeal depression medium-sized (Fig. 30); malar suture present; length of malar space 1.1 times basal width of mandible; mandible triangular and with long carina.



Figures 24–32. *Rhogadopsis longivena* sp. n., female, holotype. **24** wings **25** mesosoma lateral **26** mesosoma dorsal **27** first-fourth metasomal tergites dorsal **28** base of antenna **29** antenna **30** head anterior **31** head dorsal **32** hind leg.

Mesosoma. Length of mesosoma 1.4 times its height; dorsal pronope absent; pronotal side glabrous, mainly smooth and only medio-anteriorly and posteriorly crenulate; epicnemial area smooth; precoxal sulcus medium-sized and crenulate, remain removed from anterior and posterior margins of mesopleuron; remainder of mesopleuron smooth; pleural sulcus smooth; anterior groove of metapleuron crenulate; notauli absent on disc; mesoscutum largely glabrous, but setose along notauli courses; media-posterior depression of mesoscutum absent; scutellar sulcus rather narrow and crenulate; scutellum slightly convex medially; smooth and setose; propodeum with nearly complete medio-longitudinal carina and partly smooth anteriorly, sparsely rugose medially and with some crenulae posteriorly (Fig. 26).

Wings. Fore wing (Fig. 24): pterostigma triangular; 1-R1 ending at wing apex and 1.5 times as long as pterostigma; r:3-SR:SR1 = 10:31:52; 2-SR:3-SR:r-m = 20:31:14; r slender and about 5 times longer than wide (Figs 23–24); 1-M and SR1 slightly curved; m-cu antefurcal; cu-a oblique and far postfurcal; first subdiscal cell closed and CU1b short; apical 0.2 of M+CU1 sclerotized. Hind wing (Fig. 24): M+CU:1-M: 1r-m = 14:19:12; cu-a straight; m-cu completely absent.

Legs. Length of femur, tibia and basitarsus of hind leg 4.1, 7.8 and 5.2 times as long as wide, respectively; hind femur and tibia with long setae.

Metasoma. Length of first tergite 1.5 times its apical width, its surface moderately convex medially, some grooves and minute punctures, dorsal carinae united and with long median carina; second tergite smooth, with pair of rather large basal depressions; following tergites smooth.

Colour. Black, legs, clypeus and mandible brownish yellow (but teeth black); palpi, coxae, trochanters and trochantelli ivory; hind tarsus and apical half of tibia dark brown; malar space ivory; wing membrane subhyaline; metasoma largely (except T1) and pterostigma dark brown.

Distribution. China (Shaanxi).

Biology. Unknown.

Etymology. From “longus” (Latin for “long”) and “vena” (Latin for “vein”) because of the long vein r of the fore wing.

***Rhogadopsis mediocarinata* (Fischer, 1963), comb. n.**
Figs 33–42

Opius mediocarinatus Fischer, 1963: 297 (examined).
Opius (*Lissosema*) *mediocarinatus*; Fischer, 1972: 360–361.
Opius (*Psyttalia*) *mediocarinatus*; Tobias, 1998: 611.
Psyttalia mediocarinata; Tobias, 2000: 12.

Type material. Paratype of *O. mediocarinatus*, ♀ (Hungarian Natural History Museum, Budapest) from **Japan** (Honshu: Kamikochi) examined.

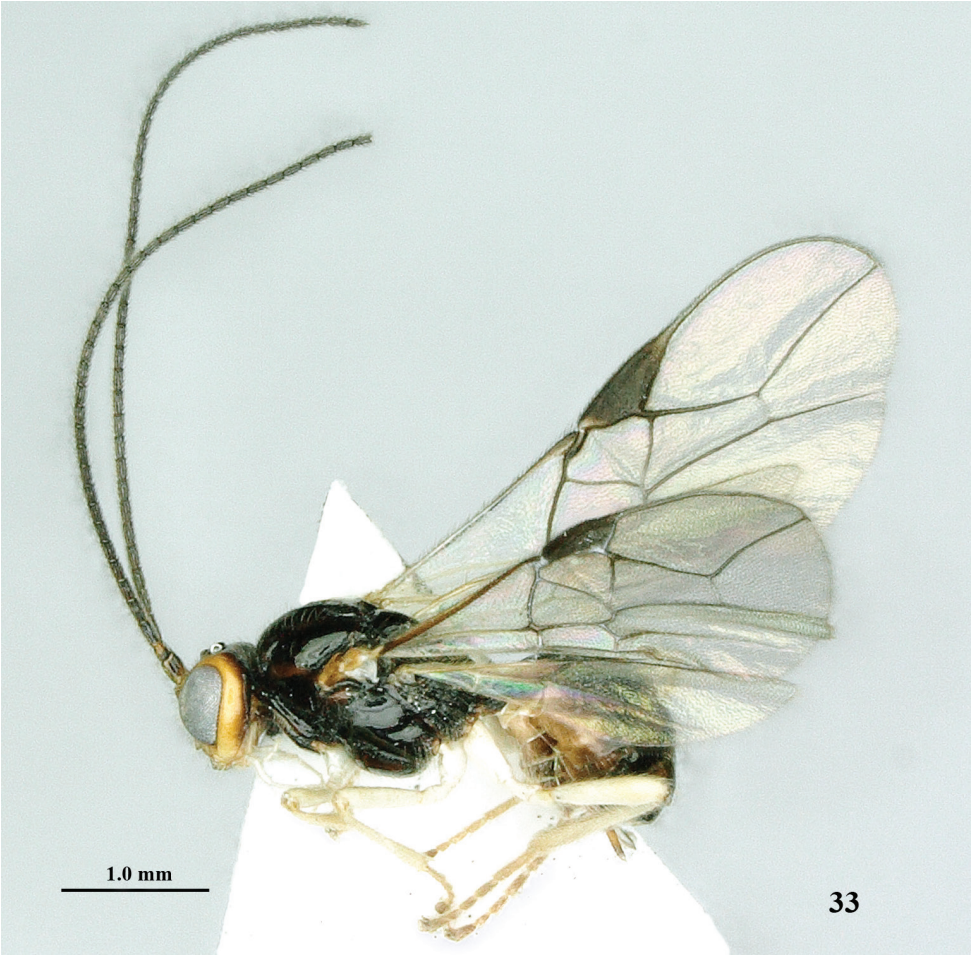


Figure 33. *Rhogadopsis mediocarinata* (Fischer), female, China, Liuba, habitus lateral.

Additional material. 1♀ (NWUX), "NW **China**: **Shaanxi**, Liuba, Hanzhong Zibai Mt. Nat. Res., N33.66° E106.78°, 5.ix.2015, c. 1627 m, Jiangli Tan, NWUX"; 1♀, "NW China: Shaanxi, Liping Nat. For. P., MT1+2, c. 1495 m, 22.vi-4.ix.2015, 32°47'33"N, 106°39'52 "E, JL Tan & C. v. Achterberg"; 1 ♀, "NW China: Shaanxi, Liping Nat. For. P., betw[een] Hongchenxia-Shicheng, c. 1490 m, 21.vi.2015, 32°47'N 106°40'E, JL Tan".

Diagnosis. The combination of lacking a medio-posterior depression of the mesoscutum and the slender first metasomal tergite with a long median carina makes this species easy to separate from all other species in China.

Description. Female from Liuba, length of body 3.7 mm, of fore wing 4.1 mm.

Head. Antenna with 39 segments and 1.3 times as long as fore wing; third segment 1.2 times as long as fourth segment, length of third, fourth and penultimate segments 3.0, 2.4 and 1.3 times their width, respectively (Fig. 42); length of maxillary palp

1.3 times height of head; labial palp segments slender; occipital carina far separated from hypostomal carina and carina dorsally absent; hypostomal carina wide; length of eye in dorsal view 3.0 times temple; frons shallowly depressed, with oblique striae and glabrous, laterally punctate and setose; face punctate, medially elevated (Fig. 39); width of clypeus 3.0 times its maximum height and 0.6 times width of face; clypeus moderately convex, punctate and protruding, straight and thin ventrally (Figs 33, 38); hypoclypeal depression medium-sized (Fig. 39); malar suture absent; length of malar space 0.5 times basal width of mandible; mandible triangular and with narrow ventral carina (Fig. 38).

Mesosoma. Length of mesosoma 1.2 times its height; pronope absent; pronotal side smooth, only anteriorly and postero-ventrally crenulate; epicnemial area crenulate; precoxal sulcus wide and mainly punctate (Fig. 35), nearly up to anterior margin of mesopleuron; remainder of mesopleuron smooth; pleural sulcus smooth; anterior groove of metapleuron crenulate; notauli absent on disc, only anteriorly with pair of largely narrow and short smooth impressions (Fig. 36); mesoscutum largely glabrous; medio-posterior depression of mesoscutum absent; scutellar sulcus rather wide and crenulate; scutellum slightly convex medially, smooth and glabrous; propodeum with nearly complete irregular medio-longitudinal carina with crenulae and remainder smooth (Figs 36–37).

Wings. Fore wing (Fig. 34): pterostigma triangular; 1-R1 ending at wing apex and 1.6 times as long as pterostigma; r:3-SR:SR1 = 3:39:60; 2-SR:3-SR:r-m = 23:40:11; r widened; 1-M nearly straight; SR1 slightly curved; m-cu and cu-a postfurcal; first subdiscal cell closed, CU1b short; apical 0.2 of M+CU1 sclerotized. Hind wing (Fig. 34): M+CU:1-M:1r-m = 22:20:13; cu-a straight; m-cu completely absent.

Legs. Length of femur, tibia and basitarsus of hind leg 5.0, 10.0 and 5.0 times as long as wide, respectively; hind femur and tibia with long setae (Fig. 41).

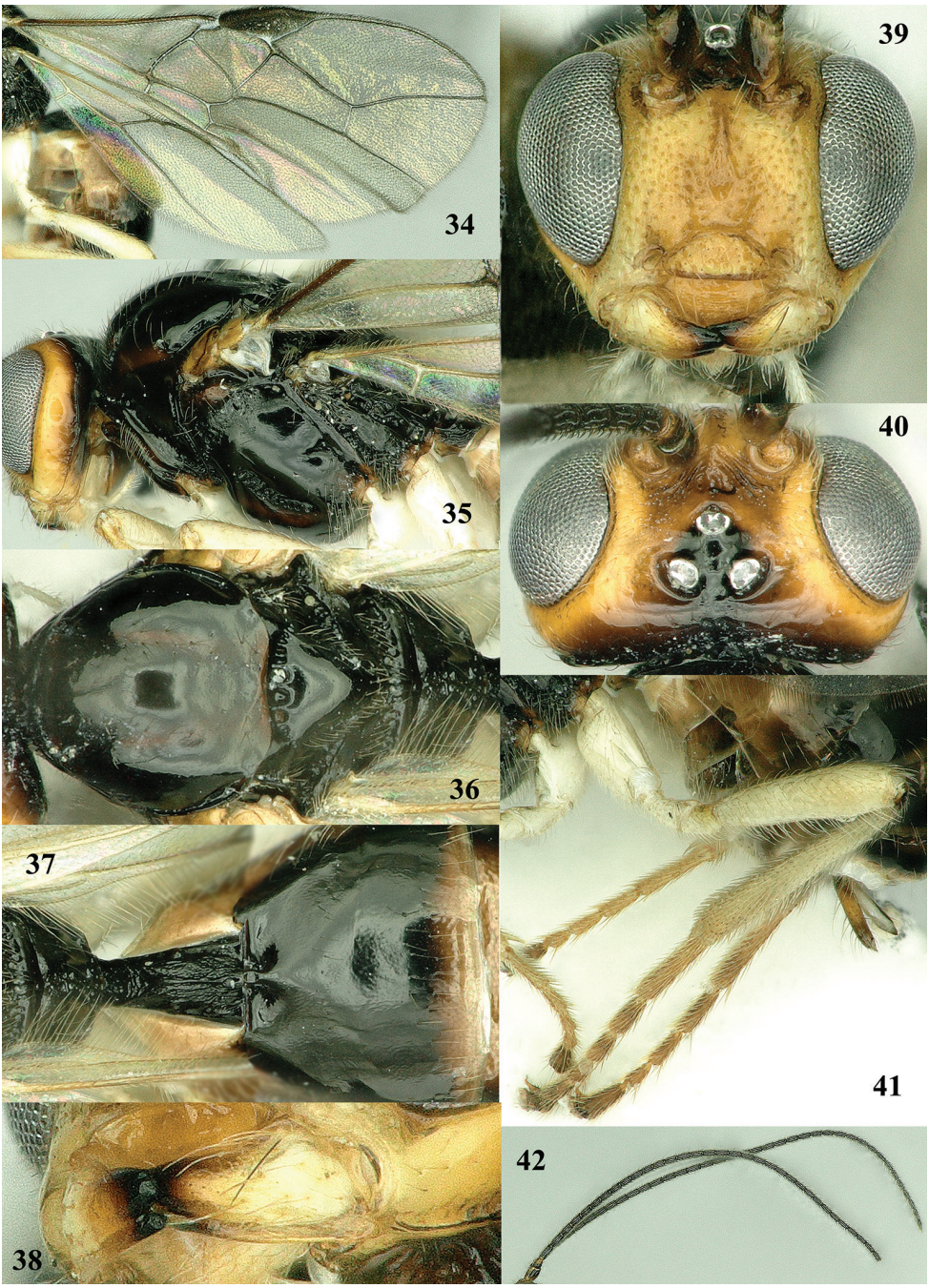
Metasoma. Length of first tergite 1.5 times its apical width, its surface rather slightly convex medially, finely rugulose, with median carina and with dorsal carinae remaining separated (Fig. 37); second tergite smooth, with pair of large basal depressions; following tergites smooth; length of setose part of ovipositor sheath 0.07 times fore wing and 0.2 times hind tibia (Fig. 41).

Colour. Black; palpi and legs (but tarsi brown) ivory or white; scapus and pedicellus ventrally, mandible (except black teeth), tegulae and head (except dark brown stemmaticum and posterior part of head yellow, but frons and face brownish medially (Fig. 39); wing membrane subhyaline; base and apex of ovipositor sheath dark brown; intermediate part of ovipositor sheath and veins of basal half of wing brown; pterostigma and remainder of veins dark brown.

Variation. Length of body 2.9–3.7 mm, of fore wing 3.1–4.1 mm; antennal segments of ♀ 35(1) or 39(1), length of first tergite 1.4–1.5 times its apical width, length of setose part of ovipositor sheath 0.07–0.10 times fore wing and 0.2–0.3 times hind tibia.

Distribution. China (Fujian, Hunan, *Shaanxi), Far East Russia, Japan, Korea. The record from Spain (Avinent and Jiménez 1987) needs reconfirmation.

Biology. Unknown.



Figures 34–42. *Rhogadopsis mediocarinata* (Fischer), female, China, Liuba. **34** wings **35** mesosoma lateral **36** mesosoma dorsal **37** first-third metasomal tergites dorsal **38** mandible lateral **39** head anterior **40** head dorsal **41** hind leg **42** antenna.

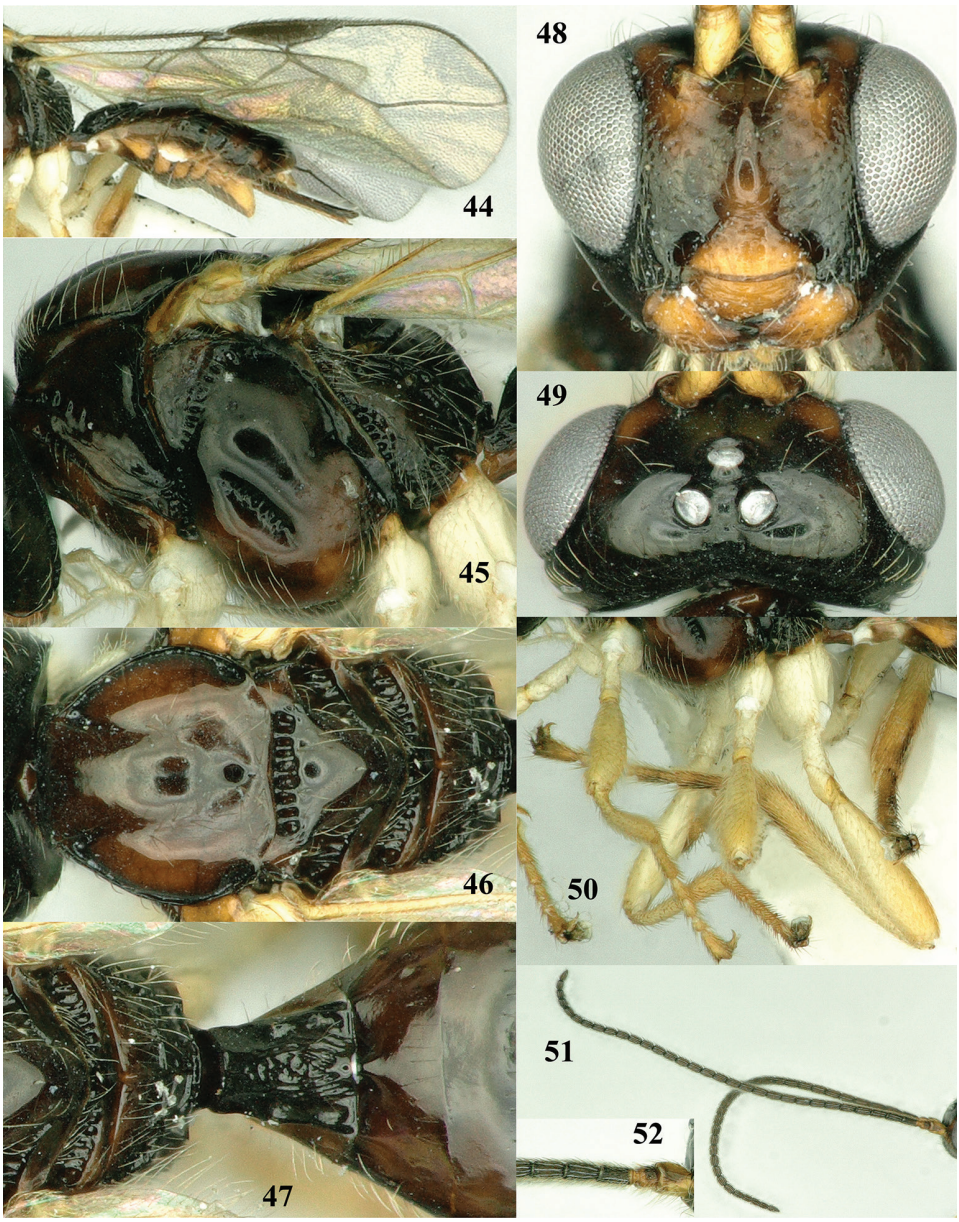
Rhogadopsis moniliata **Tan & van Achterberg, sp. n.**
http://zoobank.org/D3CB76D7-9C18-4E6D-8AF0-882E1DC64631
Figs 43–52

Type material. Holotype, ♀ (NWUX), "NW **China**: **Shaanxi**, Huanghualing Zhashui, 33.76°N, 108.85°E, 24.vii.2015, c 1377 m, Jiangli Tan, NWUX". Paratypes: 1 ♀ (RMNH), same label data as holotype; 4♀1♂ (NWUX, RMNH), "NW China: Shaanxi, Liping Nat. For. P., MT1+2, c. 1495 m, 22.vi-4.ix.2015, 32°47'33"N, 106°39'52"E, JL Tan & C. v. Achterberg"; 1 ♀ (NWUX), "NW China: Shaanxi, Baolongyu, Qin[ling] Mt[s], c 1000 m, 10.vi.2015, 34°03'N 108°09'E, Jiangli Tan, NWUX"; 1♀ (NWUX) "NW China: Shaanxi, Qinling Mts, Foping, near Biol[ogical] Stat[ion], Mal[aise] trap, 33°39'29"N, 107°48'25"E, 29.v.-19.vi.2016, c 1710 m, JL. Tan & C. v. Achterberg, NWUX".

Diagnosis. The new species is similar to *R. cracentata* but the setose part of the ovipositor sheath is longer (0.5–0.7 times hind tibia and about twice as long as hind basitarsus versus 0.2 times hind tibia and slightly shorter than hind basitarsus in *R. cracentata*), the third and fourth antennal segments of the ♀ are robust (Fig. 52; slenderer in *R. cracentata*), the first metasomal tergite is rather stout (1.2–1.4 times longer than its apical width versus 1.5–1.9 times) and the hind femur is wider (about 3.7 times as long as wide versus 4.5–4.7 times).

It shares with *R. infernalis* (Fischer, 1966) from the Philippines the robust third antennal segment (being about twice as long as wide), the rather short temple (eye 3.2–4.0 times as long as temple in dorsal view) and the robust hind femur. *Rhogadopsis infernalis*

Figure 43. *Rhogadopsis moniliata* sp. n., female, holotype, habitus lateral.



Figures 44–52. *Rhogadopsis moniliata* sp. n., female, holotype. **44** wings **45** mesosoma lateral **46** mesosoma dorsal **47** propodeum and first-third metasomal tergites dorsal **48** head anterior **49** head dorsal **50** hind leg **10** head lateral **52** base of antenna.

has the propodeum with some superficial rugae (with complete median carina and costulae in *R. cracentata*), the precoxal sulcus short (long) and the antenna has about 37 segments (30–34 segments). The length of the ovipositor sheath of *R. infernalis* is unknown because the type series consists of only males.

Description. Holotype, ♀, length of body 3.1 mm, of fore wing 3.3 mm.

Head. Antenna with 33 segments and 1.1 times as long as fore wing; third segment 1.1 times as long as fourth segment, length of third, fourth and penultimate segments 2.3, 2.1 and 2.0 times their width, respectively (Fig. 52), maxillary palp as long as height of head; labial palp segments slender; occipital carina rather far separated from hypostomal carina and carina dorsally absent; hypostomal carina wide; length of eye in dorsal view 2.6 times temple; frons shallowly depressed, striae absent, with weak medial elevation and punctulate setose; face punctulate, medially elevated (Fig. 48); width of clypeus 2.4 times its maximum height and 0.55 times width of face, clypeus moderately convex, protruding, straight and thin ventrally (Fig. 48); hypoclypeal depression large (Fig. 48); malar suture present; length of malar space 0.8 times basal width of mandible; mandible triangular and with narrow ventral carina.

Mesosoma. Length of mesosoma 1.3 times its height; dorsal pronope absent; pronotal side smooth, only anteriorly and postero-ventrally crenulate; epicnemial area crenulate; precoxal sulcus narrow and crenulate (Fig. 45), absent anteriorly and posteriorly; remainder of mesopleuron smooth; pleural sulcus smooth; anterior groove of metapleuron crenulate; notauli narrow anteriorly, on disc shallowly impressed and smooth (Fig. 46); mesoscutum largely glabrous; medio-posterior depression of mesoscutum round and deep (Fig. 46); scutellar sulcus medium-sized and crenulate; scutellum slightly convex medially; smooth and glabrous medially but laterally with long setae; propodeum with complete regular medio-longitudinal carina and with some crenulae (Fig. 47).

Wings. Fore wing (Fig. 44): pterostigma triangular; 1-R1 ending at wing apex and 1.7 times as long as pterostigma; r:3-SR:SR1 = 2:17:24; 2-SR:3-SR:r-m = 13:24:11; r short and widened; 1-M curved; SR1 slightly curved; m-cu postfurcal; first subdiscal cell closed; CU1b medium-sized; apical 0.2 of M+CU1 sclerotized; m-cu rather angled with 2-CU1. Hind wing (Fig. 44): M+CU:1-M:1r-m = 24:20:15; cu-a curved; m-cu vaguely indicated.

Legs. Length of femur, tibia and basitarsus of hind leg 3.7, 7.8 and 4.5 times as long as wide, respectively; hind femur and tibia with rather long setae.

Metasoma. Length of first tergite 1.4 times its apical width, its surface moderately convex medially, finely rugulose, dorsal carinae united and with short median carina (Fig. 47); second tergite with pair of large basal depressions; second and following tergites smooth; length of setose part of ovipositor sheath 0.16 times fore wing and 0.5 times hind tibia, entire visible sheath 0.23 times fore wing (Fig. 44).

Colour. Brownish black or black, face brown dorso-laterally and medio-ventrally; clypeus and mandible brownish yellow; scapus and pedicellus (but outer side partly dark brown), legs (but coxae and trochanters white and apex of hind tibia and hind tarsus dark brown dorsally), tegulae, base of wings and sternites laterally yellow; palpi white; sternites medially brown, pterostigma and veins (except base of wings) dark brown; wing membrane subhyaline.

Variation. Body length of 3.0–3.5 mm and of fore wing 3.3–3.7 mm; antenna of ♀ with 30(1), 31(3), 32(1) or 33(2) segments, antenna of ♂ with 34(1) segments

and third segment 2.2 times as long as wide; first tergite 1.2–1.4 times as long as its apical width; length of setose part of ovipositor sheath 0.16–0.20 times fore wing and 0.5–0.7 times hind tibia, entire visible sheath 0.18–0.23 times fore wing; anterior half of notauli hardly or not impressed but present in female from Foping; parameres dark brown; mesosoma partly dark brown or entirely black.

Distribution. China (Shaanxi).

Biology. Unknown.

Etymology. From "monile" (Latin for "necklace") because of the rather necklace-like short antennal segments of the female.

Rhogadopsis pratellae (Weng & Chen, 2005)

Figs 53–62

Opius (*Apodesmia*) *pratellae* Weng & Chen in Chen & Weng, 2005: 60–61, 189 (examined).
Rhogadopsis pratellae; Li et al., 2013: 150.

Type material. Holotype, ♀ (FAFU), "[**China**:] **Fujian**, Mt. Wuyi, 2.viii.1988, Jinhua Ge".

Additional material. 2♀4♂(NWUX, RMNH), "NW **China**: **Ningxia**, Liupan Mt, Jingyuan Dongshanpo For. Farm, N35°23'26" E106°20'34.27", 4.viii.2015, c 1800 m, Jiangli Tan, NWUX".

Diagnosis. *Rhogadopsis pratellae* shares with *R. maculosa* Li & van Achterberg, 2013, the longer vein 1-SR of the fore wing (0.5 times as long as vein 1-M), vein 3-SR of fore wing about 1.5 times as long as vein 2-SR and first metasomal tergite distinctly widened apically. It differs by having the first metasomal tergite about 1.3 times as long as wide apically (about as long as wide in *R. maculosa*), the propodeum mainly smooth except for carination (coarsely reticulate), the medio-posterior depression of the mesoscutum short elliptical or droplet-shaped (elongate), antenna with 29–34 segments (antenna with about 43 segments), area below the pterostigma subhyaline (slightly infuscate) and the anterior half of the notauli developed on the mesoscutal disc (largely absent).

Description.♀ from Liupan Mt., length of body and of fore wing 3.5 mm.

Head. Antenna with 33 segments and 1.1 times as long as fore wing; third segment 1.3 times as long as fourth segment, length of third, fourth and penultimate segments 2.2, 1.8 and 1.8 times their width, respectively (Figs 58, 62); maxillary palp as long as height of head, labial palp segments slender; occipital carina far separated from hypostomal carina and dorsally absent; hypostomal carina wide; length of eye in dorsal view 2.8 times temple; frons shallowly depressed, smooth and glabrous, laterally punctate and setose; face smooth except punctulation, medially elevated (Fig. 59); width of clypeus 2.3 times its maximum height and 0.7 times width of face; clypeus slightly convex, punctate and protruding, straight and thin ventrally (Fig. 59); hypoclypeal depression medium-sized (Fig. 59); malar suture absent, but with a short depression;

Figure 53. *Rhogadopsis pratellae* (Weng & Chen), female, China, Liupan Mt., habitus lateral.

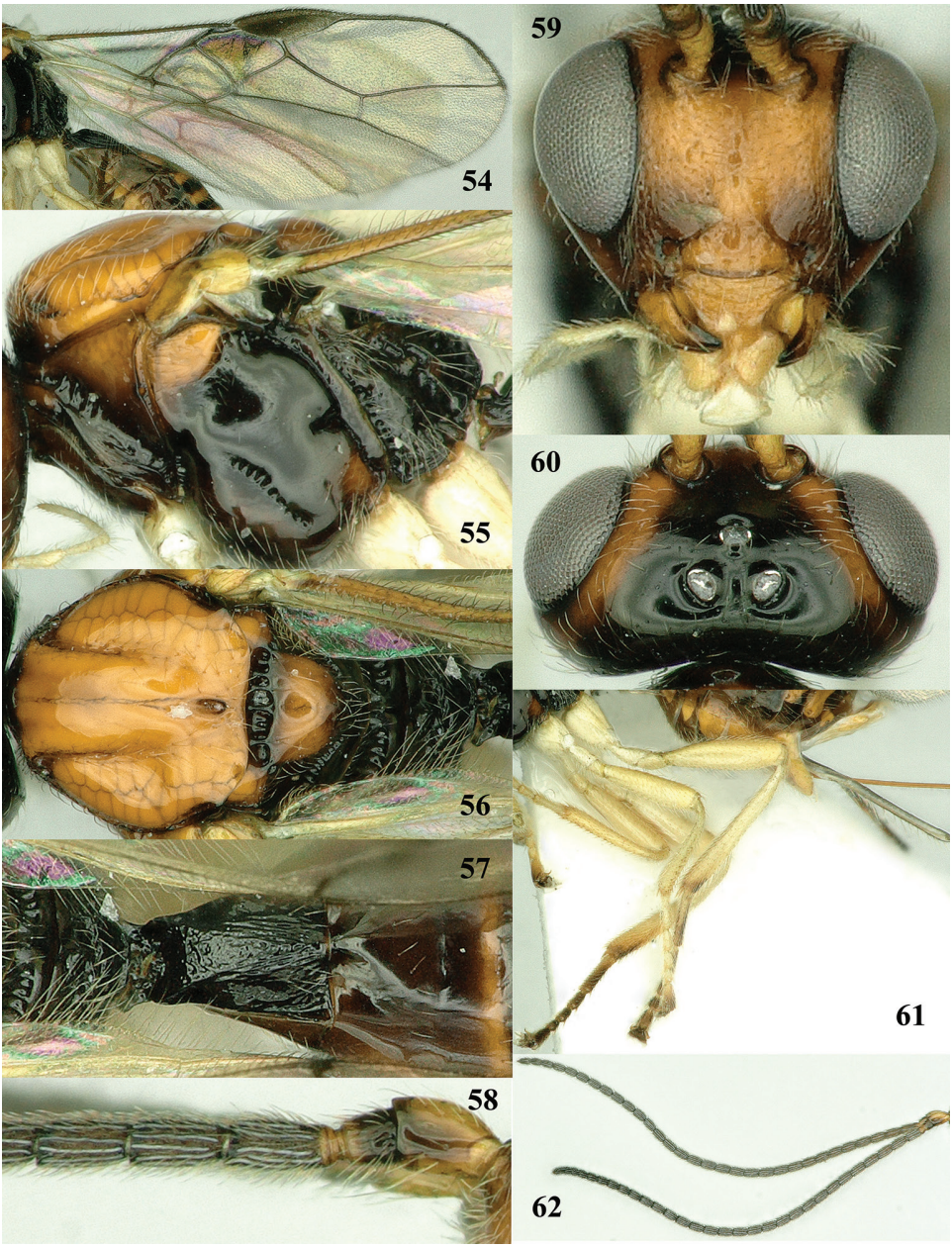
length of malar space 0.8 times basal width of mandible; mandible triangular and with narrow ventral carina (Fig. 53).

Mesosoma. Length of mesosoma 1.3 times its height; pronope large and round; pronotal side setose, mainly smooth and only crenulate medio-anteriorly; epicnemial area smooth; precoxal sulcus rather narrow and mainly crenulate (Fig. 55), remaining removed from anterior and posterior margins of mesopleuron; remainder of mesopleuron smooth; pleural sulcus smooth; anterior groove of metapleuron crenulate; notauli largely present on disc, smooth and only posteriorly absent (Fig. 56); mesoscutum largely glabrous, but sparsely setose posteriorly; medio-posterior depression of mesoscutum present, droplet-shaped (Fig. 56); scutellar sulcus rather wide and crenulate; scutellum slightly convex medially, smooth and glabrous, but setose posteriorly; propodeum with nearly complete medio-longitudinal carina and smooth anteriorly, rugose medially and with some crenulae posteriorly (Fig. 57).

Wings. Fore wing (Fig. 54): pterostigma triangular; 1-R1 ending at wing apex and 1.5 times as long as pterostigma; r:3-SR:SR1 = 5:32:54; 2-SR:3-SR:r-m = 21:30:8; r rather short and widened; 1-M and SR1 slightly curved; m-cu and cu-a postfurcal; first subdiscal cell closed, CU1b short; apical 0.3 of M+CU1 sclerotized. Hind wing (Fig. 54): M+CU:1-M:1r-m = 20:17:15; cu-a straight; m-cu nearly absent.

Legs. Length of femur, tibia and basitarsus of hind leg 4.2, 8.6 and 6.4 times as long as wide, respectively; hind femur and tibia with long setae (Fig. 61).

Metasoma. Length of first tergite 1.3 times its apical width, its surface evenly convex medially, finely striate but medially (except apically) largely rugulose (Fig. 57), without median carina and with dorsal carinae remaining separated, present on basal third of



Figures 54–62. *Rhogadopsis pratellae* (Weng & Chen), female, China, Liupan Mt. **54** wings **55** mesosoma lateral **56** mesosoma dorsal **57** propodeum and first-third metasomal tergites dorsal **58** base of antenna **59** head anterior **60** head dorsal **61** hind leg **62** antenna.

tergite; second tergite with pair of large triangular basal depressions; second and following tergites smooth; length of setose part of ovipositor sheath 0.22 times fore wing and 0.7 times hind tibia (Fig. 53); entire exposed sheath 0.28 times fore wing.

Colour. Black or blackish brown; palpi and legs (but telotarsi apically, hind tarsus largely and apical patch of hind tibia dark brown) ivory or pale yellowish; scapus (except dark brown outer side), mandible (except dark brown teeth) and tegulae yellow; remainder of antenna and ovipositor sheath dark brown; head (but dorsal part of head black except near eyes and face latero-ventrally and temple chestnut brown), mesoscutum, scutellum (except posteriorly), pronotum postero-dorsally, mesopleuron antero-dorsally, narrow dorsal transverse stripes of third-fifth tergites, lateral patches of second-seventh tergites and metasoma ventrally (except basally) yellowish brown (Fig. 53); veins of basal third of wings pale brown (except dark brown C+SC+R); pterostigma and remainder of veins dark brown; wing membrane subhyaline.

Variation. Length of body 2.6–3.5 mm, of fore wing 3.0–3.8 mm; antennal segments of ♀ 33(1) or 34(1), of ♂ 30(1), 31(2) or 32(1), length of first tergite 1.2–1.3 times its apical width, length of setose part of ovipositor sheath 0.20–0.22 times fore wing and 0.6–0.7 times hind tibia; males have mesoscutum and scutellum dark brown except more or less yellowish notaulic area, sometimes mesopleuron partly chestnut brown; males have first tergite similarly sculptured as female or rarely entirely smooth; metasoma of males (except first tergite) more or less dark brown; parameres (except basally) yellow.

Distribution. China (Fujian, *Ningxia).

Biology. Unknown.

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http://jhr.pensoft.net

RESEARCH ARTICLE

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Geometric morphometric discrimination of the three African honeybee subspecies *Apis mellifera intermissa*, *A. m. sahariensis* and *A. m. capensis* (Hymenoptera, Apidae): Fore wing and hind wing landmark configurations

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Abstract

In this study, a landmark-based geometric morphometric analysis was carried out on three honeybee subspecies: *Apis m. intermissa* and *A. m. sahariensis* collected from Algeria, and, as a reference, *A. m. capensis* collected from South Africa. The aim of this study was to discriminate honeybee subspecies by patterns of shape variation of fore and hind wings. A total of 540 wings from 270 honeybee workers were analyzed. Our results revealed very high cross-validation classification rates (96.7% based on fore wing shape and 99.6% based on the combination of fore and hind wing forms respectively). Discrimination was better using shape and form (shape + centroid size) of the fore wings than of the hind wings. The wing form parameters were found to differ significantly in shape and centroid size among the three analyzed subspecies. Finally, it may be concluded that landmark-based geometric morphometrics could be a powerful tool to characterize the Algerian honey bees.

Keywords

Bees, Africa, biodiversity, wing venation, morphometry, Procrustes superimposition, canonical variate analysis (CVA)

Introduction

For the African honeybees only limited studies are available. For example, in Algeria only a few studies were published on the local subspecies. Barour et al. (2005) by using distance measurements revealed a south-to-north clinal increase in overall size with significant population differences. This study filled a former gap in the knowledge of *Apis mellifera intermissa* population variability between Morocco and Tunisia. Recently, Barour (2012), Barour et al. (2011), Chahbar et al. (2013) and Loucif-Ayad et al. (2015) have studied the diversity of the local Algerian honeybees by using morphometric and molecular data. On the one hand, Barour et al. (2011) have demonstrated that populations can be distinguished on the basis of the shape of the fore wing venation of *A. m. intermissa* workers. On the other hand, Chahbar et al. (2013) have shown that naturally distributed honeybees in Algeria correspond to the African evolutionary lineage by determining their mitochondrial haplotype and the variation of ten microsatellite loci. Loucif-Ayad et al. (2015) have assessed the phylogenetic and population structure of many populations and have confirmed the African origin of these *A. m. intermissa* and *A. m. sahariensis* Algerian populations.

In this study, we wish to take part in an ongoing inventory program for setting up a morphological database of the Algerian honey bees. The purpose was to distinguish between African honeybee specimens: two local subspecies from Algeria, *A. m. intermissa* (Buttel-Reepen, 1906), *A. m. sahariensis* (Baldensperger, 1924), and one for comparison, *A. m. capensis* (Eschscholtz, 1821) from South Africa. Landmarks were recorded on fore and hind wing and analyzed using generalized least squares Procrustes analysis (GPA) to examine the discrimination between subspecies. Unfortunately, our *A. m. sahariensis* and *A. m. capensis* sample sizes are relatively small because in Algeria the populations of *A. m. sahariensis* are declining in abundance. They are under conservation plans and their geographic distribution is very restricted. A sample of *A. m. capensis* was provided by our South African colleagues and comprised only 90 bees. For these reasons, we have adapted the *A. m. intermissa* sample size to those of *A. m. sahariensis* and *A. m. capensis*, and we have not taken into account the biogeographic information.

Material and methods

Sample collection

Samples of workers of *A. m. intermissa* and *A. m. sahariensis* from Algeria and *A. m. capensis* from South Africa were collected from fixed-site beehives (no transhumance activities) and preserved in alcohol. The honeybees of *A. m. sahariensis* were provided by professional beekeepers and collected in the same eco-climatic region (almost a Saharan climate). The honeybees of *A. m. intermissa* were collected in the same eco-climatic region (northeastern) from two adjacent apiaries. Our *A. m. intermissa* samples were identified by a semi-automatic expert identification system of bee workers (Baylac et al. 2008) as *A. m. intermissa*, which is the only abundant honeybee subspecies in the

northern regions of Algeria. By contrast, *A. mellifera sahariensis* ranges from Aïn Sefra and Béchar in Algeria through the oases of the Sahara south of the Atlas Mountains, its natural distribution is thus restricted to few Algerian Saharan regions. Incidentally, there are no breeding activities of *A. m. sahariensis* in the northern regions of Algeria. As a result, the collected *A. m. intermissa* samples (northeastern in our case) are very distant (approximately 850 km) from those of *A. m. sahariensis* (closest to the Sahara). Random samples of 15 workers per colony were used to build the final datasets that comprise 270 worker honeybees, i.e., a total of 540 fore and hind wings from the three subspecies. Geographic data of our samples are mentioned in Table 1.

Data acquisition

For data acquisition, the right fore wing (FW) and hind wing (HW) of workers were cut at their base. Then the wings were temporarily slide mounted in distilled water and photographed using a digital camera attached to a Z6 APO Leica macroscope. For the FW, the coordinates of nineteen homologous landmarks (LM) were recorded as defined by Smith et al. (1997) (Fig. 1). Seven LM of the HW were then defined; the 1st and the 7th LM were defined as the result of the intersection of the first and the last hamuli with the radial vein (Fig. 1). All LM coordinates were digitized twice using the TPSDig2 software version 2.10 (Rohlf 2008) by the first author. The average of both repetitions was used in the final analyses in order to minimize the measurement error. All the LM correspond to type I LM *sensu* Bookstein (1991) except for LM15 on FW (maximum curvature of veins, a type III LM). The same set or a slightly reduced set of LMs has been employed in most GPA studies of honeybees (Baylac et al. 2008, Miguel et al. 2011, Barour et al. 2011; Kandemir et al. 2011, Oleksa and Tofilski 2015), but other authors have also used HW shape data from the *A. m. intermissa* and *A. m. sahariensis* populations (Barour, 2012) and from *A. mellifera* subspecies (Dolati et al. 2013).

Data analysis

Differences in FW and HW shapes between the three studied subspecies were investigated by the `Rmorph` library (Baylac 2007). The LM coordinates were then aligned using

Table 1. Origin and sample size for *Apis mellifera* subspecies.

Subspecies	Colony no.	Bee no.	Locality and province	Geographic coordinates
A. m. intermissa	03	45	Guelma-Aïn Makhlouf (Algeria)	36°14'28"N 7°14'39"E
A. m. intermissa	03	45	Guelma-Aïn Arbi (Algeria)	36°15'53"N 7°23'59"E
A. m. sahariensis	03	45	Nâama-Aïn Sefra (Algeria)	32°44'33"N 0°34'50"W
A. m. sahariensis	03	45	Béchar (Algeria)	31°36'58"N 2°13'56"W
A. m. capensis	06	90	Grahamstown (South Africa)	33°18'57"S 26°31'10"E
Total	18	270 (540 wings)		

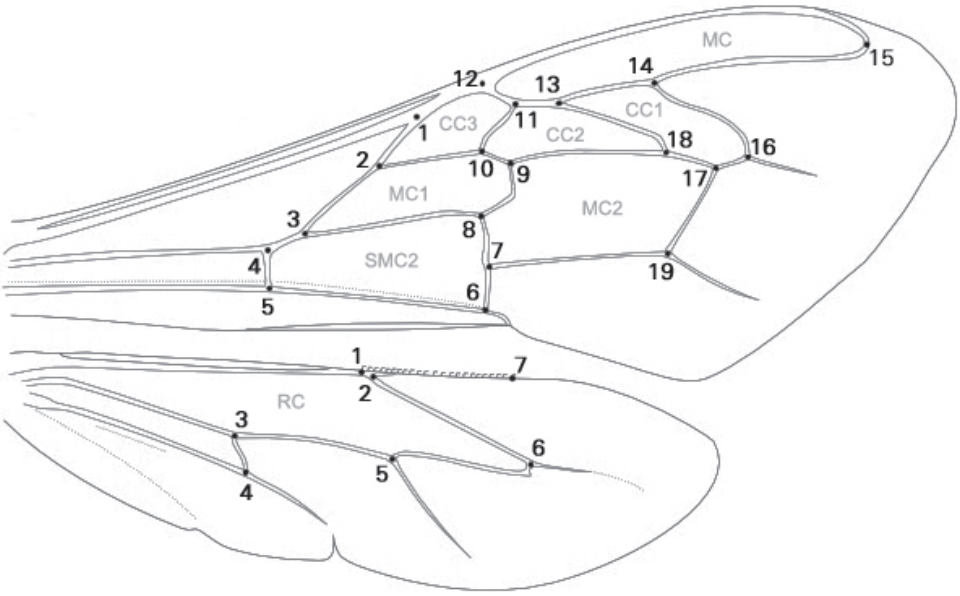

Figure 1. Location of the landmarks digitized on a right fore and hind wing of *Apis mellifera* workers (drawn to the same scale). MR: marginal cell, CC: cubital cell, MC: median cell, SMC: sub-median cell, and RC: radial cell.

the Generalized least squares Procrustes Analysis (GPA) algorithm (Goodall 1995). The FW and HW sizes were estimated by the log-transformed centroid size (CS) (Bookstein 1991). Differences between the three honeybee subspecies were analyzed by canonical variate analyses (CVA). Misclassification rates for both wing shapes and forms (shape + CS) were estimated using a leave-one-out cross validation procedure (6 contrasts were used from shape and form data and their mixing between FW and HW). Wing size differences among honeybee subspecies and colonies were analyzed through box plots and one- and two-way ANOVAs of CS. Pairwise comparisons used *t*-tests with Holm's p-value adjustment (Rice 1989). Statistical analyses were performed using R, version 3.0.3 (R Core Team 2014; Ihaka and Gentleman 1996) for Windows (http://cran.r-project.org/).

Results

Centroid size differences between the three *A. mellifera* subspecies

The analysis of size is presented for the logarithm of centroid size (CS). For the FW, a two-way ANOVA revealed highly significant differences between the honeybees for both the subspecies ($p < 0.001$) and the colony ($p < 0.001$) levels. In the case of the HW, the differences between the same honeybee samples were also highly significant ($p < 0.001$) for subspecies and colony levels. Furthermore, the subspecies × colony interaction term of

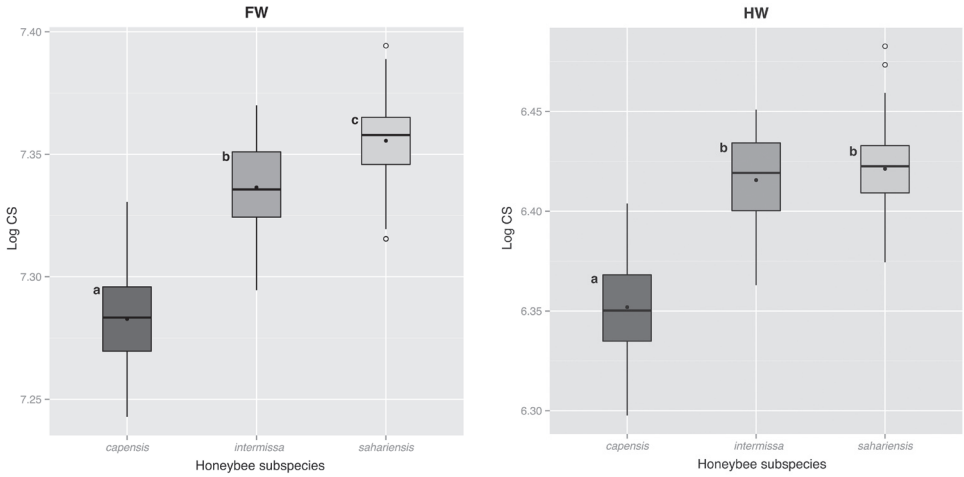

Figure 2. Box plots of the logarithm of wing centroid size for each subspecies of *Apis mellifera*.

the two-way ANOVA was highly significant ($p < 0.001$) for both the FW and HW. Pairwise comparisons using *t*-tests with Holm's p-value adjustment showed that CS_{FW} differed significantly between *intermissa-capensis* ($p < 0.001$), *sahariensis-capensis* ($p < 0.001$) and *intermissa-sahariensis* ($p < 0.001$). Pairwise comparisons were also conducted for CS_{HW} and the subspecies were found to be statistically different only between *intermissa-capensis* ($p < 0.001$) and *sahariensis-capensis* ($p < 0.001$), but no significant difference was established between the Algerian subspecies *intermissa-sahariensis* ($p > 0.05$) (Fig. 2).

Wing shape and form differences

For both FW and HW, the MANOVA results of the shape data were highly significant ($p < 0.001$) between subspecies and also between colonies. The interaction term between the two factors (levels) subspecies × colony was also highly significant ($p < 0.001$) for both $Shape_{FW}$ and $Shape_{HW,}$ which revealed that more complex patterns existed within each honeybee subspecies.

Concerning $Shape_{FW}$ variability, a scatterplot of the first two canonical variates (CV) (Fig. 3A) indicated a good discrimination of subspecies. *Apis m. intermissa*, and *A. m. capensis* were entirely separated by the first CV (explaining 57.95% of the variance), while *A. m. sahariensis* was largely separated along the second CV (explaining 42.05%). In contrast, for $Shape_{HW}$ the three subspecies were largely overlapping along the first and the second CV (explaining 61.56% and 38.44%, respectively; Fig. 3B).

FW and HW shape deformations along the first two CVs are visualized in Figures 4A, B, C and D. The first CV (Fig. 4A) mainly described the extreme shape differences observed between *A. m. intermissa* and the two others subspecies, notably *A. m. capensis*. Quite noticeably, the FW shape deformations along this CV involved almost the whole set of wing cells. For example, in *A. m. intermissa* (Black line in Fig. 4A)

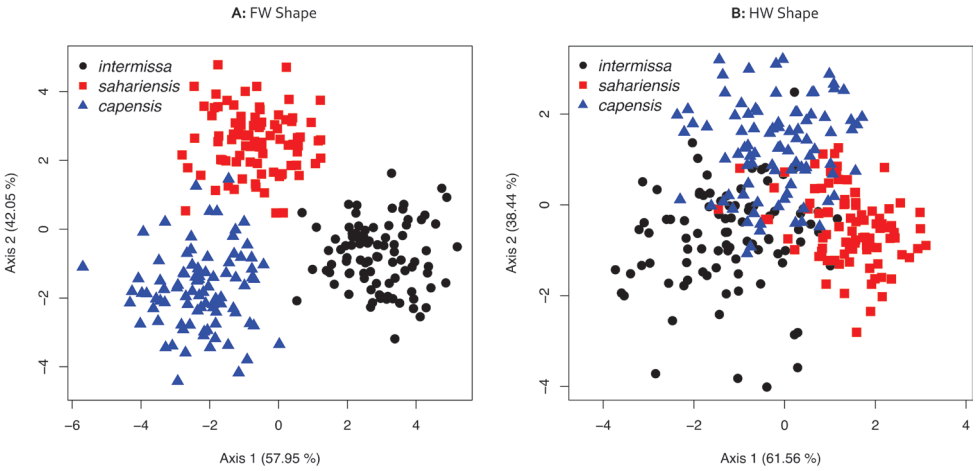

Figure 3. Shape variability among *Apis mellifera intermissa, A. m. sahariensis* and *A. m. capensis*: first two canonical variates. **A** fore wing shape **B** hind wing shape.

the marginal cell appeared longer and narrower than in *A. m. capensis* (Grey line in Fig. 4A). The first cubital cell also appeared narrower in *A. m. intermissa* than in *A. m. capensis*. By comparison, along the first CV the *A. m. sahariensis* FW shape patterns are more similar to those recorded in *A. m. capensis*. Shape changes associated with the second CV (Fig. 4B) correspond to differences between *A. m. sahariensis* (Black line in Fig. 4B) and the two others honeybee subspecies (Grey line in Fig. 4B). In addition, also on the second CV, the FW width of *A. m. intermissa* and *A. m. capensis* appear very similar and less wide than in *A. m. sahariensis*. Figure (4C) demonstrates the HW shape differences and the associated deformations of slightly overlapping clusters. On the whole, HW shape deformations along the first CV (Fig. 4C) was affected by the shifting of all seven LMs with contraction of both the radial cell and the radial vein (Distance LM1-LM7) in *A. m. intermissa* (Grey line in Fig. 4C). In comparison with *A. m. intermissa*, *A. m. sahariensis* is characterized by a shorter median vein (Black line in Fig. 4C) and a longer radial vein. Moreover, the HW shape of *A. m. capensis* has an intermediate LM configuration. In general, the contraction of both distances LM1-LM2 and LM2-LM7 could be interpreted as a variation in the number of hamuli among the three honeybee subspecies. Finally, the deformations along the second CV (Fig. 4D) highlight the major HW shape differences and LM shifts between the two Algerian subspecies (Grey line in Fig. 4D) and *A. m. capensis* (Black line in Fig. 4D).

Moreover, Table 2 shows the classification rates in the cross-validation tests on wing shapes and forms (mixing the logarithm of CS with shape parameters) among the *A. m. intermissa*, *A. m. sahariensis* and *A. m. capensis*. The cross-validated classifications calculated on $Shape_{FW}$ and $Shape_{HW}$ parameters assigned correctly 96.66% and 77.40% of the bees respectively; while cross-validated classifications on form (Shape + CS) reached 99.63% for FW and 90.00% for HW. Two other combination types between the FW and HW were used to verify that these combinations could enable even

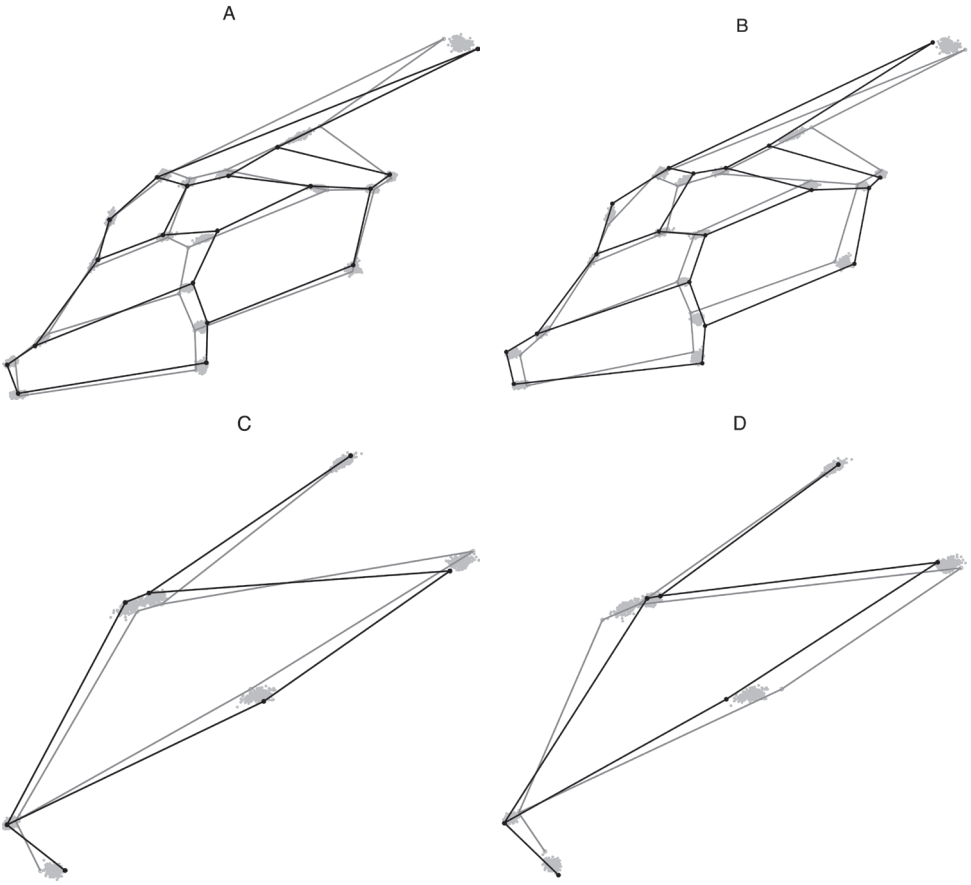

Figure 4. Extreme shape differences between *Apis mellifera intermissa*, *A. m. sahariensis* and *A. m. capensis* along the first two canonical variates (Fig. 3A, B). **A** and **B** fore wing shape differences along the first and second canonical variate, respectively. **C** and **D** hind wing shape differences along the first and second canonical variate, respectively (scale factor ×3 and ×2 respectively). Grey lines depict the shape associated with the negative values and black lines the shape associated with the positive values of the respective canonical variate.

Table 2. Reclassifications results at the subspecies level: *A. m. intermissa*, *A. m. sahariensis*, and *A. m. capensis* (always n = 90).

Type of wing	Variables	Reclassification rate
FW	$Shape_{FW}$	96.66%
HW	$Shape_{HW}$	77.40%
FW	$Shape_{FW} + CS_{FW}$	99.63%
HW	$Shape_{HW} + CS_{HW}$	90.00%
FW + HW	$Shape_{FW} + Shape_{HW}$	97.41%
FW + HW	$Shape_{FW} + CS_{FW} + Shape_{HW} + CS_{HW}$	99.63%

clearer discrimination. First, a high rate of correct classification 99.63% was obtained by using the FW and HW form combination. Second, we observed another high rate of discrimination of 97.41% by using a combination of FW and HW shape.

Discussion

Morphometric methods have been advantageously applied to evaluate biodiversity and for taxonomic purposes (Francoy et al. 2011). In the present study, the exploratory analyses on FW and HW shape of African honeybees yielded three well-defined clusters with high reclassification percentages (96.66% for FW shape and 99.63% for a combination of FW and HW forms). The results indicated that geometric morphometrics using landmarks efficiently distinguished *A. m. intermissa*, *A. m. sahariensis* and *A. m. capensis*. This result is supported by several other publications on *A. mellifera* (Baylac et al. 2008, Tofilski 2008, Barour et al. 2011, Francoy et al. 2011, Miguel et al. 2011). Kandemir et al. (2011) also reported that a landmark analysis of wing shape could be used as a reliable tool to discriminate among honeybee subspecies. Furthermore, Oleksa and Tofilski (2015) reported that in some studies, morphometrics proved to be even more effective in the identification of subspecies than molecular markers, and that the morphological characters were also more suitable for distinguishing ecotypes within *A. mellifera* subspecies. In contrast, Dolati et al. (2013) reported that for *A. m. meda* colonies of many Iranian populations only 68.2% were correctly classified by using the FW shape and 43% by using the HW shape.

Our analysis of the HW venation also showed an important shift in the position of the 1st, 2nd and 7th landmark. This variability could be explained by the distribution of the number of hamuli within *A. mellifera*. Indeed, the number of hamuli can be promising for distinguishing subspecies of *A. mellifera*, as the number of hamuli and their extent on the edge of the HW of honeybees have high heritability values and are readily modified by genetic selection (Hepburn and Radloff 2004).

In conclusion, the results presented here showed that (i) *A. m. intermissa*, *A. m. sahariensis* and *A. m. capensis* populations could be distinguished on the basis of the shape of worker wing venation. There was only a slight increase in the classification rate with form parameters, indicating that the differences involved mostly shape, whereas size was rather less important; (ii) FW venation was more powerful for discrimination than HW venation.

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RESEARCH ARTICLE

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Infestation of the woodwasp *Tremex apicalis* Matsumura (Hymenoptera, Siricidae) on the large-leaf dogwood *Swida macrophylla* (Wall.) with biological notes on its parasitoid wasps

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Abstract

The woodwasp *Tremex apicalis* (Hymenoptera: Siricidae) infesting a decayed stand of *Swida macrophylla* (Cornales: Cornaceae) was found in Honshu, Japan. *S. macrophylla* was newly recorded as a host tree of the woodwasps. We observed oviposition behavior of *T. apicalis* on the tree trunk on May, 2015. In addition, prepupae and pupae of *T. apicalis* were observed in the wood on April, 2016. However, no larvae of *T. apicalis* were found at that time. This suggests that *T. apicalis* requires one year from egg to pupation. Parasitoid wasps, *Ibalia japonica* (Hymenoptera: Ibaliidae) and *Megarhyssa* spp. (Hymenoptera: Ichneumonidae), were also observed on the trunk (oviposition behavior of adult females) and in the wood (pupae and newly emerged adults). Because *Ibalia* and *Megarhyssa* are known as larval parasitoids of woodwasps and there were no other insect species in the wood, we conclude that these wasps are parasitoids of *T. apicalis* larvae. These parasitoids appear to be major natural enemies of *T. apicalis* larvae in the study site.

Keywords

Cerrena unicolor, horntail, *Ibalia japonica*, Ibaliidae, Ichneumonidae, *Megarhyssa*, oviposition behavior, wood borer, natural enemy

Introduction

Woodwasps (= horntails) (Hymenoptera, Siricidae) are common forest pests with some species known as serious pests of trees. Some introduced woodwasps cause serious damage to forests, regardless of their extent of damage in the native habitat (Morgen 1968). All woodwasps belonging to the subfamily Tremecinae infest broad-leave trees (Okutani 1967) and female wasps deposit their eggs into the wood with their ovipositors. At least females of some species of *Tremex* (Hymenoptera: Siricidae: Tremecinae) carry symbiotic fungi in their mycangia and transfer it to trees during oviposition (Stillwell 1964, Tabata and Abe 1995, Pažoutová and Šrůtka 2007). Hatched larvae then consume the wood with the fungus. This woodwasp-fungus association damages the tree, and in some cases kills the tree (Morgan 1968).

Tremex apicalis Matsumura is distributed in Japan (Okutani 1967), China (Maa 1949) and Korea (Lee et al. 1998). This species infests at least five species of four families of broadleaf-trees (Kono and Sugihara 1939, Maa 1949, Okutani 1967, The Japanese Society of Applied Entomology and Zoology 2006), including the ornamental plant Somei-yoshino *Prunus yedoensis* and maple trees *Acer* spp. in Japan (Okutani 1967). These trees are important garden trees in Japan and have also been introduced into many countries. Therefore, these woodwasps are potential pests of forests and gardens in not only Japan but also in temperate regions worldwide. For protection including biocontrol, understanding the biology of these pests and their natural enemies is important. In biocontrol of woodwasps, parasitoid wasps are one important natural enemy (Morgen 1968, Coyle and Gandhi 2012, Schiff et al. 2012, Tabata et al. 2015). In fact, Ichneumonidae (especially Rhyssinae) and Ibaliidae contribute to the biocontrol of woodwasps (Coyle and Gandhi 2012). However, the host-parasitoid relationships between *T. apicalis* and its parasitoids are poorly known and the biology of *T. apicalis* is largely unknown.

In May 2015, we found a large-leaf dogwood, *Swida macrophylla* (Wall.) (Cornales: Cornaceae) infested by *T. apicalis* in Ibaraki, Honshu, Japan. We then observed the oviposition behavior of *T. apicalis* and its parasitoid wasps. Fortunately, we were able to obtain permission to split the wood, and observe the wasp biology inside the wood the next spring. The results of these observations provide new information on the host-parasitoid relationships and biology of *T. apicalis* and its parasitoids. This information may contribute to the protection of Japanese garden plants. In this paper, our observations on these species are described.

Materials and methods

Study site and host tree

A field survey of *T. apicalis* was carried out at the Botanical Garden in the Agricultural and Forestry Research Center (36°07'10"N; 140°05'50"E (DMS), ca. 25 m a.s.l.),

University of Tsukuba, Ibaraki Prefecture, Honshu, Japan. In the study site, we found one *S. macrophylla* tree with numerous emergence holes of *T. apicalis* in the trunk on May 6, 2015 (Fig. 1). The *S. macrophylla* tree was approximately 9 m in height and 40 cm in diameter at breast height.

Field observations and wood splitting

We observed the target *S. macrophylla* tree from 11:30 to 12:30 on May 6, 2015. Species of hymenopteran insects that landed on the *S. macrophylla* tree and their behavior were recorded for 60 min. From the observation day until March 1, 2016, we observed the infested tree approximately once a week whether or not adult woodwasps visited.

The infested tree was felled with a chainsaw on March 8, 2016 and the wood kept outside. The infested part, total 14.725 kg wet wt with woodwasp emergence holes, was split using a 7.2 ton electric wood splitting machine (E'Z - Splitter IG-700A, Husqvarna Zenoah Co. Ltd) and a hatchet on April 10, 2016. Insect species and their stages were tallied.

Voucher specimens are deposited in the Laboratory of Applied Entomology and Zoology, University of Tsukuba (Tsukuba City, Japan) and Kanagawa Prefectural Museum of Natural History (Odawara City, Japan).

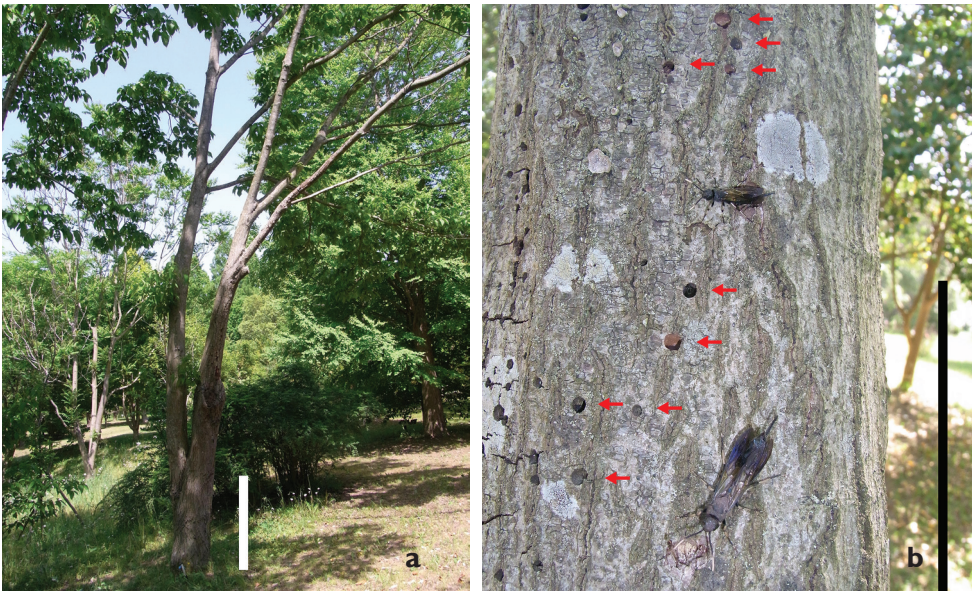

Figure 1. Infested *Swida macrophylla* at Botanical Garden, University of Tsukuba, Honshu, Japan. **a** a decayed *S. macrophylla* infested with *T. apicalis* **b** *T. apicalis* adults and their emergence holes (red arrows) on the tree trunk. Scale lines = (**a**) 100 cm; (**b**) 100 mm.

Results

In the field survey, we observed a total of 10 *T. apicalis* (3 males, 7 females) and 24 parasitoid wasps, i.e. *Ibalia japonica* Matsumura (Hymenoptera: Ibaliidae), *Megarhyssa jezoensis* (Matsumura) and *M.* sp.1 (Hymenoptera: Ichneumonidae), that landed on the tree (Fig. 2, Table 1). In addition, six dead bodies of female *T. apicalis* were observed on the tree trunk. Two of them were whole bodies and the others were only ovipositors with abdomens attached to the trunk (Fig. 2b). Some females of the hymenopteran species were observed inserting their long ovipositors into the trunk (Fig. 2). Of the three males of *T. apicalis*, two males were mounting the female on the trunk. One female was observed inserting her ovipositor into the trunk with a male on her back. No *T. apicalis* adults were observed on the trunk between June 2015 until March 2016.

From the *S. macrophylla* wood, 35 prepupal or pupal *T. apicalis* and 16 pupal or adult parasitoids were obtained (Table 2, Figs 3, 4). Basidiocarps of the fungus *Cerrena unicolor* were observed on the bark of the infested wood and the inside of the wood was partly discolored (Fig. 3a, b). All woodwasp prepupae and pupae collected, and their larval tunnels were found in the discolored part of the wood (Fig. 3c). All *T. apicalis* constructed longitudinal pupal chambers in the wood (Fig. 3c). We also found pupae and adults but no larvae of *I. japonica* and *Megarhyssa* spp. in the wood (Table 2). All collected prepupae and pupae of *T. apicalis* were individually stored in plastic bags in the laboratory. Of nine *T. apicalis* prepupae, only one pupated within one week after collection, while all others died. The pupated *T. apicalis* also died after five days. Four pupae of the 26 collected pupae emerged between 2-4 weeks after collection, while all others died.

Table 1. Number of hymenopteran insects that landed on decayed *S. macrophylla*.

	male	female	Total
Tremex apicalis	3	7	10
Ibalia japonica	9	5	14
Megarhyssa spp.	2	8	10
M. jezoensis female	-	5	5
M. sp.1 female	-	3	3
M. spp. male[a]	2	-	2

[a] males not identified to species.

Table 2. Number of hymenopteran insects found in the *S. macrophylla* wood.

	prepupa	pupa	adult	total	propotion
Tremex apicalis	9	26[a]	0	35	0.69
Ibalia japonica	0	3	0	3	0.06
Megarhyssa spp.	0	2	11	13	0.25
M. jezoensis female	0	0	4	4	
M. sp. 1 female	0	1	4	5	
M. spp. male [b]	0	1	3	4	

[a] 14 males, 11 females and 1 unknown.

[b] males not identified to species.

Figure 2. Hymenopteran insects landing on and inserting their ovipositor into the *S. macrophylla* tree trunk. **a** *T. apicalis* female **b** *T. apicalis* ovipositor with abdomen inserted into the wood **c** *I. japonica* female **d** *M. jezoensis*. female. Scale lines = 10 mm.

Figure 3. *S. macrophylla* wood infested with *T. apicalis*. **a** Wood discoloration in the cross section with *T. apicalis* infestation **b** Basidiocarp of *Cerrena unicolor* in the wood infested with *T. apicalis* **c** Longitudinal section through stem of the wood infested with *T. apicalis* and woodwasp larvae, pupae and larval tunnels. Scale lines = (**a, c**) 100 mm; (**b**)10 mm.

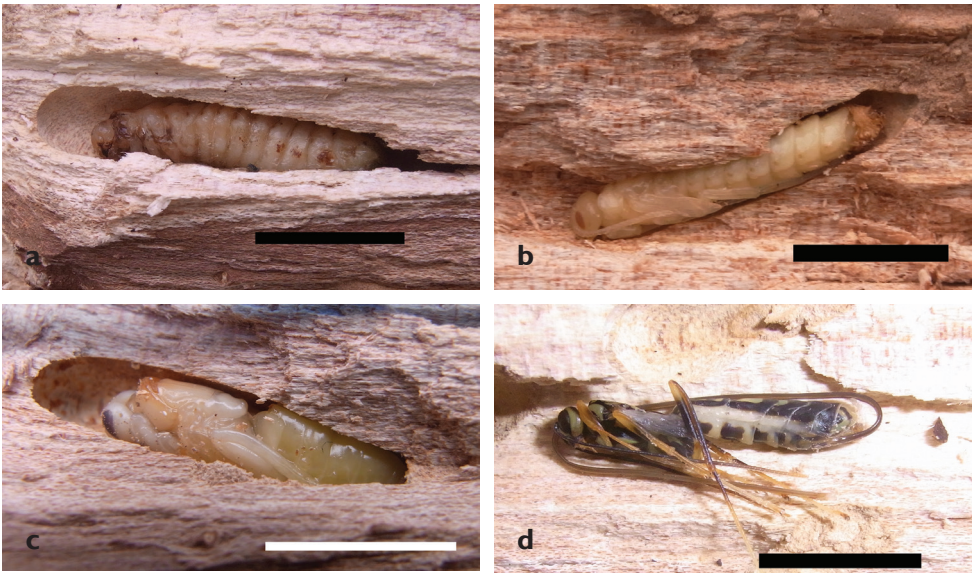

Figure 4. Hymenopteran insects found in *S. macrophylla*. **a** *T. apicalis* prepupa **b** pupa of *T. apicalis* female **c** *I. japonica* pupa **d** pupa of *M.* sp.1 female. Scale lines = 10 mm.

Discussion

In this study, we observed oviposition behavior of *T. apicalis* on a *S. macrophylla* tree, and the presence of prepupae and pupae in the tree. The order Cornales, which includes *S. macrophylla*, is a newly recorded host of *T. apicalis*.

In a field survey, many ovipositors of *T. apicalis* were observed on the trunk of a *S. macrophylla* tree. Yamazaki and Matsumoto (2009) also observed ovipositors with abdomens on host wood in a related species *T. longicollis* Konow. They suggested that this phenomenon was caused by predation during oviposition. However, we observed two females of *T. apicalis* that died without external damage. Not only predation but also other physiological factors may cause the death of *T. apicalis* during oviposition. In other woodwasp species, female parasitoids of *Ibalia* spp. oviposit their eggs on woodwasp larva by using the oviposition holes created by the female woodwasps (Spradbery 1970, 1974). The dead body of female *T. apicalis* attached to the wood may indicate the female is defending its larvae from ibaliid parasitoids.

No *T. apicalis* adults were observed on the tree trunk from June 2015 until the following spring. Hence *T. apicalis* is univoltine, active mainly in the spring. After wood splitting, we observed prepupae and pupae of *T. apicalis* but no larvae in the wood. This suggests that *T. apicalis* takes almost one year to develop from egg to pupal stages. Since most of the collected prepupae died after wood splitting, we were unable to observe whether they would emerge within this year.

All *T. apicalis* prepupae and pupae were found in the discolored part of the wood and the wood had basidiocarps of *Cerrena unicolor* on the bark (Fig. 3). Adult females of Siricidae carry the symbiotic fungus in their mycangia, and inject it during oviposition so hatched larvae can feed on wood infested with fungi (Tabata 2003). Some *Tremex* woodwasps, i.e. *T. longicollis* and *T. fuscicornis*, are associated with the fungus *C. unicolor* (Tabata and Abe 1995, Pažoutová and Šrůtka 2007). *T. apicalis* probably uses *C. unicolor* as a symbiotic fungus. Identification of the fungus in the woodwasp mycangia should be carried out in future studies.

Hymenopteran parasitoids, *I. japonica*, *M. jezoensis* and *Megarhyssa* sp. 1, were also observed in/on *T. apicalis* infested *S. macrophylla*. We were unable to observe the larvae that parasitized *T. apicalis* larvae. However, all known ibaliids are primary solitary, koinobiont endoparasitoids of woodwasps (Liu and Nordlander 1994, Choi et al. 2013), especially species of the subgenus *Tremibalia* that includes *I. japonica*, and parasitize Tremicinae wood wasps (Liu and Nordlander 1994). Similarly, *Megarhyssa* are idiobiont ectoparasitoids of woodwasps and other hosts in the same habitat (Quicke 2015). Since we observed no other woodwasp species and no other insects in the wood, we conclude that these wasps parasitize *T. apicalis* larvae. To our knowledge, *I. japonica* is the second ibaliid parasitoid species of *T. apicalis*, the first being *I. takachihoi* (Kim 1971). *T. apicalis* is the first host species of *I. japonica*. Some species of *Megarhyssa* are known as parasitoids of *Tremex* (Heatwole and Davis 1965, Kim 1971, Yamazaki and Matsumoto 2009, Pook et al. 2016). *M. jezoensis* has been reported as parasitoids of *T. apicalis* in Korea (Kim 1971). In our survey, *Megarhyssa* spp. were the dominant parasitoid wasp in the infested wood (Table 2).

Because *Ibalia* and *Megarhyssa* are known as solitary parasitoids, their proportion in the wood (Table 2) can be interpreted as the parasitism rate. According to the data in Table 2, the parasitism rate of *T. apicalis* larvae by all larval parasitoids species is approximately 31.4 %. These parasitoids appear to be the major natural enemies of *T. apicalis* larvae and may regulate woodwasp populations in the study site.

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RESEARCH ARTICLE

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A preliminary survey of flower visiting by aculeate wasps and bees in the Dubai Desert Conservation Reserve, UAE

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Abstract

The present contribution is a first brief attempt to give an overview of flower visiting by aculeate wasps and bees in the Dubai Desert Conservation Reserve (DDCR), and as far as has been established the first of its kind for the United Arab Emirates. Seventeen sites within the reserve were well sampled and, in order to see the reserve in relation to its position in the peninsula, two one day transects were undertaken, one of brief sampling at six sites east from the reserve to the coast at Khor Kalba and the other of brief sampling at five sites west from the reserve to the coast in the marine reserve of the Emirates Marine Environmental Group (EMEC). Flower visitors were observed and sampled on 21 species of plants within the DDCR and on two additional species east of the DDCR and two west of the DDCR. Fifty-one species of aculeate wasps and 27 species of bees were recorded. Of the wasps, 34 species were from the DDCR and the additional 15 from transects east and west of the Reserve. Of the bees, 23 species were from the DDCR and the additional two from transects east and west of the Reserve. Flower sampling yielded flower visiting records for 39 species of aculeate wasps and 23 species of bees. Although this preliminary survey of flower visiting by wasps and bees in the DDCR was conducted over a limited period of time, during a dry spring, following seven dry years, it has provided sufficient data to draw some general conclusions: most of the plants attract visits from a complex of both wasps and bees; the flowers of some plants attract a wide range of wasps and bees but there were no flowers that were attractive to all available wasps and bees at any one site; very few species of the wasps and bees encountered were specialists; and the plants on which these specialist wasps and bees were dependent were not themselves dependent on these species for pollination.

Keywords

Aculeate wasps, pollen wasps, bees, distributions, flower visiting, potential pollinators

Introduction

The present contribution is a first brief attempt to give an overview of flower visiting by aculeate wasps and bees in the Dubai Desert Conservation Reserve, and, as far as has been established, the first of its kind for the United Arab Emirates.

In 2015 a preliminary survey of the aculeate wasps and bees of the Dubai Desert Conservation Reserve was undertaken by Sarah Gess assisted by Peter Roosenschoon, Conservation Officer. The focus was on flower visitation. The survey took place between 18 April 2015 and 4 May 2015 towards the end of spring.

The Dubai Desert Conservation Reserve (DDCR) lies approximately midway between the west and east coasts of the United Arab Emirates with sand plains to the west and the Hajar Mountains to the east (Figure 1).

Seventeen sites within the DDCR were well sampled and, in order to see the Reserve in relation to its position in the peninsula, two one day transects were undertaken, one of brief sampling at six sites east from the Reserve to the coast at Khor Kalba and the other of brief sampling at five sites west from the Reserve to the coast in the marine reserve of the Emirates Marine Environmental Group (EMEC). (see map Figure 1 and Table 1)

History of the DDCR (extracted from www.ddcr.org)

In 1999 the Al Maha Resort and Spa was established with an area of 27 square kilometres as a conservation reserve for the protection of the desert fauna and flora. Seventy Arabian oryx were introduced and indigenous trees and shrubs were planted. In 2002 the resort managers began an environmental audit of the surrounding areas. Researchers were tasked with exploring the then current and potential threats to endangered species and disappearing desert habitats. The Al Maha management then submitted proposals to the government for the formation of a formal national park.

The proposal was accepted and the Dubai Desert Conservation Board was established. In 2003 the DDCR with an area of 225 square kilometres was proclaimed. The Reserve constitutes 4.7% of Dubai's total land area. The first wildlife releases into the newly created reserve took place in 2004.

The Al Maha Resort lies within the boundaries of the Reserve but is being managed independently.

The DDCR is a member of IUCN and UNEP. The vision for it is "to create a permanently protected area which ensures the future of the region's desert habitats and bio-diversity managed according to sound scientific ecological principles, aimed at protecting natural resources (water being the most obvious one, but extending to many others as well), and maintaining original desert landscapes."

The area enclosed to form the DDCR is principally made up of low to medium sized sand dunes interspersed with sand flats and gravel plains. At the extreme north of the reserve there is a rocky outcrop, Quarn Nazwa. The altitude of the Reserve ranges

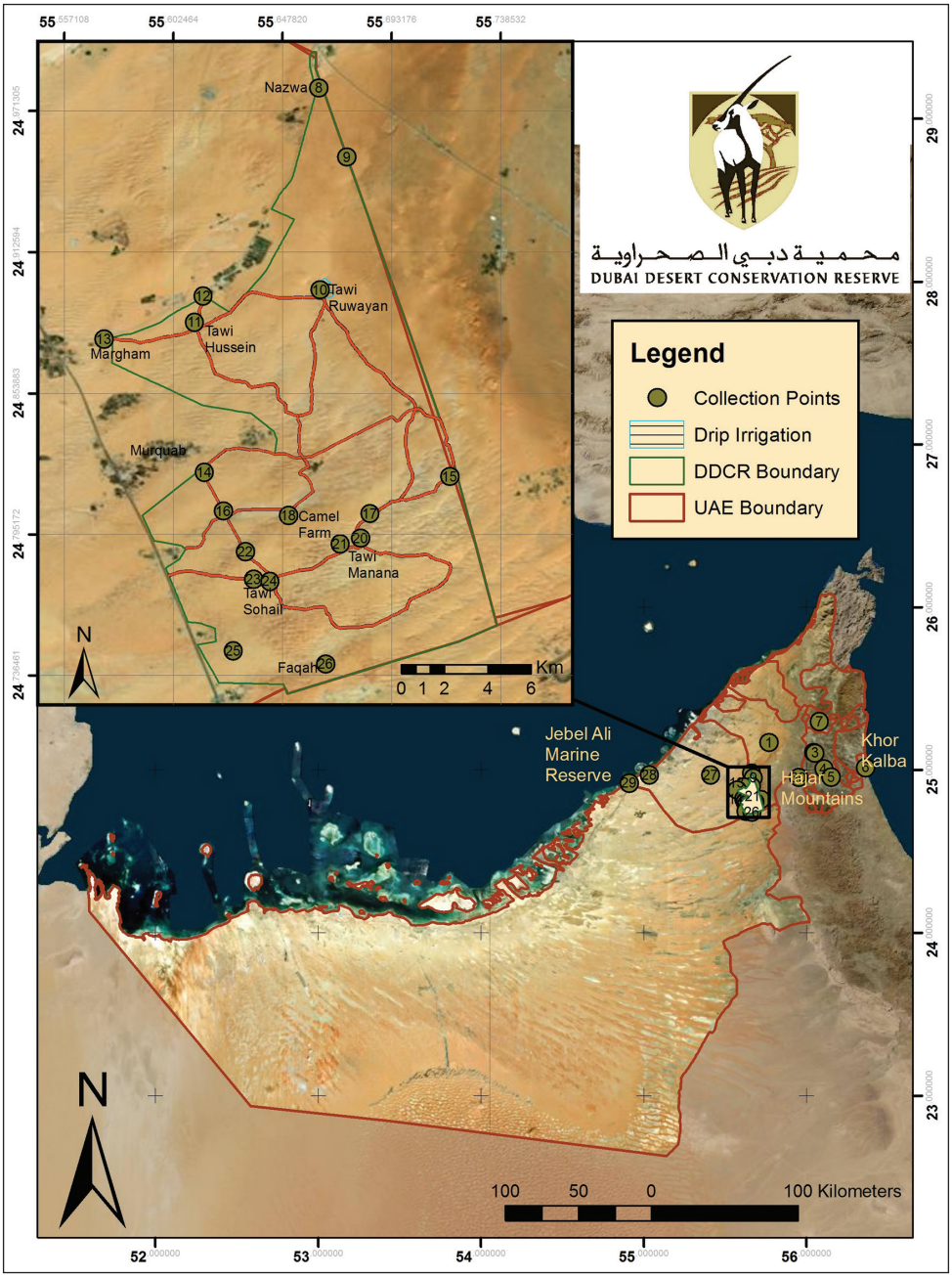


Figure 1. Map of the UAE with inset enlargement of the DDCR, giving the positions of the collection sites.

from 260m above sea level in the south to 180m in the north (Khafga 2009). Before enclosure the entire area had been heavily grazed by camels and domestic livestock. In 2004 the number of camels counted in the DDCR was 1,209, that is 5.37 camels per

Table 1. Study sites.

Site no.	Latitude	Longitude	Area	Name of site	Nature of site
1	25.1678	55.7696	east of DDCR		sandy roadside
2	25.1066	56.0441	east of DDCR	Shawka	area fringing dam
3	25.1024	56.0534	east of DDCR		Wadi
4	25.0065	56.1066	east of DDCR		Wadi
5	24.9563	56.1512	east of DDCR	Munay	outskirts of village
6	5.0152	56.3608	east of DDCR	Ramsa, Khor Kalba	sandy bank of lagoon
7	25.25.2967	56.078	east of DDCR		Wadi
8	24.9808	55.6628	DDCR	Quarn Nazwa	rocky outcrop
9	24.9521	55.6746	DDCR		sand dunes
10	24.8968	55.6635	DDCR	Tawi Ruwayyan	drip irrigation area
11	24.8834	55.6113	DDCR	Date Farm	palm grove
12	24.8943	55.6147	DDCR	Margham Gate	sand dunes
13	24.8763	55.5735	DDCR	Margham Road	sandy roadside
14	24.8210	55.6153	DDCR	Dune enclosure	sand dunes
15	24.8192	55.7174	DDCR		gravel plain
16	24.8048	55.6233	DDCR	Al Maha Gate	Sand
17	24.8037	55.6841	DDCR		irrigated trees in wire cages
18	24.8030	55.6503	DDCR	Camel Farm	palm grove
19	24.7935	55.6802	DDCR	Tawi Manana	drip irrigation area
20	24.7935	55.6802	DDCR	Tawi Manana	small lake
21	24.7912	55.6718	DDCR		sand dunes
22	24.7879	55.6358	DDCR		sand dunes
23	24.7764	55.6358	DDCR		sand dunes
24	24.7757	55.6427	DDCR	Lucerne Farm	sand dunes
25	24.7467	55.6275	DDCR		sand dunes
26	24.7412	55.6657	DDCR	Faqah	watering point
27	24.9696	55.4118	west of DDCR		sandy roadside
28	24.9684	55.0355	west of DDCR	Ghantoot	sandy plain
29	24.9110	55.9513	west of DDCR	EMEC	coastal sand inland from beach
30	24.9532	55.9512	west of DDCR	EMEC	coastal sand inland from beach

square kilometre (Alqamy 2004). By 2007 the number of camels had been reduced to around 600 and by December 2008 all domestic livestock had been removed (Khafga 2009). Arabian oryx, mountain gazelle and sand gazelle had been introduced.

At Tawi Manana a small lake, stocking fish, was completed in 2011.

Three areas, two of sand dunes and the third a gravel plain, have been fenced off to exclude grazing and browsing by oryx and gazelle. One fenced dune area surrounds a lucerne farm established in September 2012 to give supplementary feed for the oryx. The other, solely an enclosed dune area, was fenced in December 2012.

Date palm, *Phoenix dactilifera* L. (Arecaceae) had been cultivated and these remain as palm groves at two main sites, the Camel Farm at which the camels are confined within cages, and the Date Farm, and as the outer boundary of Tawi Manana irrigation plot.

Trees, protected by wire cages and irrigated, were planted in selected areas. Most, but not all, are indigenous to the area. In 2012, 9,830 trees were planted mainly around the lake and generators as well as close to Tawi Manana. Then in 2013, 15,700 trees were planted at the solar irrigation sites.

In order to encourage the regrowth of plants two drip irrigation plots, Tawi Ruwayyan in the north and Tawi Manana in the south, were established in 2013. These plots over which drip irrigation pipes have been laid are supplied with water pumped up from subterranean reservoirs. The pumps are run off power generated by solar panels.

Feeding points for the oryx had been used since they were introduced into the Al Maha Resort's reserve in 1999 and are also used in the DDCR. In order to minimize the impact of these gathering points they are moved every 4-6 weeks.

Watering points for the large mammals were created within the Al Maha reserve in 1999 and at various points within the DDCR in 2001.

Climate

The climate of this area is of a bi-seasonal Mediterranean type, characterized by low rainfall and high summer temperatures. Most precipitation is expected in the winter and spring between December and April. Mist and fog can occur throughout the year but they are more likely in the winter months and at the end of summer.

Very little was known about weather conditions in the UAE until the 1950s when oil prospecting began and it was not until the opening of the UAE international airports in the 1970s that full 24-hour weather records became available (Perry 2008). Rain is always localized, sporadic and shows considerable variation from year to year. The average annual rainfall for Sarjah airport for the 12 years 1992-2004 was 50mm (Alqamy 2004).

Winter, December to March, is the most unsettled season when active weather systems can bring rain and strong winds. Weather systems in the region are associated with the Sub-Tropical Jet Stream, which lies over the Middle East at this time of the year. The frequency of these westerly disturbances is governed by the weather pattern prevailing over Europe and the Mediterranean. They account for most of the annual rainfall, but both the amount and frequency of rain varies greatly from year to year.

Towards spring, April to May, the frequency of westerly disturbances decreases as the Sub-Tropical Jet Stream weakens and begins to move northwards. Rain and thunderstorms can still occur but are more likely over the northern Gulf. Maximum temperatures increase rapidly.

Summer, June to September, is characterized by hot and dusty conditions, resulting from intense solar heating establishing an area of low pressure over India and Pakistan gradually extending west into Iran and over the Gulf. During these months there may be some rain over the mountains and surrounding plains. Decreasing minimum temperatures towards the end of summer lead to an increase in the incidence of early morning fog.

Autumn, October to November, is characterized by the most settled weather conditions.

Vegetation

Until recently the vegetation of the UAE was poorly known. The work of A.R Western (Western 1989) served as a major stimulus for floristic research in the UAE (Perry 2008). *The Comprehensive Guide to the Wildflowers of the United Arab Emirates* (Jongbloed 2003) incorporates the work of several active and enthusiastic botanists, including that of Benno Böer.

Two vegetation surveys have been conducted in the Al Maha reserve and the DDCR since the proclamation of the DDCR (Husam El Algamy 2004 and Tamer Khafga 2009). The total number of species recorded from the gravel plains within the DDCR in 2004 was 15 compared with 27 in 2009. Of the additional species 11 were perennial species and four were annual. This was considered to represent positive rehabilitation of the gravel plains during the five years between the two surveys. Similarly the total number of species recorded for the sand dunes in 2004 was 16 compared with 34 in 2009. What should also be taken into account is that the second survey was undertaken in 2008 a year of unusually good rains.

Due to the generally low rainfall, when good rains do occur they have, as in all hot arid areas, a more pronounced influence on biological activity than in more temperate regions of the world (Perry 2008). Rain is most effective for the vegetation when it occurs during the cooler part of the year due to the fact that less water is lost to evaporation and it is at this season that plant growth takes place.

Methods

As flower visitors were being targeted most of the sampling was undertaken using hand nets. At all sites plants in flower were sampled for flower visitors. In addition wasps and bees perching on plants, resting on the ground, cruising, nesting and visiting water were collected.

One malaise trap was set up at Tawi Ruwayyan. Bundles of six trap nests with two of the trap nests each of one of three diameter borings (Krombein design) were positioned in trees at Tawi Ruwayyan and on palm trunks at the Camel Farm, where naturally occurring borings were observed.

Plant and insect names listed with the author's name in the appendices are given without the author's name in the text and tables. Plant names not listed in the appendices are given with the author's name where they occur in the text.

Study sites within the DDCR

Site 8. Quarn Nazwa, southwestern foot (Figures 2 and 3)

Figures 2–7. Study sites in DDCR: **2** Site 8 – Quarn Nazwa, watering point **3** Site 8 – Quarn Nazwa, southeast slope **4** Site 10 – Tawi Ruwayyan **5** Site 14 – Dune grazing and browsing exclusion plot **6** Site 15 – Gravel plain without irrigation **7** Site 17. Irrigated planted trees in netting cages.

Quarn Nazwa is a rocky outcrop at the extreme north of the reserve. At its southwest foot is a level area within which is a watering point, a low vertical bank below an access road, and bordering the road to the south sand dunes. Around the watering point and the bases of the dunes facing it were plants in flower, principally *Aerva javanica* (Amaranthaceae), *Centaurea pseudosinaica* (Asteraceae), *Arnebia hispida* (Boraginaceae), *Dipterygium glaucum* (Capparaceae), and *Limeum arabicum* (Molluginaceae). On the other aspects of the outcrop most flowering plants were almost completely dried out.

Site 9. Sand dunes, A single *Calotropis procera* (Apocynaceae, Asclepiadoideae) tree.

Site 10. Tawi Ruwayyan (Figure 4)

The area sampled was the drip irrigation area together with the surrounding non-irrigated area. The drip area is mainly level with a strong growth of low shrubby perennials, principally *Heliotropium kotschyi* (Boraginaceae), *Dipterygium glaucum*, *Fagonia indica* and *Cyperus conglomeratus* Rottb. (Cyperaceae) growing along the irrigation lines. The area attracts grazing and browsing by oryx and gazelle and so there is little evidence of the more palatable plants, particularly annuals.

Within the irrigated area are small groups of fenced planted trees. Beyond the irrigated area the perennial plants are more widely dispersed and less succulent. On the surrounding dunes are scattered larger shrubs, *Leptadenia pyrotechnica* (Apocynaceae: Asclepiadoideae) and *Salvadora persica* (Salvadoraceae), and the small tree *Calotropis procera*. Also present beyond the irrigation plot is a clump of ghaf trees, *Prosopis cineraria* (Fabaceae: Mimosoideae) and tamarix, *Tamarix nilotica* (Tamaricaceae).

Site 11. Date Farm

A shady grove of date palms with outside the grove an area of irrigated planted trees in cages. Within the cages are growing palatable plants beyond the reach of browsers. Of interest was the presence in one of these cages of flowering *Sesuvium verrucosum* (Aizoaceae), not listed for the DDCR in Khafga (2009).

Site 12. Margham Gate

An area of low dunes with shrubs and hollows between dunes with almost entirely browsed off *Tribulus* (Zygophyllaceae)

Site 13. Roadside of Margham Road, just outside the DDCR

Well grown flowering *Tribulus* spp. were present along the sandy roadside.

Site 14. Dune grazing and browsing exclusion plot (Figure 5)

An area of dunes protected from grazing and browsing by oryx and gazelle. Noticeably better vegetated than the surrounding area. Of particular note was the presence of numerous well-grown plants of *Crotalaria aegyptiaca* (Fabaceae: Papilionoideae) in flower.

Site 15. Gravel plain without irrigation (Figure 6)

This gravel plain site adjoined one of the planted tree sites. Scattered across the gravel plain the dominant plant was a small shrubby perennial, *Rhanterium epapposum* (Asteraceae) with at intervals *Acacia tortilis* (Fabaceae: Mimosoideae). The planted trees are young ghaf trees, *Prosopis cineraria*. Within the cages around the trees, encouraged by the irrigation and protected from grazing, are plants of *Arnebia hispidissima* (Boraginaceae).

Site 16. Al Maha Gate

A non-irrigated sandy area with the dominant plant being *Heliotropium kotschyi* (Boraginaceae).

Site 17. Low sand dunes (Figure 7)

Irrigated planted trees in netting cages with *Launaea procumbens* (Asteraceae) growing within the cages.

Site 18. Camel Farm

A small grove of date palms watered by irrigation furrows. The camels are all restrained in cages. The banks of the furrows, cavities in palm tree stumps and insect borings in palm leaf bases offer nesting sites for wasps and bees. Also present outside the Ðdate Palm grove are Ǥghaf trees.

Site 19/20 Tawi Manana lake (Figure 8) and drip irrigation area (Figure 9)

The area sampled for flower visitors was the main level drip irrigation area, which is surrounded on all four sides by a border of palm trees, the outer, less moist, sloping sandy drip area and the surrounding non-irrigated area. The drip area is mainly level with a strong growth of low shrubby perennials, principally *Dipterygium glaucum* with to a lesser degree than at Tawi Ruwayyan *Heliotropium kotschyi* and *Fagonia indica,* growing along the irrigation lines. The area attracts grazing and browsing by oryx and gazelle and so there is little evidence of the more palatable plants, particularly annuals. On the lower slopes of the dunes above the main drip area were a large number of flowering, well-grown, scattered plants of palatable *Limeum arabicum* (Molluginaceae). Also present are a *Calotropis procera* tree and a clump of ghaf trees, *Prosopis cineraria*.

Site 21. Sand dunes, *Calotropis procera* tree

Site 22. Sand dunes, *Calotropis procera* tree

Site 23. Sand dunes, *Calotropis procera* tree

Site 24. Lucerne Farm grazing and browsing exclusion area (Figures 10 and 11)

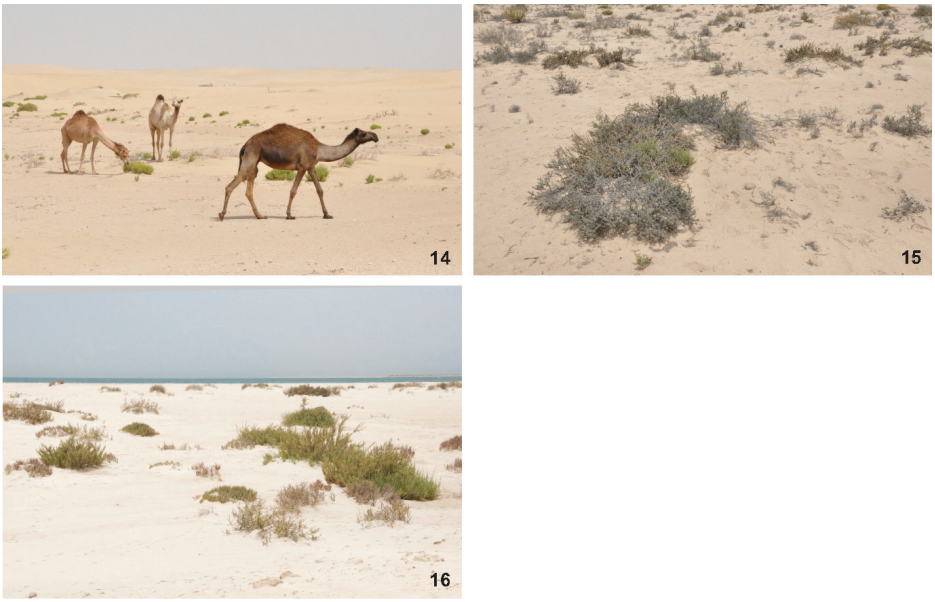
Between the fenced fields of lucerne, which are irrigated, and the perimeter fence is a large area of non-irrigated dunes protected from grazing and browsing by oryx and gazelle. In this area were a few scattered, well grown, flowering *Calotropis procera, Leptadenia pyrotechnica* and *Acacia tortilis* (Fabaceae: Papilionoideae), and numerous scattered flowering *Heliotropium kotschyi*, *Tribulus macropterus* with less abundantly flowering *Moltkiopsis ciliata* (Boraginaceae) and a few scattered flowering

Figures 8–13. Study sites in DDCR: **8** Site 19/20 Tawi Manana Lake **9** Site 19/20 Tawi Manana drip irrigation area **10** Site 24 Lucerne Farm **11** Site 24 Lucerne Farm grazing and browsing exclusion area **12** Site 25 Sand dunes with isolated *Calotropis procera* trees **13** Site 26 Faqah watering point with planted *Prosopis cineraria*.

Polycarpaea repens (Caryophyllaceae) and *Neurada procumbens* (Neuradaceae). Only one plant each of *Indigofera intricata*, *Crotalaria aegyptiaca* and *Citrullus colocynthis* (Cucurbitaceae) were noted.

Site 25. Sand dunes with scattered *Calotropis procera* trees (Figure 12)

Site 26. Faqah watering point (Figure 13)



Figures 14–16. Study sites to the west of DDCR: **14** Crossing from the DDCR to the coast the dunes level out and the dominant plants are scattered plants of *Zygophyllum* species (Zygophyllaceae), not found within the DDCR **15** Site 28. Ghantoot. In addition to *Zygophyllum qatarense* (Zygophyllaceae), well grown plants of *Heliotropium kotschyi* (Boraginaceae) were abundant and in flower **16** Site 30. EMEC, coastal sand inland from beach.

Faqah is in the extreme south of the Reserve, the last area from which camels and domestic stock were removed. The area surrounding the watering point was very dry with no plants in flower. The planted *Prosopis cineraria*, which were in flower, were therefore the only plants sampled for flower visitors.

Sites to the west of DDCR to the coast

Crossing from the DDCR to the coast the dunes level out and the dominant plants are scattered plants of *Zygophyllum* species (Zygophyllaceae), not found within the DDCR (Figure 14), until the coast is neared where the plants become more diverse.

Site 27. Roadside, sandy depression

The plants in the depression were more diverse than in the surrounding area. In addition to flowering *Zygophyllum simplex* and *Zygophyllum qatarense*, some plants of a species of Asteraceae were present.

Site 28. Ghantoot, sandy plain (Figure 15)

In addition to *Zygophyllum qatarense*, well grown plants of *Heliotropium kotschyi* were abundant and in flower.

Site 29. EMEC, coastal sand inland from beach

The dominant plant in flower was *Zygophyllum qatarense*.

Site 30. EMEC, coastal sand inland from beach (Figure 16)

The dominant plant in flower in the dry sandy area was *Zygophyllum qatarense* with its root parasite *Cistanche tubulosa* (Schenk) Wright (Orobanchaceae). *Arthrocnemum macrostachyum* (Moric.) C. Koch (Chenopodiaceae) was also present in the more saline areas associated with channels. In this area of the coast there are in addition salt pans, where *Z. qatarense* is absent and the dominant plant is *Salsola imbricata* Forssk (Chenopodiaceae), and mud flats dominated by mangroves, *Avicennia marina* (Forssk.) Vierh. (Acanthaceae).

Study sites east of the DDCR to the coast

Most of the sites chosen east of the DDCR in the Hajar Mountains were localities from which *Anticharis arabica* Endl. (Scrophulariaceae: Aptosimae) has been recorded (coordinates of localities supplied by Tamer Khafaga). The reason for this choice being that in southern Africa all Aptosimae are visited by and pollinated by Masarinae (Gess and Gess 2014) and it was hoped that an equivalent association would be found. However, due to the dryness no plants of *A. arabica* were found. The sites in the Hajar Mountains, mostly wadis, ranged in elevation from 284 m to 355 m.

Site 1. Sandy roadside

Scattered plants of *Tribulus* spp., *Heliotropium kotschyi*, *Dipterygium glaucum* and a species of Convolvulaceae were in flower.

Site 2. Shawka

Rumex dentatus (Polygonaceae) was in flower, fringing the area from which the water had retreated. (Figure 17)

Site 3. Wadi

Very dry, little in flower other than *Acacia tortilis*. (Figure 18)

Site 4. Wadi

Very dry, almost all plants in fruit.

Figures 17–19. Study sites to east of DDCR: **17** Site 2. Shawka dam *Rumex dentatus* (Polygonaceae) fringing the area from which water had retreated **18** Site 3. Wadi in Hajar Mountains **19** Site 6. Khor Kalba, Ramsa outside Mangrove and Alhafeya Protected Area.

Site 5. Munay, outskirts of village

Most plants were dried up. *Solanum nigrum* (Solanaceae), in flower near a leaking tap, was sampled for flower visitors.

Site 6. Khor Kalba, Ramsa outside Mangrove and Alhafeya Protected Area

Heliotropium kotschyi and *Zygophyllum qatarense* were in flower along the sandy bank of lagoon. *Avicennia marina* was in flower at water's edge. (Figure 19)

All other plants dried out.

Results

Flowering plants recorded

Forty-six plant species were recorded by Tamer Khafaga from the dunes and gravel plains of the DDCR in his 2008/2009 study of the vegetation after rain (Khafaga 2009). These include 41 species of dicots and only five species of monocots. Of the

dicots 33 were noted in the present survey (Table 2). The smaller number of species of plants noted can to a large degree be attributed to the sampling period in 2015 having followed seven dry years, resulting in a paucity of annual plants. *Launaea procumbens* (Asteraceae), widespread in the northern emirates, and an exotic weed, *Sesuvium verrucosum* (Aizoaceae) were found growing inside the cages surrounding planted trees.

The monocots are not included in Table 2 or in Appendix 1. They are the common and widespread palatable sedge, *Cyperus conglomeratus* (Cyperaceae), and four grass species (Poaceae). Grasses were noted in the present survey but were not identified. They were uncommon and outside the enclosures had been heavily grazed.

Flower visitors were observed and sampled on 21 species of plants within the DDCR and on two additional species east of the Reserve and two west of the Reserve (Table 3 and Appendix 1, giving global distributions). Of these 25 species, four species are known only from the Arabian Peninsula. The distributions of the other 19 variously include: the Mediterranean fringe; the Middle East; Asia; North Africa and Asia; North Africa; the Middle East and Asia; Africa from north to south; Africa from north to south together with the Middle East and Asia; and Europe together with the Mediterranean and Asia.

Aculeate wasps and bees recorded

In the present first survey 53 species of aculeate wasps and 26 species of bees were recorded (Appendix 2, giving global distributions). Known distributions suggest that of these species, 11% are known only from the Arabian Peninsula, 65% include North Africa, 27% include in addition to North Africa, the Middle East and Asia, 9% further include Europe, 6% further include Africa from north to south and west to east, 8% in addition to Arabia have distributions only extending east into Asia, 8% have circum-Mediterranean distributions, 3% distributions from Arabia to southern Africa and 2% distributions from Arabia north into the Middle East as well as south through Africa.

Some understanding of the biogeography of bees in Sahara and Arabian deserts has resulted from the analysis by Patiny and Michez (2007), however, the taxa used in their study (19 species in seven sub-families) are not ones encountered in the present survey, making their conclusions of doubtful merit in the present context.

Of the wasps, 40 species were from the DDCR and the additional 11 from our transect to the east of and two from our transect to the west of the DDCR. Of the bees, 21 species were from the DDCR and an additional two from our transect to the east of the Reserve. Flower sampling yielded flower visiting records for 39 species of aculeate wasps and 23 species of bees. The results of flower sampling are presented in Tables 3 and 4.

Flowers visited by aculeate wasps and bees

Table 3 lists the plants, from the flowers of which aculeate wasps and bees were collected, together with the names, number and sex of the wasps and bees, and the collection sites.

Table 2. Dicotyledonous plants recorded for the DDCR by Khafaga (2009) and in the present survey, flower visitors collected and sites where sampled in the present survey.

Plant family	Plant genus and species	Recorded by Khafaga 2009	Recorded in present survey	Flowers visitors collected	Sites where sampled
Aizoaceae	*Sesuvium verrucosum* Raf.	-	+	+	Site 11.
Amaranthaceae	*Aerva javanica* (Burm. *f.*)	+	+	+	Site 8.
Apocynaceae: Asclepiadoideae (formerly Asclepiadaceae)	*Calotropis procera* (Aiton) W.T. Aiton	+	+	+	Sites 9, 10, 20, 21, 22, 23, 24
	Leptadenia pyrotechnica (Forssk.) Decne.	+	+	+	Site 24
Asteraceae	*Atractylis carduus* (Forssk.) C. Chr.	+	+	-	
	Centaurea pseudosinaica Czerep.	+	+	+	Site 8.
	Launaea procumbens (Roxb.) Ramayya & Rajogopal	-	+	+	Site 17
	Rhanterium epapposum Oilv.	+	+	+	Site 15.
Boraginaceae	*Arnebia hispidissima* (Lehm.) DC.	+	+	+	Site 8.
	Heliotropium digynum (Forssk.) Asch. ex C. Chr.	+	+	-	
	Heliotropium kotschyi (Bge.) Gurke	+	+	+	Site 10, 16, 20, 24. Also outside DDCR, Site 28
	Moltkiopsis ciliata (Forssk.) I.M.Johnst.	+	+	+	Site 24.
	Ogastemma pusillum (Coss. & Durand ex Bonnet & Baratte) Brummitt	+	-	-	
Brassicaceae	*Brassica muricata* (L.) Asch.	+	-	-	
	Eremobium aegyptiacum (Spreng.) Boiss.	+	-	-	
	Farsetia linearis Decne. Ex Boiss.	+	+	+	Site 24
	Sisymbrium erysimoides Desf.	+	-	-	
Capparaceae	*Dipterygium glaucum* Decne.	+	+	+	Sites 8, 10, 20, 24
Caryophyllaceae	*Polycarpaea repens* (Forssk.) Asch. & Schweinf.	+	+	+	Site 24.
	Sclerocephalus arabicus Boiss.	+	-	-	
	Silene villosa Forssk.	+	+	-	
Chenopodiaceae	*Haloxylon salicornicum* (Moq.) Bunge ex Boiss.	+	+	-	
Cucurbitaceae	*Citrullus colocynthis* (L.) Schrad.	+	+	-	

Plant family	Plant genus and species	Recorded by Khafaga 2009	Recorded in present survey	Flowers visitors collected	Sites where sampled
Euphorbiaceae	*Chrozophora oblongifolia* (Delile) Spreng.	+	+	-	
Fabaceae: Mimosoideae	*Acacia tortilis* (Forssk.) Hayne.	+	+	+	Site 20, also Site 3. Wadi to east
	Prosopis cineraria (L.) Druce.	+	+	+	Site 10, 20, 26
Fabaceae: Papilionoideae	*Crotalaria aegyptiaca* Benth.	+	+	+	Site14, 24
	Indigofera colutea (Burm. *f.*) Merr.	+	+	-	
	Indigofera intricata Boiss.	+	+	-	
Geraniaceae	*Monsonia nivea* (Decne.) Webb	+	-	-	
Molluginaceae	*Limeum arabicum* Fried.	+	+	+	Sites 8, 20, 24
Neuradaceae	*Neurada procumbens* L.	+	+	+	Site 24.
Plantaginaceae	*Plantago boissieri* Hausskn. & Bornm.	+	+	-	
Polygalaceae	*Polygala erioptera* DC.	+	-	-	
Polygonaceae	*Calligonum comosum* L' Her.	+	+	-	
	Rumex dentatus L.	-	-	+	Site 2. East of DDCR
Salvadoraceae	*Salvadora persica* L.	+	+	-	Site 10
Solanaceae	*Lycium shawii* Roem. & Schult.	+	+	+	
	Solanum nigrum L.	-	-	+	Site 5. East of DDCR
Tamaricaceae	*Tamarix aphylla* (L.) Karst.	+	+	-	
Zygophyllaceae	*Fagonia indica* Burm. *f.*	+	+	-	
	Fagonia sp.	+	-	-	
	Tribulus macropterus Boiss.	+	+	+	Site 24 also Site 13. roadside outside DDCR
	Tribulus omanense Hosni	+	+	+	Site 24
	Tribulus pentandrus Forssk.	+	+	-	
	Zygophyllum qatarense Hadidi	-	-	+	Sites 28, 29, 30 - west of DDCR
	Zygophyllum simplex	-	-	+	Site 27 - west of

Table 3. Plants with flowers visited by aculeate wasps and bees, the wasp and bee visitors, the number and sex of the voucher specimens and the sampling Sites.

Plant Family	Plant genus and species	Wasps	Bees and Pollen Wasps
AMARANTHACEAE			
	Aerva javanica	VESPIDAE: Polistinae *Polistes watti* Site 8 CRABRONIDAE: Crabroninae: Palarini *Palarus laetus*, 2 f, Site 8 CRABRONIDAE: Bembicinae: Bembicini *Bembix freygessneri*, 1f, 1f, Site 8	MEGACHILIDAE: Megachilinae: Anthidiini *Pseudoanthidium ochrognathum,* 1 Site 8
AIZOACEAE			
	Sesuvium verrucosum		HALICTIDAE: Nomioidinae *Nomioides klausi* 1f Site 11
APOCYNACEAE: Asclepiadoideae			
	Calotropis procera	CHRYSIDIDAE VESPIDAE: Eumeninae *Rhynchium oculatum* Site 24 POMPILIDAE: Pompilinae *Telostegus argyrellus* 1f, Site 21 TIPHIIDAE 1m Site 9 f Site 24 SCOLIIDAE: Campsomerinae *Campsomeriella thoracica* 1f, 1f, Site 24 *Micromeriella hyalina* 1f Site 21 SCOLIIDAE: Scoliinae *Scolia flaviceps* 2f, Site 19/20 CRABRONIDAE: Crabroninae: Larrini *Tachytes comberi* 1m Site 26 CRABRONIDAE: Eremiaspheciinae *Laphyragogus* sp. nov 1m Site 21 CRABRONIDAE: Bembicinae: Bembicini	HALICTIDAE: Nomiinae *Ceylalictus karachiensis* 1f, 3m Site 9 APIDAE: Xylocopinae *Xylocopa fenestrata* *Xylocopa aestuans* APIDAE: Apinae: Anthophorini *Amegilla byssina* (carrying polinia), 1f & 2m Site 21 APIDAE: Apinae: Apini *Apis florea* (carrying polinia)

Plant Family	Plant genus and species	Wasps	Bees and Pollen Wasps
		Bembix hauseri 3f Site 19/20, 5f Site 9, 3 Crabronidae: Philanthinae: Philanthini *Philanthus coarctatus* 3f, Site 21 *Philanthus pallidus* 1m, Site 21 Crabronidae: Philanthinae: Cercerini Cerceris chromatica 1m, 1m, Site 9, 1m, Site 21	
	Leptadenia pyrotechnica	CRABRONIDAE: Crabroninae: Palarini *Palarus laetus* 1m Site 24 CRABRONIDAE: Bembicinae: Bembicini *Bembix hameri* 1f Site 24	MEGACHILIDAE: Megachilinae: Megachilini *Megachile concinna* 1f Site 24 *Megachile patellimana* 1m Site 24
ASTERACEAE			
	Centaurea pseudosinaica	CRABRONIDAE: Crabroninae: Palarini *Palarus laetus* 2f Site 8 CRABRONIDAE: Bembicinae: Bembicini *Bembix fregessneri* 1f Site 8 CRABRONIDAE: Philanthinae: Philanthini *Philanthus pallidus* 1f Site 8	MEGACHILIDAE: Megachilinae: Megachilini *Megachile patellimana* 1f Site 8 APIDAE: Xylocopinae: Xylocopini *Xylocopa fenestrata* (Fabricius) 1f Site 8 APIDAE: Apinae: Anthophorini *Amegilla byssina* 1f Site 8
	Rhanterium epapposum	CRABRONIDAE: Crabroninae: Larrini *Gastrosericus moricei* 1f Site 15 CRABRONIDAE: Crabroninae: Palurini *Palarus laetus* 1f Site 15 CRABRONIDAE: Philanthinae: Philanthini *Philanthus coarctatus* 1m Site 15	
	Launaea procumbens		two small halictid bees, Site 17
BORAGINACEAE			
	Arnebia hispidissima	CRABRONIDAE: Crabroninae: Palurini *Palarus laetus* 2f Site 8	Apidae: Apinae: Anthophorini *Amegilla byssina* 1f, 1f, 1m Site 8
		CHRYSIDIDAE One sp. 1 Site 10 POMPILIDAE: Ceropalinae *Ceropales kriechbaumeri* 1f Site 10	VESPIDAE: Masarinae *Celonites jousseaumei* (flying above flowers) 1f Site 10 *Quartinia nubiana* 2f Site 10 HALICTIDAE: Nomioidinae

Plant Family	Plant genus and species	Wasps	Bees and Pollen Wasps
	Heliotropium kotschyi	SCOLIIDAE *Micromeriella hyalina* 1m, Site 10 CRABRONIDAE: Crabroninae: Palurini *Palarus bisignatus* 1f Site 24 *Palarus laetus* 1f Site 10, 1f Site 24 CRABRONIDAE: Bembicinae: Bembicini *Bembix freygessneri* 1f, 1f & 2m, 1f Site 24 *Bembix hameri* 1f, 1f, 1m Site 24 *Bembix hauseri* 1f Site 19/20, 1f Site 24 *Bembix kohli* 1f Site 24 *Bembix rochei* 1f Site 24 *Bembix saadensis* 1m Site 24	*Ceylalictus karachiensis* 1f, 5m Site 10 *Ceylalictus punjabensis* 1f Site 10 *Ceylalictus variegatus* 1m Site 10 *Nomioides klausi* 1f, 2m, Site 10, 2 Site 19/20 MEGACHILIDAE: Megachilinae: Megachilini *Megachile concinna* 1f, 1m Site 24, 1f site 19/20 *Megachile patellimana* 1f & 1m, 2f Site 10, 1f & 1m, 1f & 1m, 1m Site 24, 1f & 2m Site 19/20 *Coelioxys indica* 1 Site 10 Megachilinae: Anthidiini *Pseudoanthidium ochrognathum,* 1f Site 10 Megachilinae: Osmiini *Haetosmia circumventa* 1f, Site 24, 2m, 3m, 6m Site 10, 2f Site 27 APIDAE: Xylocopinae *Ceratina parvula* Site 24 APIDAE: Apinae: Anthophorini *Amegilla byssina* 1f Site 19/20, 1f & 1m Site 24 *Anthophora tenella* 1m Site 10, 1m Site 28 APIDAE: Apinae: Melectini *Thyreus hyalinatus* 1m, 1f Site 10
	Moltkiopsis ciliata	CRABRONIDAE: Bembicinae: Bembicini *Bembix hauseri* 2f and 1m Site 24	VESPIDAE: Masarinae *Celonites jousseaumei* (flying above flowers) site record HALICTIDAE: Nomioidinae *Ceylalictus karachiensis* 1f Site 24 MEGACHILIDAE: Megachilinae: Anthidiini *Pseudoanthidium ochrognathum,* 1f Site 24 APIDAE: Apinae: Anthophorini *Amegilla byssina* 3f, 2f Site 24
BRASSICACEAE			
	Farsetia linearis		APIDAE: Xylocopinae: Ceratinini *Ceratina parvula* 1f Site 24

Plant Family	Plant genus and species	Wasps	Bees and Pollen Wasps
CAPPARACEAE			
	Dipterygium glaucum	CHRYSIDIDAE Chrysidid 1 site 8 CRABRONIDAE: Bembicinae: Bembicini *Bembix saadensis* 1f Site 24	APIDAE: Apinae: Anthophorini *Amegilla byssina* 1m Site 10 APIDAE: Apinae: Melectini *Thyreus elegans* 1f Site 8
CARYOPHYLLACEAE			
	Polycarpaea repens	CRABRONIDAE: Crabroninae: Palurini *Palarus parvulus* 1m Site 24	
FABACEAE: Mimosoideae			
	Acacia tortilis	SCOLIIDAE *Micromeriella hyalina* 1m Site 3 CRABRONIDAE: Crabroninae: Oxbelini *Oxybellus lamellatus* 1m Site 3 CRABRONIDAE: Bembicinae: Bembicini *Stizoides assimilis* 1f Site 3 *Bembix chopardi* 2m Site 3	HALICTIDAE: Nomioidinae 1 male *Ceylalictus variegatus* 1m Site 3 MEGACHILIDAE: Megachilnae: Megachilini *Megachile concinna*1f, 1m Site 3 APIDAE: Xylocopinae: Ceratinini *Ceratina tarsata* 1f Site 3 APIDAE: Apinae: Melectini *Thyreus hyalinatus* 1f Site 10
	Prosopis cineraria	SPHECIDAE: Sphecinae *Prionyx nigropectinatus* 1f Site 26 CRABRONIDAE: Crabroninae: Miscophini *Plenoculus vanharteni* 1f Site 10 CRABRONIDAE: Crabroninae: Larrini *Tachysphex micans* 1f Site 26 CRABRONIDAE: Crabroninae: Palurini *Palarus laetus* 1f & 6m Site 26 *Palarus parvulus* 1m Site 26 CRABRONIDAE: Bembicinae: Bembicini *Bembix freygessneri* 1f Site 26 CRABRONIDAE: Philanthinae *Cerceris albocincta* 5m Site 26 *Cerceris chromatica* 2f & 6m Site 26 *Cerceris* sp. 1 Site 10	HALICTIDAE: Nomioidinae *Ceylalictus karachiensis* 1f, 3m Site 9 *Ceylalictus punjabensis* 1f Site 10 *Ceylalictus variegatus* 1m Site 10, 1f Site 21 MEGACHILIDAE: Megachilinae: Megachilini *Megachile minutissima* 1m Site 10 *Megachile patellimana* 1f Site 10 APIDAE: Apinae: Apini *Apis florea* hive Site 10

Plant Family	Plant genus and species	Wasps	Bees and Pollen Wasps
FABACEAE: Papilionoideae			
	Crotalaria aegyptiaca	CRABRONIDAE: Eremiaspheciinae *Laphrogogus* n. sp. 2m Site 14	MEGACHILIDAE: Megachilinae: Anthidiini *Icteranthidium* sp., 1m, 1m & 3f Site 14 MEGACHILIDAE: Megachilinae: Megachilini *Megachile patellimana*1f Site 24 APIDAE: Apinae *Amegilla byssina* 2f Site 14
MOLLUGINACEAE			
	Limeum arabicum	CRABRONIDAE: Crabroninae: Palurini *Palarus bisignatus* 1f & 4m, 1m Site 24 *Palarus dongalensis* 1 Site 24 *Palarus parvulus* 1m Site 8 CABRONIDAE: Eremiaspheciinae *Laphyrogogus* n. sp. 1m Site 19/20 CRABONIDAE: Bembicinae: Bembicini *Bembix gazella* 1m Site 24 *Bembix saadensis* 1f Site 24	HALICTIDAE: Nomiinae *Pseudapis nilotica* 1f Site 24 APIDAE: Xylocopinae: Ceratinini *Ceratina parvula* 1f & 2m Site 24
NEURADACEAE			
	Neurada procumbens		1 halictid bee
POLYGONACEAE			
	Rumex dentatus	VESPIDAE: Eumeninae *Delta esuriens esuriens* 1 Site 2 VESPIDAE: Polistinae *Polistes watti* 2 Site 2 VESPIDAE: Vespinae *Vespa orientalis* POMPILIDAE *Anoplius suspectus* 1f Site 2 SPHECIDAE: Sceliphronini *Sceliphron madraspatanum pictum* 1 Site 2 CRABRONIDAE: Bembicinae: Bembicini *Bembix arenaria* 1f Site 2 *Bembix oculata* 2f Site 2	HALICTIDAE: Halictinae *Seladonia lucidipennis* 1f, 1m Site 2

Plant Family	Plant genus and species	Wasps	Bees and Pollen Wasps
SOLANACEAE			
	Solanum nigrum	POMPILIDAE: Ceropalinae *Ceropales kriechbaumeri* 2f Site 5 SCOLIIDAE: Campsomerinae *Micromeriella hyalina* 1 Site 5 SPHECIDAE: Ammophilinae *Ammophila rubripes* 1m Site 5 CRABRONIDAE: Philanthinae *Cerceris* sp. 1 Site 5	HALICTIDAE: Nomiinae *Crocisaspidia vespoides* 1m Site 5
ZYGOPHYLLACEAE			
	Tribulus macropterus	CRABRONIDAE: Crabroninae: Palurini *Palarus laetus* 1m, 1m Site 24 CRABRONIDAE: Bembicinae: Bembicini *Bembix fregessneri* 1f Site 24 *Bembix gazella* 1m, 4m, 1m Site 24 *Bembix kohli* 1f & 1male Site 24 *Bembix rochei* 1f Site 13, 2f Site 24	HALICTIDAE: Nomioidinae 1 male *Nomioides klausi* 1m Site 24 MEGACHILIDAE; Megachilinae: Megachilini *Megachile patellimana* 6f &1m, 6f, 4f Site 24 APIDAE: Xylcocopinae: Ceratinini *Ceratina parvula* 1f, 2 Site 24
	Zygophyllum qatarense	POMPILIDAE: Pompilinae *Telostegus argyrellus* 2 Site 30 CRABRONIDAE: Crabroninae: Larrini *Gastrosericus waltlii* 1m Site 30 CRABRONIDAE: Philanthinae *Cerceris albicincta* 1m *Cerceris chromatica* 1m Site 29	
	Zygophyllum simplex	TIPHIIDAE: Thynninae 1m Site 27 CRABRONIDAE: Crabroninae: Palurini *Palarus parvulus* 1m Site 27 CRABRONIDAE: Philanthinae *Cerceris* sp. 1 Site 27	MEGACHILDAE: Megachilinae: Megachilini *Megachile* 1 Site 27

Table 4. Aculeate wasps and bees collected visiting flowers, plants, collection Sites and sex of wasp and bee voucher specimens.

Aculeate Family and Subfamily	Aculeate genus and species	Plant Family	Plant genus and species
CHRYSIDOIDEA			
CHRYSIDIDAE		APOCYNACEAE: Asclepiadoideae BORAGINACEAE CAPPARACEAE	*Calotropis procera* 1 Site 21 *Heliotropium kotschyi* 1 Site 10 *Dipterygium glaucum* 1 Site 8
VESPOIDEA			
VESPIDAE: Masarinae			
	Celonites jousseaumei (flying above flowers)	BORAGINACEAE	*Heliotropium kotschyi* 1f Site 10 *Moltkiopsis ciliata* site record
	Quartinia nubiana	BORAGINACEAE	*Heliotropium kotschyi* 2f Site 10
VESPIDAE: Eumeninae			
	Delta esuriens esuriens	POLYGONACEAE	*Rumex dentatus* Site 2
	Rhynchium oculatum	APOCYNACEAE: Ascepiadoideae	*Calotropis procera* Site 24
Vespidae: Polistinae			
	Polistes watti	AMARANTHACEAE	*Aerva javanica* Site 8
		POLYGONACEAE	*Rumex dentatus* 2 Site 2
POMPILIDAE: Pompilinae			
	Anoplius suspectus	POLYGONACEAE	*Rumex dentatus* 1f Site 2
	Telostegus argyrellus	APOCYNACEAE: Asclepiadoideae ZYGOPHYLLACEAE	*Calotropis procera* 1f, Site 21 *Zygophyllum qatarense* 2 Site 30
POMPILIDAE: Ceropalinae			
	Ceropales kriechbaumeri	BORAGINACEAE SOLANACEAE	*Heliotropium kotschyi* 1f Site 10 *Solanum nigrum,* 2f Site 5
TIPHIIDAE		APOCYNACEAE: Asclepiadoideae	*Calotropis procera* 1, Site 9
TIPHIIDAE: Thynninae		ZYGOPHYLLACEAE	*Zygophyllum simplex* 1 Site 27
SCOLIIDAE: Campsomerinae			
	Campsomeriella thoracica	APOCYNACEAE: Asclepiadoideae	*Calotropis procera* 1f, 1f, Site 24

Aculeate Family and Subfamily	Aculeate genus and species	Plant Family	Plant genus and species
	Micromeriella hyalina	APOCYNACEAE: Asclepiadoideae BORAGINACEAE FABACEAE: Mimosoideae SOLANACEAE	*Calotropis procera* 1f Site 21 *Heliotropium kotschyi* 1m, Site 10 *Acacia tortilis* 1m Site 3 *Solanum nigrum* 1 Site 5
SCOLIIDAE: Scoliinae			
	Scolia flaviceps	APOCYNACEAE: Asclepiadoideae	*Calotropis procera* 2f Site 19/20
SCOLIIDAE: Campsomerinae			
	Campsomeriella thoracica *Micromeriella hyalina*	APOCYNACEAE: Asclepiadoideae APOCYNACEAE: Asclepiadoideae	*Calotropis procera* 1f, 1f, Site 24 *Calotropis procera* 1f Site 21
APOIDEA: SPHECIFORMES			
SPHECIDAE: Sphecinae			
	Prionyx nigropectinatus	FABACEAE: Mimosoideae	*Prosopis cineraria* 1f Site 26
SPHECIDAE: Sceliphrinae			
	Sceliphron madraspatanum pictum	POLYGONACEAE	*Rumex dentatus* 1 Site 2
SPHECIDAE: Ammophilinae			
	Ammophila rubripes	SOLANACEAE	*Solanum nigrum* 1m Site 5
CRABRONIDAE: Crabroninae: Larrini			
	Gastrosericus moricei	ASTERACEAE	*Rhanterium epapposum* 1f Site 15
	Gastrosericus waltlii	ZYGOPHYLLACEAE	*Zygophyllum qatarense* 1m Site 30
	Tachytes comberi	APOCYNACEAE: Asclepiadoideae	*Calotropis procera* 1m Site 26
	Tachysphex micans	FABACEAE: Mimosoideae	*Prosopis cineraria* 1f Site 26
CRABRONIDAE: Crabroninae: Oxybellini			
	Oxybellus lamellatus	FABACEAE: Mimosoideae	*Acacia tortilis* 1m Site 3
CRABRONIDAE: Crabroninae: Palurini			
	Palarus bisignatus	BORAGINACEAE MOLLUGINACEAE	*Heliotropium kotschyi* 1f Site 24 *Limeum arabicum* 1f & 4m, 1m Site 24
	Palarus dongalensis	MOLLUGINACEAE	*Limeum arabicum* 1 Site 24

Aculeate Family and Subfamily	Aculeate genus and species	Plant Family	Plant genus and species
	Palarus laetus	AMARANTHACEAE APOCYNACEAE: Asclepiadoideae ASTERACEAE BORAGINACEAE FABACEAE: Mimosoideae ZYGOPHYLLACEAE	*Aerva javanica* 2f Site 8 *Leptadenia pyrotechnica* 1f Site 24 *Centaurea pseudosinaica* 2f Site 8 *Arnebia hispidissima* 2f Site 8 *Heliotropium kotschyi* 1f Site 10, 1f Site 24 *Prosopis cineraria* 1f & 6m Site 26 *Tribulus macropterus* var, *arabicus* 1m, 1m Site 24
	Palarus parvulus	CARYOPHYLLACEAE MOLLUGINACEAE	*Polycarpaea repens* 1m Site 24 *Limeum arabicum* 1f & 2m Site 24
CRABRONIDAE: Crabroninae: Miscophini			
	Plenoculus vanharteni	FABACEAE: Mimosoideae	*Prosopis cineraria* 1f Site 10
CRABRONIDAE: Bembicinae: Bembicini			
	Bembix arenaria	POLYGONACEAE	*Rumex dentatus* 1f Site 2
	Bembix chopardi	FABACEAE: Mimosoideae	*Acacia tortilis* 2m Site 3
	Bembix freygessneri	AMARANTHACEAE ASTERACEAE BORAGINACEAE ZYGOPHYLLACEAE	*Aerva javanica* 1f, 1f, Site 8 *Centaurea pseudosinaica* 1f Site 8 *Heliotropium kotschyi* 1f, 1f & 2m, 1f Site 24 *Tribulus macropterus* 1f Site 24
	Bembix gazella	MOLLUGINACEAE FABACEAE: Mimosoideae ZYGOPHYLLACEAE	*Limeum arabicum* 1m Site 24 *Prosopis cineraria* 1f Site 26 *Tribulus macropterus* 1m, 4m, 1m Site 24
	Bembix hameri	APOCYNACEAE: Asclepiadoideae BORAGINACEAE	*Leptadenia pyrotechnica* 1f Site 24 *Heliotropium kotschyi* (Bge.) Gurke, 1f, 1f, 1m Site 24
	Bembix hauseri	APOCYNACEAE: Asclepiadoideae BORAGINACEAE	*Calotropis procera* 3f Site 19/20, 5f Site 9, 3f Site 24 *Heliotropium kotschyi* 1f Site 19/20, 1f Site 24 *Moltkiopsis ciliata* 2f & 1m Site 24
	Bembix kohli	APOCYNACEAE: Asclepiadoideae BORAGINACEAE ZYGOPHYLLACEAE	*Calotropis procera* 1f, Site 2 (flying), 1m, Site 24 *Heliotropium kotschyi* 1f Site 24 *Tribulus macropterus* 1f & 1m Site 24
	Bembix oculata	POLYGONACEAE	*Rumex dentatus* 2f Site 2

Aculeate Family and Subfamily	Aculeate genus and species	Plant Family	Plant genus and species
	Bembix rochei	BORAGINACEAE ZYGOPHYLLACEAE	*Heliotropium kotschyi* 1f Site 24 *Tribulus macropterus* 1f Site 13 2f Site 24
	Bembix saadensis	BORAGINACEAE CAPPARACEAE MOLLUGINACEAE	*Heliotropium kotschyi* 1m Site 24 *Dipterygium glaucum* 1f Site 24 *Limeum arabicum* 1f Site 24
	Stizoides assimilis	FABACEAE: Mimosoideae	*Acacia tortilis* 1m Site 3
CRABRONIDAE: Eremiaspheciinae: Eremiaspheciini			
	Laphyragogus sp. nov	APOCYNACEAE: Asclepiadoideae FABACEAE: Papilionoideae MOLLUGINACEAE	*Calotropis procera* 1m Site 21 *Crotalaria aegyptiaca* 2m Site 14 *Limeum arabicum*, 1m Site 19/20
CRABRONIDAE: Bembicinae Philanthinae: Philanthini			
	Philanthus coarctatus	APOCYNACEAE: Asclepiadoideae ASTERACEAE	*Calotropis procera* 3f, Site 21 *Rhanterium epapposum,* 1m Site 15
	Philanthus pallidus	APOCYNACEAE: Asclepiadoideae ASTERACEAE	*Calotropis procera* 1m, Site 21 *Centaurea pseudosinaica* 1f Site 8
Bembicinae Philanthinae: Cercerini			
	Cerceris albocincta	FABACEAE: Mimosoideae ZYGOPHYLLACEAE	*Prosopis cineraria* 5m Site 26 *Zygophyllum qatarense* 1m
	Cerceris chromatica	APOCYNACEAE: Asclepiadoideae FABABCEAE: Mimosoideae ZYGOPHYLLACEAE	*Calotropis procera* 1m, 1m, Site 9, 1m, Site 21 *Prosopis cineraria* 2f & 6m Site 26 *Zygophyllum qatarense* 1m Site 29
	Cerceris sp.	FABACEAE: Mimosoideae	*Prosopis cineraria* 1 Site 10
	Cerceris sp.	SOLANACEAE	*Solanum nigrum* 1 Site 5
	Cerceris sp.	ZYGOPHYLLACEAE	*Zygophyllum simplex* 1 Site 27
APOIDEA: APIFORMES			
HALICTIDAE: Halictinae			
	Halictus lucidipennis	POLYGONACEAE	*Rumex dentatus* 1f, 1m, Site 2

Aculeate Family and Subfamily	Aculeate genus and species	Plant Family	Plant genus and species
HALICTIDAE: Nomiinae			
	Nomia vespoides	SOLANACEAE	*Solanum nigrum* 1m Site 5
	Pseudapis nilotica	MOLLUGINACEAE	*Limeum arabicum* 1f Site 24
HALICTIDAE: Nomioidinae			
	Ceylalictus karachiensis	APOCYNACEAE: Asclepiadoideae BORAGINACEAE FABACEAE: Mimosoideae	*Calotropis procera* 1f, 3m, Site 9 *Heliotropium kotschyi* 1f, 5m, Site 10 *Moltkiopsis ciliata* 1f, Site 24 *Prosopis cineraria* 1f, 3m Site 9
	Ceylalictus punjabensis	BORAGINACEAE FABACEAE: Mimosoideae	*Heliotropium kotschyi* 1f, Site 10 *Prosopis cineraria* 1f, Site 10
	Ceylalictus variegatus	BORAGINACEAE FABACEAE: Mimosoideae	*Heliotropium kotschyi* 1m, Site 10 *Acacia tortilus* 1m, Site 3 *Prosopis cineraria* 1m Site 10, 1f Site 21
	Nomioides klausi	AIZOACEAE BORAGINACEAE ZYGOPHYLLACEAE	*Sesuvium verrucosum* 1f Site 11 *Heliotropium kotschyi* 2 Site 19/20 *Tribulus macropterus* 1m Site 24
MEGACHILIDAE: Megachilinae: Megachilini			
	Megachile concinna	APOCYNACEAE: Asclepiadoideae BORAGINACEAE FABACEAE: Mimosoideae	*Leptadenia pyrotechnica* 1f Site 24 *Heliotropium kotschyi* 1f, 1m Site 24, 1f Site 19/20 *Acacia tortilis* 1m Site 3
	Megachile minutissima	FABACEAE: Mimosoideae	*Prosopis cineraria* 1m Site 10
	Megachile patellimana	APOCYNACEAE: Asclepiadoideae ASTERACEAE BORAGINACEAE BRASSICACEAE FABACEAE: Mimosoideae FABACEAE: Papilionoideae ZYGOPHYLLACEAE	*Leptadenia pyrotechnica* 1m Site 24 *Centaurea pseudosinaica* 1f Site 8 *Heliotropium kotschyi* 1f & 1m, 2f Site 10, 1f & 1m, 1f & 1m, 1m Site 24, 1f & 2m Site 19/20 *Farsetia linearis* 1f Site 24 *Prosopis cineraria* 1m Site 10 *Crotalaria aegyptiaca* 1f Site 24 *Tribulus macropterus* 6f &1m, 6f, 4f Site 24
	Coelioxys indica		*Heliotropium kotschyi* Site 10

Aculeate Family and Subfamily	Aculeate genus and species	Plant Family	Plant genus and species
MEGACHILIDAE: Megachilinae: Osmiini			
	Haetosmia circumventa	BORAGINACEAE	*Heliotropium kotschyi* 1f Site 24, 2m, 3m, 6m Site10, 2f Site 27
MEGACHILIDAE: Megachilinae: Anthidiini			
	Icteranthidium n. sp.	FABACEAE: Papilionoideae	*Crotalaria aegyptiaca*, 1m, 1m&3f Site 14
	Pseudoanthidium ochrognathum	AMARANTHACEAE BORAGINACEAE	*Aerva javanica,* 1f, Site 8 *Heliotropium kotschyi*, 1f, 3 Site *Moltkiopsis ciliata,* 1F, site 24
APIDAE: Xylocopinae: Xylocopini			
	*Xylocopa fenestrat*a	APOCYNACEAE: Asclepiadoideae ASTERACEAE	*Calotropis procera* 1f Site 8 *Centaurea pseudosinaica* 1f Site 8
	Xylocopa aestuans	APOCYNACEAE: Asclepiadoideae	*Calotropis procera* site records
APIDAE: Xylocopinae: Ceratinini	*Ceratina parvula*	BORAGINACEAE MOLLUGINACEAE ZYGOPHYLLACEAE	*Heliotropium kotschyi* 1 Site 24 *Limeum arabicum* 1f & 2m Site 24 *Tribulus macropterus* 1f, 2 Site 24
	Ceratina tarsata	FABACEAE: Mimosoideae	*Acacia tortilis* 1f Site 3
APIDAE: Apinae: Anthophorini			
	Amegilla byssina	APOCYNACEAE: Asclepiadoideae ASTERACEAE BORAGINACEAE CAPPARACEAE FABACEAE: Papilionoideae	*Calotropis procera* 1f & 2m Site 21 *Centaurea pseudosinacea* 1f *Arnebia hispidissima* 1f, 1f, 1m Site 8 *Heliotropium kotschyi* 1f & 1m Site 24 *Moltkiopsis ciliata* 3f, 2f Site 24 *Dipterygium glaucum* 1m Site 10 *Crotalaria aegyptiaca* 2f Site 14
	Anthophora tenella	BORAGINACEAE	*Heliotropium kotschyi* 1m Site 10, 1m Site 28
APIDAE: Apinae: Melectini			
	Thyreus elegans	CAPPARACEAE	*Dipterygium glaucum* 1f Site 8
	Thyreus hyalinatus	BORAGINACEAE FABACEAE: Mimosoideae	*Heliotropium kotschyi* 1m, 1f Site 10 *Prosopis cineraria* 1f Site10
APIDAE: Apinae: Apini	*Apis florea*	APOCYNACEAE: Asclepiadoideae FABACEAE: Mimosoideae	*Calotropis procera* (carrying polinia) *Prosopis cineraria* (hive in tree) Site 10

Visits by hunting wasps and nest parasites were for imbibing nectar and visits by bees and pollen wasps for imbibing nectar and/or gathering pollen. Pollen and nectar collecting visits were not distinguished. Following Jongbloed (2003, *The comprehensive guide to the wild flowers of the United Arab Emirates*) the plant families have been arranged in alphabetical order not grouped under Orders.

Discussion

The Arabian Peninsula lies between similar latitudes in the northern hemisphere as do the semi-arid to arid desertic areas in southern Africa, the principal area in which Sarah Gess with Friedrich Gess made a 40 year study of aculeate wasps and bees. Although the preliminary survey of flower visiting by aculeate wasps and bees here reported and discussed spanned only a matter of weeks it is of interest and informative to make some comparisons.

Amaranthaceae

Jongbloed (2003) gives accounts for 10 species of Amaranthaceae occurring in the UAE, most to the east or west of the DDCR. Only one species, *Aerva javanica* (Figure 20), the only species widespread in the central dune desert, has been recorded for the DDCR (Khafaga 2009). By comparison Amaranthaceae forms a notable component of the vegetation of northern Namaqualand and Namibia where the most numerous species of solitary wasp and bee visitors belong to the Crabronidae: Bembicinae (formerly Nyssonidae) and of solitary bees to the Megachilidae (Gess and Gess 2006). It is perhaps significant that in the present study these two taxa are represented amongst the small number of wasps and bees recorded from *Aerva javanica*. The only other wasp visiting the flowers was *Polistes watti* (Polistinae) and the only bee, unexpectedly, the small anthidiine, *Pseudoanthidium ochrognathum*, otherwise collected from Boraginaceae both in the reserve and to the east.

Aizoaceae

Whereas Aizoaceae, both Mesembryanthema (formerly Mesembryanthemaceae) and non-Mesembryanthema are widespread and species diverse in the semi-arid to arid areas of Southern Africa only one species of Mesembryanthema and three species of non-Mesembryanthema, all coastal species, are recorded from the UAE in Jongbloed (2003).

In the present study one species *Sesuvium verrucosum* (non-Mesembryanthema) was recorded. It was growing inside the cage of an irrigated planted tree in the DDCR (Figure 21). It is an American species, which has become naturalized in the UAE where

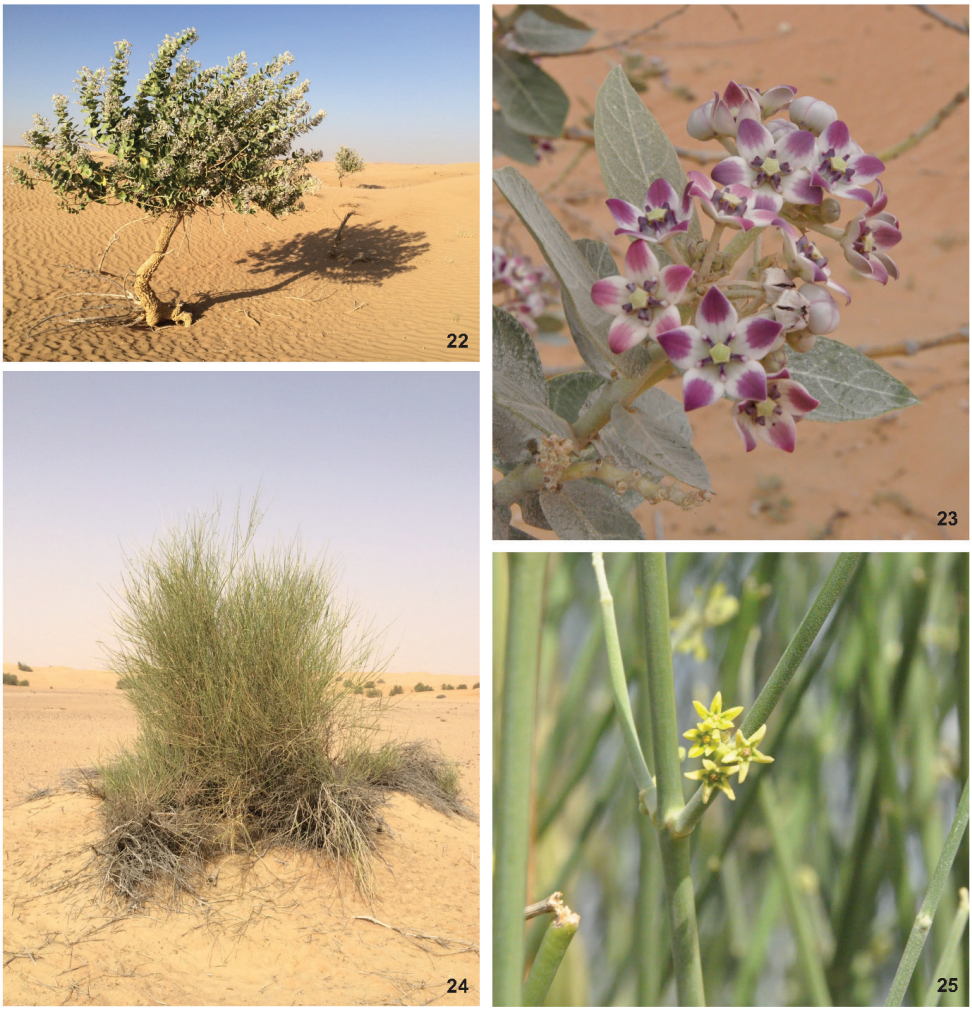
Figure 20–21. 20 Amaranthaceae, *Aerva javanica* **21** Aizoaceae, *Sesuvium verrucosum* in tree cage.

it is most usually found along the west coast. One halictid bee, a female *Nomioides klausi,* was visiting the flowers. At other sites this bee was visiting *Heliotropium kotschyi* (Boraginaceae) and *Tribulus macropterus* (Zygophyllaceae).

Apocynaceae: Asclepiadoideae

Jongbloed (2003) gives accounts for eight species of Asclepiadoideae in the UAE. Of these most occur to the east of the DDCR. Two species of perennial woody Asclepiadoideae, *Calotropis procera* (Figures 22 and 23) and *Leptadenia pyrotechnica* (Figures 24 and 25), which are characteristic of the central dune desert, are listed for the DDCR in Khafaga (2009). They are widely present on the dunes where, not being palatable, they are often the only plants. Samples of wasps and bees visiting *C. procera* were taken at five widely separated sites. Wasps represented in total were of the wasp families Chrysididae (1 sp.), Tiphiidae (1 sp.), Vespidae: Eumeninae (1 sp.), Scoliidae 2 spp.), Pompilidae (1sp.), Crabronidae: Bembicinae (2 spp.), Eremiaspheciinae (1 sp.) and Philanthinae (2 spp.) and the bee family Apidae (Apinae: Apini (1 sp.) and Anthophorini (1 sp.) and Apidae: Xylocopinae (2 spp.)).

In a detailed study of the pollination of *Calotropis procera* in Pakistan (Ali and Ali 1988) a much more limited range of visitors was recorded. Insects bearing polinia were classified as pollinators. On this basis those authors concluded that two Apidae, *Xylocopa pubescens* Spinola and *X. fenestrata* were the main pollinators and that a third *Apis florea* was a minor pollinator. It is likely that in the DDCR *Xylocopa fenestrata* and *X. aestuans* are similarly potential pollinators of *C. procera*. In the



Figures 22–25. Apocynaceae, Asclepiadoideae: **22, 23** *Calotropis procera* **24, 25** *Leptadenia pyrotechnica.*

present survey visitors carrying pollinia were two Apidae, *Amegilla bysina* and *Apis florea*, and one crabronid, *Bembix kohli*, making them additional potential pollinators of this plant.

The diversity of visitors to *Calotropis procera,* though not as great, is comparable with that to a shrubby species of Asclepiadoideae, *Gomphocarpus filiformis* (E. Mey.) Dietr., in the western semi-arid to arid areas of southern Africa, which also includes Chrysididae (2 spp.), Vespidae, Pompilidae (9 spp.), Scoliidae (3 spp.), Crabronidae: Crabroninae (7 spp.) and Bembicinae (2 spp.), Apidae: Apinae (6 spp.) and Xylocopinae (2 spp.) with, however, in addition Tiphiidae (4 spp.), Sphecidae (7 spp.), and one species each of Bradynobaeinidae, Halictidae, Colletidae, and Melittidae (Gess and Gess 2003 and Gess and Gess 2006).

Leptadenia pyrotechnica, though widespread, was being less commonly visited, flower visitors having been observed only at Site 24, the Lucerne Farm enclosure. There the visitors obtained were less diverse, wasps of Crabronidae: Crabroninae (1sp.) and Bembicinae (1 sp.) and Palurini (1 sp.), and bees of Megachilidae: Megachilinae: Megachilini (2 spp.), with sight records for *Apis florea*.

Asteraceae

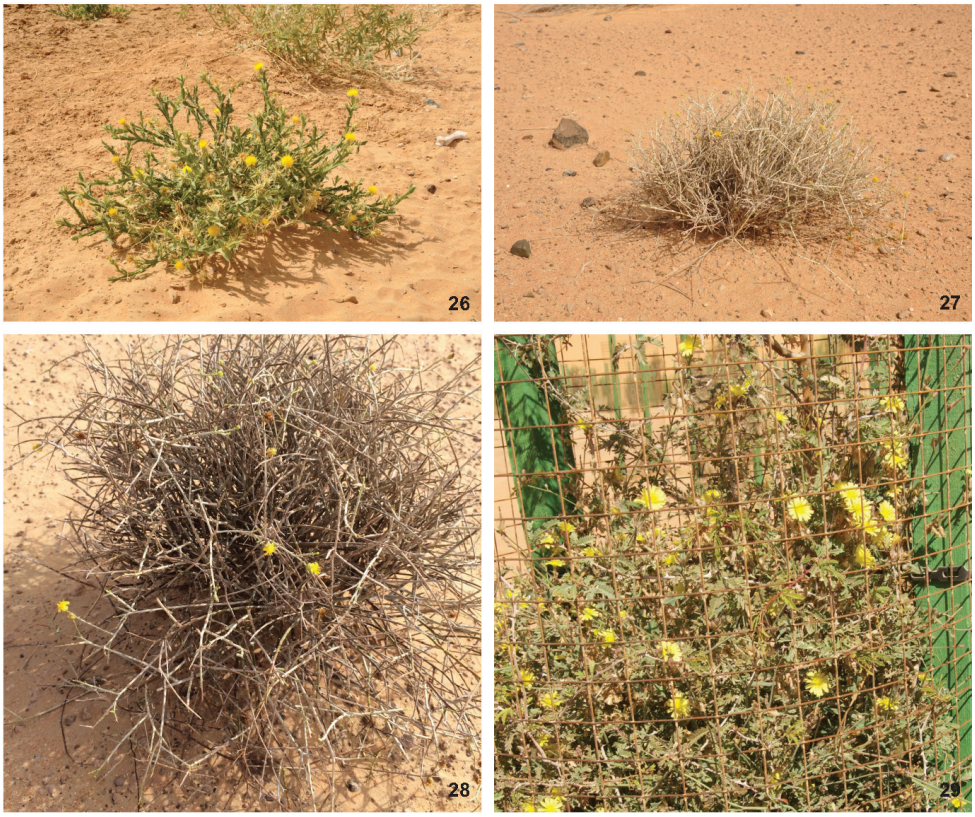
Jongbloed (2003) gives accounts for 58 species of Asteraceae in the United Arab Emirates most having been recorded from the mountainous area to the East of the DDCR. Khafaga (2009) recorded only three, *Atractylis carduus, Centaurea pseudosinaica* and *Rhanterium eppaposum,* from the DDCR (Table 2). Of these *C. pseudosinaica* (Figure 26) and *R. eppaposum* (Figures 17 and 18) were found in flower and in addition *Launaea procumbens* (Figure 29), a common and widespread weed, was found growing and flowering, like *S. verrucosum*, inside the cage of a planted tree.

At the time of sampling, *Centaurea pseudosinaica* was being visited by three species of aculeate wasps of three sub-families of Crabronidae, one species of Megachilidae and two species of Apidae, one each of Apinae and Xylocopinae. However, *Rhanterium eppaposum* was visited solely by Crabronidae of two sub-families and *Launaea procumbens* by two small halictid bees.

A greater diversity of visitors had been expected. In the semi-arid to arid areas of southern Africa, where Asteraceae is the largest family in the Karoo-Namib Region (Cowling and Hilton Taylor 1999), it was recorded as being visited by a diverse range of aculeate wasps of eight families, including pollen wasps, and all families of bees (Gess and Gess 2006).

Boraginaceae

Jongbloed (2003) gives accounts for 22 species of Boraginaceae occurring in the UAE. Of these, four species are given as widespread in the central desert, all are listed in Khafaga (2009) for the DDCR. In the present study all four, *Arnebia hispidissima* (Figure 30), *Heliotropium digynum, Heliotropium kotschyi* (Figures 31 and 32) and *Moltkiopsis ciliata* (Figure 33 and 34), were sampled for flower visitors. The only species not being visited at that time was *H. digynum*. *Heliotropium kotschyi*, the most widespread and abundant species, was sampled for flower visitors at three sites within the DDCR and one site near to the coast west of the DDCR. At all three sites in the reserve wasps of the family Crabronidae (sites grouped, Crabroninae: Palurini, 2 spp. and Bembicinae: Bembicini, 6 spp.) and bees of the families Megachilidae (sites grouped together, Megachilinae: Megachilini 3 spp., Osmiini 1 sp. and Anthidiini 1 sp.) and Apidae (sites grouped together Xylocopinae: Ceratinini 1 sp., Apinae: Anthophorini 2 spp.) were recorded, with in addition from the drip area at Tawi Ruwayyan wasps of the families,



Figures 26–29. Asteraceae: **26** *Centaurea pseudosinaica* **27, 28** *Rhanterium epapposum* **29** *Launaea procumbens.*

Chrysididae (1 sp), Vespidae: Masarinae (2 spp.), Pompilidae (1sp.), Scoliidae (1 sp.), and from the drip area at Tawi Manana bees of the family Halictidae (4 spp.). Other noticeable but not common visitors to the flowers were braconid wasps in the DDCR and bombyliid flies both in the DDCR and at Ghantoot, inland from the west coast.

The two species of Masarinae were *Quartinia nubiana* (2 females caught visiting flowers) and *Celonites jousseaumei* (flying over flowers).

Of particular interest was the presence of an oligolectic osmiine bee, *Haetosmia circumventa*, which specialises in collecting pollen from the flowers of *Heliotropium* (Gotlieb et al. 2014).

Arnebia hispidissima and *Moltkiopsis ciliata* were only present and sampled at one site each, Quarn Nazwa and the dune enclosure at the Lucerne Farm respectively. Both, like *Heliotropium kotschyi,* were receiving visits from *Amegilla byssina* (Apidae: Apinae) with the former in addition *Palarus laetus* (Crabronidae: Crabroninae: Palurinini) and the latter *Bembix hauseri* (Crabronidae: Bembicinae) and *Ceylalictus karachiensis* (Halictidae: Nomiinae). Of particular interest was a site record for *M. ciliata* of a *Celonites*, presumably *jousseaumei*.

Figures 30–34. Boraginaceae: **30** *Arnebia hispidissima* **31, 32** *Heliotropium kotschyi* **33, 34** *Moltkiopsis ciliata*.

The associations with *Celonites jousseaumei* are of further interest when considered together with a close association of this pollen wasp with *Heliotropium* in Morocco (Volker Mauss, pers. com.) and close associations between *Heliotropium* and other masarines, *Trimeria buyssoni* Brethes in South America (Neff and Simpson 1985) and

Jugurtia namibicola Gess and *Celonites heliotropii* Gess with *Heliotropium tubulosum* Gess in Namibia (Gess, F.W. 2004, Gess, F.W. 2007, Gess, S.K. and Gess, F.W. 2010, Gess, S.K. and Gess, F.W. 2014).

In the semi-arid to arid areas of southern Africa six genera of Boraginaceae (sensu lato) were sampled. Grouped together they were recorded as visited by 12 species of wasps representing four families, including pollen wasps, and 52 species of bees representing five families. In addition to the two apparently monophagous species of pollen wasps closely associated with *Heliotropium tubulosum* E. Mey. Ex A.DC., two further species of pollen wasps, *Jugurtia codoni* Gess and *Quartinia codoni* Gess (Gess 2007) were found to be closely associated with *Codon royeni* L.

Brassicaceae

Brassicaceae is well represented in the UAE, 23 species having been recorded in Jongbloed (2003). Of these most are found to the east of the DDCR. Khafaga (2009) lists three annuals, *Brassica muricata*, *Eremobium aegyptiacum*, *Sisymbrium erysimoides*, and one perennial, *Farsetia linearis*, within the DDCR.

Farsetia linearis was encountered only in the enclosure at the Lucerne Farm where only one flower visitor, a female *Ceratina parvula* (Xylocopinae) was recorded.

Capparaceae

Jongbloed (2003) gives an account of 11 species of Capparacae occurring in the UAE. Most species occur to the east or west of the central desert. Only two species are expected in the central desert, the most widespread, *Dipterygium glaucum*, is the only species recorded from the DDCR by Khafaga (2009) and the only species found in flower and sampled in the present study. The other species likely to bee found within the DDCR is *Cleome amblyocarpa* Barr. & Murb.

During the present study the flowering of *Dipterygium glaucum* (Figure 35) was nearing its end and very few flower visitors were observed. At Quarn Nazwa one chry-

Figure 35. Capparaceae: *Dipterygium glaucum*.

sidid and one *Thyreus elegans* (Apidae: Apinae: Melectini) were recorded, from Tawi Ruwayan one *Amegilla byssina* (Apidae: Apinae) and one megachilid, and from the enclosed dune area at the Lucerne Farm one *Bembix saadensis* (Crabronidae: Bembicinae). This is unlikely to be truly representative. Petals were being eaten by two species of meloid beetles.

Caryophyllaceae

Twenty-one species of Caryophyllaceae are given in Jongbloed (2003), most to the east or west of the central desert and are therefore not expected in the DDCR. Khafaga (2009) recorded *Polycarpaea repens, Sclerocephalus arabicus* and *Silene villosa*. In the present study none was common, however, scattered plants of *P. repens* and *S. villosa* were present in flower in the enclosed area of the Lucerne Farm. Only one visitor to *P. repens*, *Palarus parvulus* (Crabronidae: Crabroninae: Palurini), was recorded.

Fabaceae: Mimosoideae

Jongbloed (2003) gives accounts for three species of *Acacia* and three species of *Prosopis*, one exotic, occurring in the UAE. Of these Khafaga (2009) recorded *Acacia tortilis* and *Prosopis cineraria* from the DDCR. *Acacia nilotica* (L.) Delile has been introduced in various areas where trees have been planted.

Surprisingly, within the DDCR *Acacia tortilis* (Figures 36 and 37) was receiving very few visits, only *Thyreus hyalinatus* (Apidae: Apinae: Melectini) having been recorded. However, at a site to the east of the reserve, in a single sampling, Scoliidae (1 sp.), Crabronidae (Crabroninae 3 spp., Bembicinae 2 spp.), Halictidae (Nomioidinae 1 sp.), Megachilidae (Megachilinae: Megachilini 1 sp.), and Apidae (Apinae: Anthophorini 1 sp., Xylocopinae: Ceratinini 1 sp) were recorded.

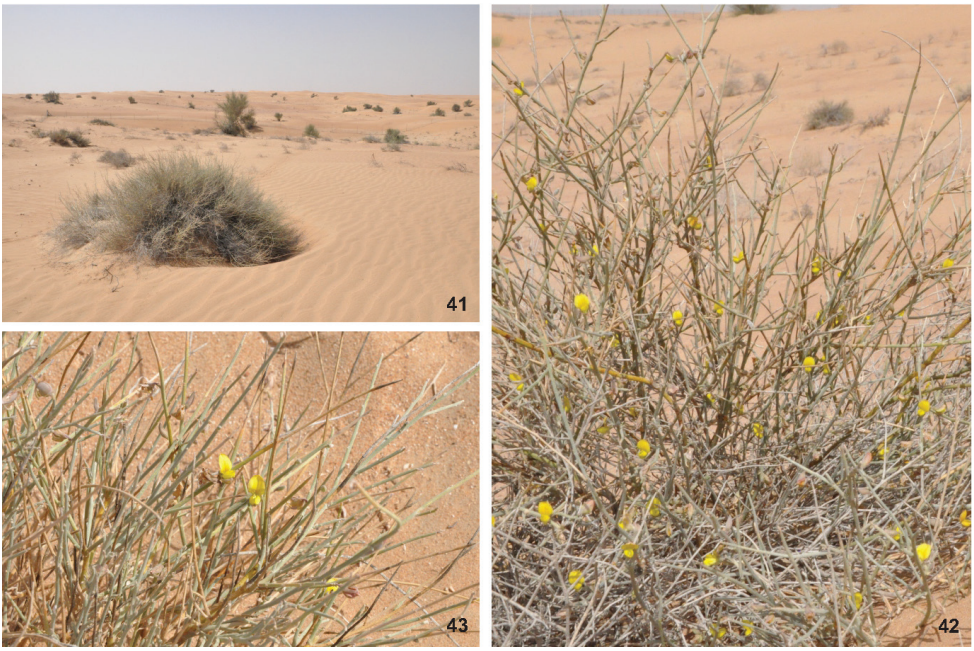
Prosopis cineraria (Figures 38–40) in some parts of the reserve was receiving very few visits whereas in others it was well visited, receiving visits from wasps Sphecidae: Sphecinae, Crabronidae (Crabroninae 4 spp., Bembicinae 1 sp.) and Philanthinae (3 spp.) and bees Halictidae (Nomioidinae 3 spp.), Megachilidae (Megachilinae (2 spp.), and Apinae (*Apis* (*Micrapis*) *florea* which had a hive in one of the trees at Tawi Ruwayan). Occasionally the flowers were visited by braconid wasps.

It seems probable that in a good season there would be a much greater diversity of flower visitors. In the semi-arid to arid areas of southern Africa activity varies considerably from year to year, however, in the survey by the Gesses over many years, the total number of wasp species visiting Mimosoideae was 114 species representing eight families (30.04% of the total number of species of wasps recorded from flowers) with, however, only 28 species of bees, all polyphagous, of four families (6.2% of the total number of species of bees recorded from flowers) (Gess and Gess 2006).

Figures 36–40. Fabaceae, Mimosoideae: **36, 37** *Acacia tortilis* **38–40** *Prosopis cineraria*.

Fabaceae: Papilionoideae

Papilionoideae are well represented in the UAE by 44 species (Jongbloed 2003). Most species occur to the east and west of the central desert. As could be expected from



Figures 41–43. Fabaceae: Papilionoideae: *Crotalaria aegyptiaca*.

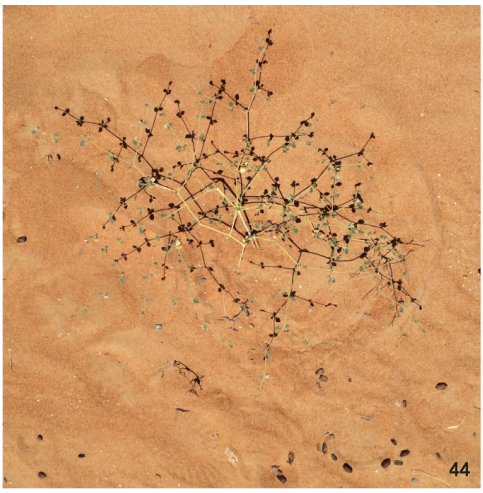
known distributions Khafaga (2009) recorded three species, *Crotalaria aegyptiaca*, *Indigofera colutea* and *I. intricata* from the DDCR.

During the present study *Crotalaria aegyptiaca* and *Indigofera intricata* were found in flower and were observed for flower visitors, the former in the dune enclosure where there were a good number of plants and the Lucerne Farm dune enclosure where only one plant each of this species and of *I. intricata* were found.

Within the Dune Enclosure *Crotalaria aegyptiaca* (Figures 41–43) was well visited by two species of bees, an un-described species of *Icteranthidium* (Megachilidae: Anthidiini), not recorded from any other plant and therefore possibly specializing in visiting the flowers of the Papilionoideae, and by polyphagus *Amegilla byssina* (Apidae: Apinae). Both in size and behavior are potential pollinators, however, *Icteranthidium* is likely to be the most reliable pollinator. The only other visitor to the flowers was a small polyphagous wasp, an undescribed species of *Laphrogogus* (Crabronidae: Eremiasphecinae), which can be discounted as a potential pollinator.

The presence of Anthidiini in the samples from Papilionoideae but not from Mimosoideae is expected, if comparison is made with Papilionoideae and Mimosoideae in southern Africa (Gess and Gess 2006).

The only visitor recorded as visiting *Crotalaria aegyptiaca* in the Lucerne Farm dune enclosure was a polyphagous bee, *Megachile patellimana* (Megachilini), also recorded from Apocynaceae, Boraginaceae, Brassicaceae, and Zygophyllaceae in the dune enclosure at the Lucerne Farm. It is of interest that *M. patellimana,* in Namibia was recorded from flowers of *Crotalaria podocarpa* DC (Papilionoideae) (Gess and Gess 2003).



Figures 44–45. Molluginaceae: *Limeum arabicum*.

Molluginaceae

Only one species of Molluginaceae, *Limeum arabicum*, was listed for the DDCR by Khafaga (2009). However, Jongbloed (2003) gives in addition two other species, *Limeum obovatum* and *Gisekia pharnaceoides* L., occurring in the central desert. *Gisekia pharnaceoides* is known to occur in the DDCR after rain (Greg Simkins pers. com.) and *Limeum obovatum* may well be found in the DDCR.

During the present survey *Limeum arabicum* (Figures 44 and 45), growing on sand dunes, was sampled for flower visitors in the Lucerne Farm dune enclosure, at Tawi Manana and at Quarn Nazwa. At all three sites the flowers were being visited by polyphagous crabronid wasps, represented in the Lucerne Farm dune enclosure by two species of *Palarus* (Crabroninae) and two species of *Bembix* (Bembicinae), at Quarn Nazwa by a third species of *Palarus* and at Tawi Manana by the undescribed species of *Laphrogogus*. At the Lucerne Farm, only, bees were amongst the visitors. They were of two families Halictidae, represented by *Pseudapis nilotica* (Nomiinae), and Apidae, represented by *Ceratina parvula* (Xylocopinae). Three species of meloid beetles were present on the flowers, eating them.

In the arid areas of southern Africa although all Crabronidae visiting *Limeum* are polyphagous, flowers of *Limeum* species are considered to be an important nectar source for these wasps and that in all probability they provide a pollination service (Gess and Gess 2006).

Neuradaceae

Neuradaceae is a small family restricted to semi-arid to arid regions. One genus *Neurada* is represented in North Africa across the Middle East and Arabia to India. In southern Africa it is represented by two genera *Grielum* and *Neuradopsis*.

Figure 46. Neuradaceae: *Neurada procumbens*.

In the UAE (Jongbloed 2003) Neuradaceae appears to be represented by only one species, *Neurada procumbens* (Figure 46), common and widespread except in the mountains. It is recorded from the DDCR (Khafaga 2009). During the present study *N. procumbens* was found in very small numbers only in the Lucerne Farm dune enclosure where the only recorded visitor to its small white flowers was a small halictid bee (Tables 3 and 4).

The southern African species have larger yellow flowers that attract bees from five families, including Halictidae. Also amongst their visitors is a pollen wasp, a species of *Quartinia*, and a chrysidid.

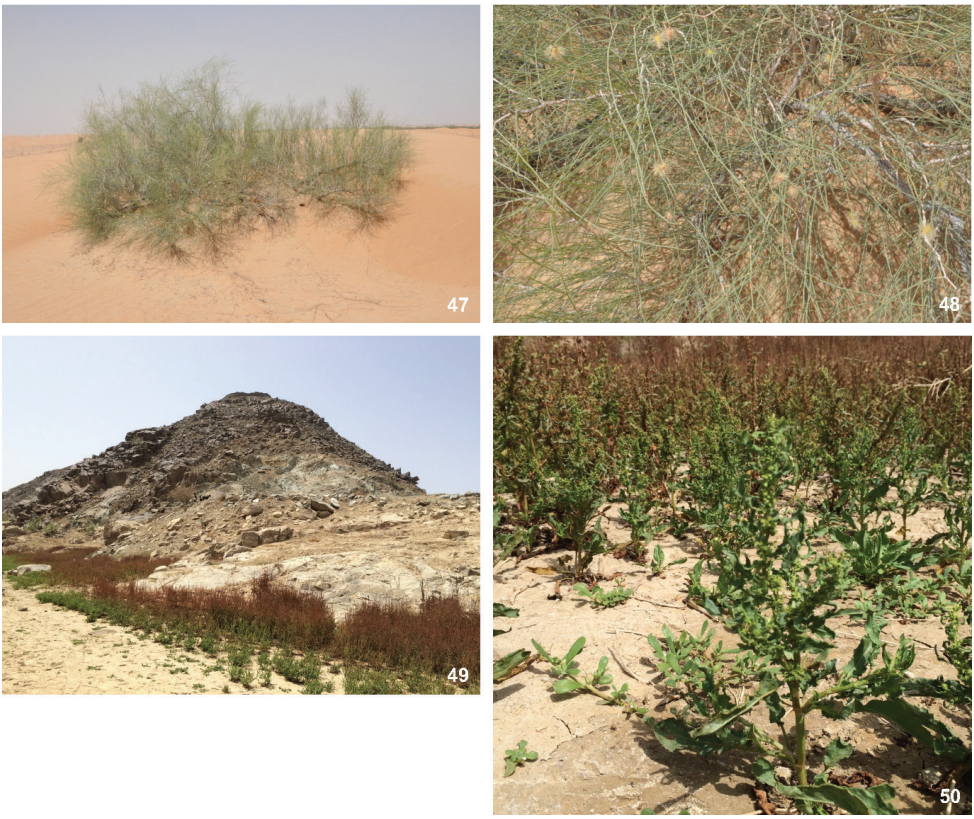
Polygonaceae

For Polygonaceae Jongbloed (2003) gives accounts for eight species in four genera. Of these only the woody shrub *Calligonum comosum* (Figures 47 and 48), common on sand dunes and plains in the UAE, was recorded from the DDCR (Khafaga 2009). At the time of this survey no plants were found in flower.

To the east of the Reserve *Rumex dentatus*, recorded by Jongbloed from scattered locations along the Gulf Coast, was found in flower fringing the area from which the water had retreated at Shawka dam in the Haja Mountains. At this site *R. dentatus* (Figures 49 and 50) was attracting visits from aculeate wasps of the families, Vespidae (Emeninae and Polistinae), Pompilidae, Sphecidae, Crabronidae and bees of the family Halictidae (Tables 3 and 4).

Solanaceae

For Solanaceae Jongbloed (2003) gives accounts for eight species, in seven genera. Of these all but one, a woody shrub, *Lycium shawii* (Figures 51 and 52), are absent from the central desert and it is only this species that is listed for the DDCR (Khafaga 2009). In the present study *L. shawii* was observed for flower visitors at several scat-



Figures 47–50. Polygonaceae: **47, 48** *Calligonum comosum* **49, 50** *Rumex dentatus*.

tered localities, including Quarn Nazwa, where it was growing on the sides of dunes. From sampling *Lycium* flowers in the semi-arid to arid areas of southern Africa it was expected that the flowers would be visited by diverse wasps and bees (Gess and Gess 2006), however, no visitors were observed.

An exotic weed, *Solanum nigrum* (Figure 53), which offers nectar produced from extra-floral nectaries on petioles, leaves and stems (Anderson and Simon 1985), was growing near a dripping tap on he outskirts of the village of Munay in the east. It was sampled, yielding one species each of the families Pompilidae, Scoliidae, Sphecidae, Crabronidae and Halictidae.

Zygophyllaceae

Jongbloed (2003) gives accounts for 11 species of Zygophyllaceae, three species of *Fagonia*, five species of *Tribulus*, and three species of *Zygophyllum*. Of these Khafaga (2009) lists *Fagonia indica*, *Fagonia* sp., *Tribulus macropterus*, *T. omanense*, and *T. pentandrus*.

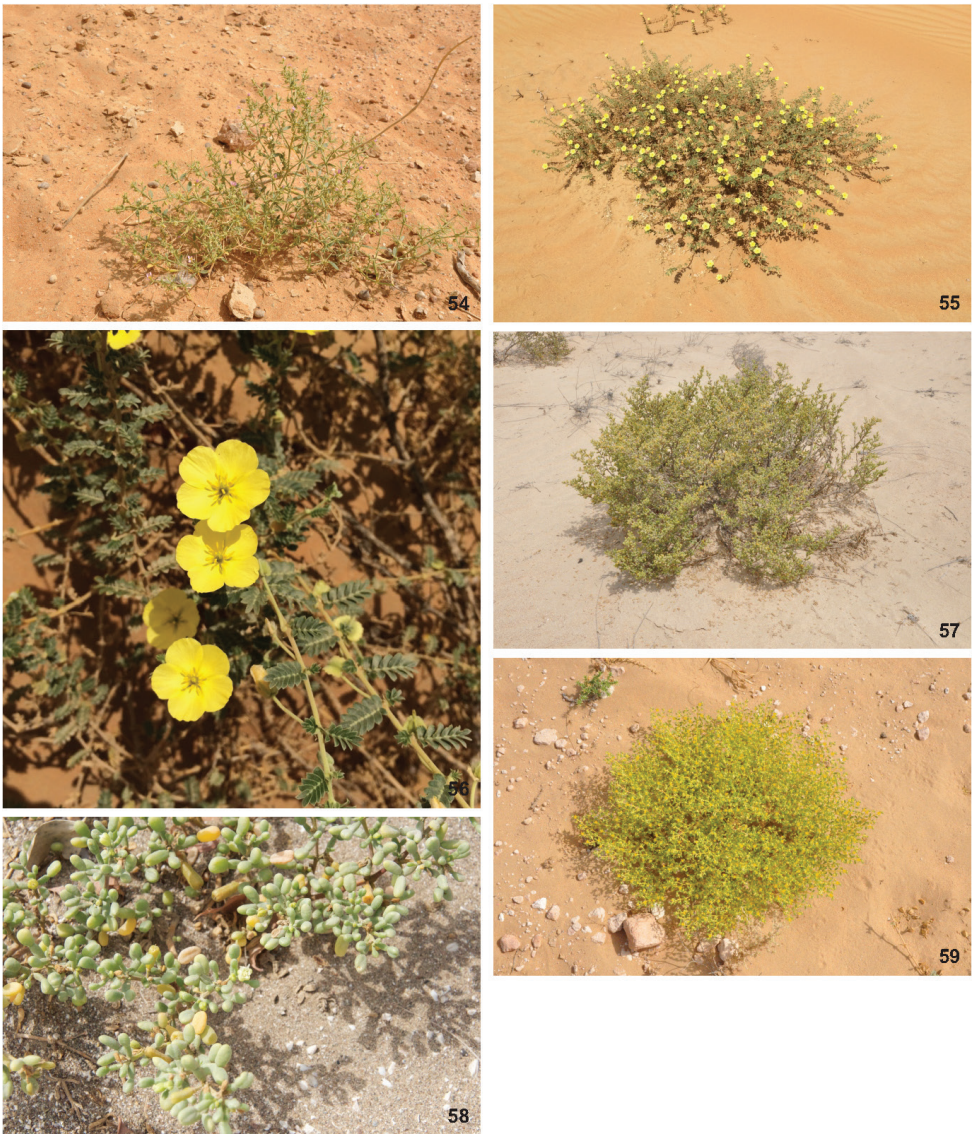
Figures 51–53. Solanaceae: **51–52** *Lycium shawii* **53** *Solanum nigrum*.

Fagonia indica (Figure 54) was in flower during the present survey but no visitors to its flowers were observed.

Well grown plants of *Tribulus macropterus* (Figures 55 and 56) in full flower were abundant within the Lucerne Farm dune enclosure where they were being well visited. Sampling was undertaken on three days, yielding most commonly five species of crabronid wasps, *Palarus laetus* (Crabroninae: Palurini) and four species of *Bembix* (Bembicinae: Bembicini), and by a megachilid bee, *Megachile patellimana*. Less commonly two other bees were represented, *Ceratina parvula* (Apidae: Xylocopinae: Ceratinini) and *Nomioides klausi* (Halictidae: Nomioidinae). Several species of meloid beetles were commonly present, eating the petals of the flowers. Outside the enclosure scattered remnants of grazed plants were occasionally found.

Along the side of the Margham Road outside the DDCR large plants of *Tribulus macropterus* were in flower. Some of these were checked, briefly, for visitors. The only visitor recorded was a single female of *Bembix rochei*, one of the four species of *Bembix* recorded at the Lucerne Farm.

Although it would appear from distributions given in Jongbloed (2003) that some species of *Zygophyllum* might be found in the DDCR none was recorded by Khafaga (2009) and none was found in the DDCR during the present survey.



Figures 54–59. Zygophyllaceae: **54** *Fagonia indica* **55, 56** *Tribulus macropterus* **57, 58** *Zygophyllum qatarense* **59** *Zygophyllum simplex.*

Zygophyllum species are amongst the dominant plants across the sandy plains to the west coast. *Zygophyllum qatarense* (Figure 33), a perennial dwarf shrub, and *Z. simplex* (Figure 34), a succulent annual, were sampled to the west of the reserve during the one-day transect to the west coast.

Zygophyllum qatarense (Figures 57 and 58) and *Z. simplex* (Figure 59), like *Tribulus macropterus*, were principally visited by Crabronidae, however, the assemblages did

not share species in common. Recorded were two species of *Cerceris* (Philanthinae) and *Gastrosericus waltlii* (Larrini) also recorded visiting flowers of *Z. simplex* in Namibia, southern Africa (Gess and Gess 2003). In addition *Telostegus argyrellus*, the only pompilid recorded from Zygophyllaceae was visiting *Z. qatarense* at the coast.

In southern Africa, *Zygophyllum* is more species diverse and more diverse in habit than in Arabia and the suites of visitors are, not surprisingly, more diverse. However, comparable species are *Z. simplex*, which is widespread from northern Richtersveld northwards through Namibia, and several northern coastal and desert perennial dwarf shrubs. *Z. simplex* is an important resource for wasps and bees in that area. Amongst the visitors Gess and Gess (2006) recorded 21 species of hunting wasps representing six families, five species of pollen wasps and 15 species of bees. The perennial dwarf shrubs are equally attractive to hunting wasps, pollen wasps and bees although they never attract as great a diversity and as great a number of individuals as does *Z. simplex.*

Aculeate wasps and bees visiting flowers

Table 4 lists the names of the aculeate wasps and bees recorded from flowers with the plant names together with the numbers and sex of the visitors and the collection sites.

Chrysidoidea

Chrysididae

Very few Chrysididae were observed during the survey. Single specimens, not identified beyond family, were collected from flowers of Asclepiadoideae, *Calotropis procera*, Boraginaceae, *Heliotropium kotschyi*, and Capparaceae, *Dipterygium glaucum*, at three widely separated sites within the DDCR.

Vespoidea

Vespidae
Masarinae

At the time of the survey Masarinae were uncommon, two species, *Celonites jousseaumei* and *Quartinia nubiana*, were collected within the DDCR and one, *Celonites yemenensis*, to the east of the reserve.

The flower associations were for two species of Boraginaceae. *Quartinia nubiana,* represented by two females, was visiting flowers of *Heliotropium kotschyi* at Tawi Ruwayyan. One specimen of *C. jousseaumei* was caught flying over flowering *Heliotropium kotschyi* at the same site and another was observed flying away from an isolated

plant of *Moltkiopsis ciliata* at the Lucerne Farm, suggesting an association with *Heliotropium* and its allies, supported by an association of this species with *Heliotropium* in Morocco (Volker Mauss pers. com.).

Two specimens of *Celonites yemenensis* in flight, not associated with flowers, were collected, one in a wadi in the Hajar Mountains and the other on the bank of the lagoon at Khor Kalba where it was flying between *Zygophyllum qatarense* and *Heliotropium kotschyi.*

Of interest is the photographic record of M. Hauser of *Jugurtia jemenensis* Kostylev visiting flowers of Asteraceae (plate 74 in Gusenleitner 2010). No locality is given, however, the collection records given for this species are all wadis in the Hajar Mountains.

Eumeninae

Remarkably few Eumeninae were encountered during the present survey. Within the DDCR the only eumenine observed visiting flowers was *Rhynchium oculatum,* which was recorded from flowers of *Calotropis procera* (Asclepiadoideae). The only other species taken from flowers was *Delta esuriens esuriens* visiting *Rumex dentatus* (Polygonaceae), growing around Shawka Dam east of the reserve.

Polistinae

One species of Polistinae, *Polistes watti,* was encountered at two sites within the DDCR, Quarn Nazwa watering point at the northern end of the reserve and the palm grove at the Camel Farm, and one site, Shawka Dam, east of the reserve. Water was being imbibed at all sites, and nests were present in the palm grove. Flower visiting was observed at only two plants, *Aerva javanica* (Amaranthaceae) at Quarn Nazwa and *Rumex dentatus* (Polygonaceae) at Shawka Dam.

Vespinae

Vespa orientalis was not observed in the DDCR but was present to the east at Shawka Dam where it was associated with plants of *Rumex dentatus* (Polygonaceae).

Pompilidae

Remarkably few pompilids were encountered during the present survey: three species of Pompilinae, *Anoplius suspectus*, visiting *Rumex dentatus* (Polygonaceae) to the east of the reserve at Shawka Dam; *Telostegus argyrellus*, visiting *Calotropis procera* (Asclepiadoideae) at one site in the reserve, and *Zygophyllum qatarense* to the west of the reserve; and one species of Ceropalinae, *Ceropales kriechbaumeri* on *Heliotropium kotschyi* (Boraginaceae) within the reserve and on the solanaceous weed, *Solanum nigrum*, to the east.

Tiphiidae

In the present survey only two species of tiphiids were observed visiting flowers: *Calotropis procera* (Asclepiadoideae) within the DDCR, and *Zygophyllum simplex* to the west of the reserve.

Mutillidae

No mutillidae were observed visiting flowers. Those seen were males coming to the light in the evening.

Scoliidae

Scoliids were observed principally visiting the flowers of *Calotropis procera* (Asclepiadoideae) from which, due to the size of the plant, they were difficult to catch, however, voucher specimens of two Campsomerinae, *Campsomeriella procera* (two females, one on each of two days) and *Micromeriella hyalina* (one female), and one Scoliinae, *Scolia flaviceps* (four females, two on each of two days) were taken from three sites within the DDCR, two of which offered a good diversity of flowers. Clearly, though not restricted to *C. procera,* scoliids appear to be strongly attracted to this plant. They are, however, only one of six families of wasps and one family of bees visiting this plant.

Males of the third species, *Micromeriella hyalina*, were caught on *Heliotropium kotschyi* (Boraginaceae) at a fourth site in the reserve, and at two sites east of the reserve, at one on *Acacia tortilis* (Mimosoideae) and at the other on a weed, *Solanum nigrum* (Solanacae) on the outskirts of a village.

Apoidea - Spheciformes

Sphecidae

Sphecidae were remarkably uncommon. Only one species was encountered within the reserve, namely *Prionyx nigropectinatus* (Sphecinae), which was visiting the flowers of *Prosopis cineraria* (Mimosoideae) at the Faqah watering point at the southern end of the reserve.

Two other species were found east of the reserve: *Ammophila rubripes* (Ammophilinae) visiting the solanaceous weed, *Solanum nigrum*; and *Sceliphron madraspatanum pictum* (Sceliphrinae) visiting *Rumex dentatus* (Polygonaceae).

Crabronidae

Crabronidae was the only family of wasps well represented during the present survey, with 27 species from within the DDCR, five additional species to the east and another

one to the west – in all 33 species representing 14 genera, nine tribes and five subfamilies with almost a third of the species belonging to the genus *Bembix*.

In all Crabronidae were recorded from 10 plant families, 59% of the families from which flower visitors were recorded. The percentages of these species visiting these 10 families was 57% Fabaceae (Mimosoideae), 43% Zygophyllaceae, 38% Apocynaceae (Asclepiadoidea), 38% Boraginaceae, 29% Molluginaceae, 24% Asteraceae, and 10% and fewer Amaranthaceae, Capparaceae, Caryophyllaceae, Fabaceae (Papilionoideae), Solanaceae and Polygonaceae.

Of interest, a specimen of *Bembix kohli*, collected from *Calotropis procera*, was carrying pollinia, making it a potential pollinator of this plant.

Apoidea – Apiformes

The total number of species of bees (23 spp.), 20 from within the DDCR and an additional three from the east, was surprisingly low, compared with the number of Crabronidae.

Halictidae

Of the large family Halictidae only six species representing four genera were recorded from flowers: within the DDCR – *Nomia* (*Pseudapis*) (1 sp.) (Nomiinae), and *Ceylalictus* (3 spp.) and *Nomioides* (1 sp.) (Nomioidinae); and to the east the same species of *Nomia* (*Pseudapis*) plus *Nomia* (*Crocisaspidia*) (1 sp.). Strangely no Halictinae were recorded.

In total, flowers of five families of plants within the reserve and two further to the east, were recorded as visited, the number of families visited by single species ranging from one to three. The plant families visited by more than one species were Borgaginaceae, four species, and Fabaceae (Mimosoideae) three species, all within the reserve.

In the semi-arid to arid areas of southern Africa Halictidae are species diverse and include some of the commonest bees (Eardley et al. 2010, Eardley and Urban 2010, Gess and Gess, 2014). Gess and Gess (2004 and 2014) recorded a high incidence of polyphagy throughout the family with possible preferences being discernable in the Halictinae.

Colletidae

One species only of Colletidae was collected but it was not associated with a flower.

Megachilidiae

Megachilidae collected in the DDCR were represented by seven species of Megachilinae: five Megachilini, *Megachile concinna*, *M. minutissima*, *M. patellimana*, *M. maxillosa* and

Coelioxys indica; one Osmiini, *Haetosmia circumventa*; and two Anthidiini, *Icteranthidium* n. sp. and *Pseudoanthidium ochrognathum*.

Megachile concinna, *M. minutissima* and *M. patellimana*, were all collected from flowers of Fabaceae (Mimosoideae); *M. concinna* and *M. patellimana* in addition from Apocynaceae (Asclepiadoidea), *Leptadenia pyrotechnica*; and *M. patellimana*, the most common species, in addition from Asteraceae, Boraginaceae, Brassicaeae, Fabaceae (Papilionoideae) and Zygophyllaceae but most commonly from *Heliotropium kotschyi* at three sites and *Tribulus macropterus* at one of the same sites, none the less demonstrating broad polyphagy.

A female *Megachile patellimana,* captured carrying leaf pieces, was nesting in the sand beneath *H.eliotropium kotschyi* where *Coelioxys indica* was seen to be inspecting burrow openings. *Coelioxys indica* was visiting *H.eliotropium kotschyi* together with *M. patellimana*. As *Coelioxys* are known to be cleptoparasites of megachilids it is suggested that *M. patellimana* is a host of *Coelioxys indica.*

Megachile patellimana is represented in Namibia, where it has been collected from flowers of *Crotalaria podocarpa* DC (Papilionoideae) (Gess and Gess 2003).

No visits to flowers were observed for *Megachile maxillosa,* although it was nesting in trap nests, one bundle tied to a branch of *Calotropis procera* outside the drip irrigation area at Tawi Ruwyyan and the other on the trunk of a palm tree in the grove at the Camel Farm. This species was commonly collected visiting flowers in the semi-arid to arid areas of South Africa and Namibia (Gess and Gess 2003) where it was shown to be polyphagous, having been collected from flowers of Acanthaceae, Asclepiadoideae, Asteraceae, Brassicaceae, Fabaceae (Caesalpinioideae, Mimosoideae and Papilionoideae), Pedaliaceae and Polygalaceae, however, in Namibia it was most commonly visiting Papilionoideae, most notably species of *Crotalaria*.

Haetosmia circumventa was collected from three sites during five collecting events. All specimens were visiting flowers of *Heliotropium kotschyi* (Boraginaceae), suggesting a preference for Boraginaceae, supported by Gotlieb et al. (2014) in which it is recorded that *H. circumventa* is oligolectic, specialising in collecting pollen from the flowers of *Heliotropium*, for which purpose the mouthparts are modified to extract pollen from narrow floral tubes.

Icteranthidium n. sp was observed during two collecting events at *Crotalaria aegyptiaca* to be the most common visitor to flowers of this plant. Furthermore, it was not visiting other flowers at the same or any other site, suggesting that it may specialize in visiting Papilionoideae, which taken together with its behavior and fit would suggest that it is a likely pollinator of *C. aegyptiaca*.

Pseudoanthidium ochrognathum was most commonly observed visiting flowers of Boraginaceae, *Heliotropium kotschyi* and *Moltkiopsis ciliata*, suggesting a preference for Boraginaceae, however, one specimen was taken from *Aerva javanica* growing in close proximity to *M. ciliata*.

It would appear that in the DDCR, as in the semi-arid to arid areas of southern Africa (Gess and Gess 2004 and 2014) Megachilini are polyphagous but for some species of Osmiini and Anthidiini strong preferences are suggested.

Apidae

During the course of the present survey, remarkably few species of Apidae were observed visiting flowers: six species of Apinae, two Apini and four Anthophorini; and four species of Xylocopinae, two Xylocopini and two Ceratinini.

The two species of *Apis*, *A.* (*Micrapis*) *florea* and *A. mellifera*, are well known to be broadly polyphagous.

The two species of Anthophorini, *Amegilla bysina* and *Anthophora tenella*, and one of the two species of Melectini, *Thyreus hyalinatus*, were represented amongst the visitors to *Heliotropium kotschyi*. However, *A. bysina*, typically for *Amegilla*, is broadly polyphagous. In the DDCR it was represented in samples from, Asclepiadoideae, Asteraceae and Papilionoideae, in addition to Boraginaceae.

Anthophora tenella was taken not only from flowers of Boraginaceae but also of Mimosoideae. *Thyreus elegans* was uncommon, only one specimen, a single female, having been found visiting flowers of *Dipterygium glaucum* (Capparaceae). As *Thyreus* are nest parasites of anthophorines it was surprising that they were so uncommon.

The two large carpenter bees, *Xylocopa fenestrata* and *X. aestuans* were both commonly seen visiting *Calotropis procera* (Asclepiadoideae) at various sites. At Quarn Nazwa, where *C. procera* was not present, *X. fenestrata* was collected from flowers of *Centaurea pseudosinaica* (Asteraceae).

The two small carpenter bees, *Ceratina parvula* and *C. tarsata* were not represented in samples from *Calotropis procera.* In the dune enclosure at the Lucerne farm, where *C. procera* is well represented, *C. parvula* was visiting flowers of *Heliotropium kotschyi*, *Limeum arabicum* and *Tribulus macropterus*. *Ceratina tarsata*, represented by a single female, was taken in a sample of visitors to flowers of *Acacia tortilis* at a site east of the DDCR.

Conclusions

Although this first survey of flower visiting by wasps and bees in the UAE, with the DDCR as the focus of the study, was conducted over a limited period of time, during a dry spring, following seven dry years, it has provided sufficient data to draw some general conclusions.

- Most of the plants sampled attract visits from a complex of both wasps and bees.
- The flowers of some of these plants attract a wide range of wasps and bees but there were no flowers that were attractive to all available wasps and bees at any one site.
- Very few species of the wasps and bees encountered were specialists.
- The plants on which these specialist wasps and bees were dependent were not themselves dependent on these wasps and bees for pollination, however, some of the specialist wasps and bees are likely to be their most dependable pollinators.

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Appendix 1

List of plants from the flowers of which aculeate wasps and bees were collected, with global distributions.

ACANTHACEAE: *Aerva javanica* (Burm. *f.*) Juss. ex Schult. – Northern Africa to southwestern Asia. Introduced and naturalised in northern Arabia (http://www.ddcr.org/florafauna) Sampled in **DDCR**

AIZOACEAE

Sesuvium verrucosum Raf. – native to the Americas, where it can be found in the southwestern quadrant of the United States (California, Oregon, Baja California, east to Utah, Kansas, Texas) and northern Mexico, it also occurs in southern Brazil. It is naturalized in the Arabian Peninsula (http://www.llifle.com/Encyclopedia/SUCCULENTS/Family/Aizoaceae/28896/Sesuvium_verrucosum) Sampled in **DDCR**

APOCYNACEAE (Asclepiadoideae)

Calotropis procera (Aiton) W.T. Aiton – native to West Africa as far south as Angola, North and East Africa, Madagascar, the Arabian Peninsular, Southern Asia and Indo-China to Malaysia. Introduced and naturalized in Australia, many Pacific Islands, Mexicao, Central and South America and the Caribbean Islands (http://www.ddcr.org/florafauna) Sampled in **DDCR**

Leptadenia pyrotechnica (Forssk.) Decne – Senegal, Mauritania to north of Nigeria, the semi-desert areas across Africa (Egypt, Sudan, Somalia, Chad, Libya, Algeria) to Western India (Pakistan and India) – (http://www.ddcr.org/florafauna) Sampled in **DDCR**

ASTERACEAE

Centaurea pseudosinaica Cerep. – Western Asia, Iraq, Iran, Arabian Peninsula, including UAE (http://www.catalogueoflife.org/col/details/species/id/6a39f8876432e32027c6dcb108b5781f/source/tree) Sampled in **DDCR**

Launaea procumbens (Roxb.) Ramayya and Rajagopal – Egypt, Iraq, Iran, Asia (Turkmenistan, Uzbekistan, Tadzhikistan, Afghanistan, Pakistan, India, Nepal, Burma, China). Arabian Peninsula including the UAE (eol.org) Sampled in the **DDCR**

Rhanterium epapposum Oliv. – Western North Africa, Iraq, Iran, Arabian Peninsula, including UAE (http://www.ddcr.org/florafauna) Sampled in **DDCR**

BORAGINACEAE

Arnebia hispidissima (Lehm.) DC; *Heliotropium digynum* (Forssk.) Asch. ex Chr. – Northern Africa (Nigeria, Cameroon, Chad, Sudan, Egypt) to the Arabian Peninsula, northern India and Pakistan (http://www.ddcr.org/florafauna) **DDCR**

Heliotropium kotschyi (Bge.) Gurke – Arabian Peninsula. Sampled in **DDCR** and also west of the DDCR

Moltkiopsis ciliata (Forssk.) I.M. Johnst. – Widely distributed in Mediterranean Region and Arabia including UAE (http://www.ddcr.org/florafauna) Sampled in **DDCR**

BRASSICACEAE

Farsetia linearis Decne. Ex Boiss. Arabian Peninsula, Yemen, Oman, UAE. Sampled in **DDCR**

CAPPARACEAE:

Dipterygium glaucum Decne. – Northern Sudan and Egypt east of the Nile through the Arabian Peninsula to the desert areas of North West India (Rajasthan, Gujarat and Pakistan) (http://www.ddcr.org/florafauna) Sampled in **DDCR**

CARYOPHYLLACEAE

Polycarpaea repens (Forssk.) Asch. & Schweinf. – Mauritania, Niger, Chad, Libya, Tunisia, Algeria, Morocco, Sahara, Egypt, Iraq, Iran, Israel, Sinai, Arabian Peninsula (www.gbif.org) Sampled in **DDCR**

FABACEAE: Mimosoideae

Acacia tortilis (Forssk.) Hayne – Widespread in Africa from South Africa northwards to Algeria and Egypt, extending to Asia and southern Arabia. Cultivated in India and Pakistan ((http://www.ddcr.org/florafauna) Sampled in **DDCR** and also east of the DDCR

Prosopis cineraria (L.) Druce – India, Pakistan, Afghanistan, Iran, Arabian Peninsula (http://www.ddcr.org/florafauna) Sampled in **DDCR**

FABACEAE: Papilionoideae

Crotalaria aegyptiaca Benth. – Egypt, Somalia, Iran, Arabian Peninsula (Saudi Arabia, Oman, Yemen, UAE), Jordan, Palestine, Israel (http://www.ddcr.org/florafauna) Sampled in **DDCR**.

MOLLUGINACEAE

Limeum arabicum Friedr. – Saudi Arabia, Oman, Yemen, UAE (http://www.catalogueoflife.org) Sampled in **DDCR**

NEURADACEAE

Neurada procumbens L. – North Africa, East Mediterranean Region, Sinai, Sahara, Sudan, Ethiopia, Arabia to Indian Desert. (http://eol.org/pages/6872917/overview) Sampled in **DDCR**

POLYGONACEAE

Rumex dentatus L. – Europe, Mediterranean region, Arabia, Asia (http://eol.org/pages/587351/details#overview) Sampled to the west of the DDCR

SOLANACEAE

Solanum nigrum L. – native to Europe and western Asia, introduced in North America, Africa, Asia and Australia (http://www.globinmed.com/) and Arabia. Sampled to the west of the DDCR

ZYGOPHYLLACEAE

Tribulus macropterus Boiss. – Algeria, Libya, Egypt, Palestine, Arabia, Iraq, Iran, Afghanistan, Sudan (http://eol.org/pages/5633281/details) Sampled in **DDCR**

Zygophyllum qatarense Hadidi – Arabian Penisula. Sampled to the west of the DDCR

Zygophyllum simplex L. – Africa, Madagascar, Arabia, Palestine, India (http://eol.org/pages/5633281/details) Sampled to the west of the DDCR

Appendix 2

List of aculeate wasps and bees collected in the DDCR and from the transect to the east and west coasts, with global distributions.

Chrysidoidea

Chrysididae

Undetermined, **DDCR**

Vespoidea

Vespidae

Masarinae

Celonites jousseaumei du Buysson, 1906, Algeria to Israel, southwards to Sudan and the Arabian Peninsula, including the UAE (Schmid-Egger, 2015) **DDCR**

Celonites yemenensis Giordani Soika, 1957, Arabian Peninsula including UAE, Ethiopia (Schmid-Egger 2015) in present survey found to the east of the DDCR

Quartinia nubiana Richards, 1962, Tunisia, Libya, Egypt and UAE (Schmid-Egger 2015) **DDCR**

Eumeninae

Delta esuriens esuriens (Fabricius, 1787), India through to Iran and the Arabian Peninsula, including UAE (Gusesenleitner 2010) in present survey found to the east of the DDCR

Rhynchium oculatum (Fabricius, 1781), Mediterranean Region to India, Arabian Peninsula including UAE (Gusesenleitner 2010) **DDCR**

Polistinae

Polistes watti Cameron, 1900, Arabian Peninsula including UAE to China (Gusesenleitner 2010) **DDCR**

Vespinae

Vespa orientalis Linnaeus, 1771, Southern Italy and Libya to India and Nepal, UAE (Gusesenleitner 2010) in present survey found east of the DDCR

Pompilidae

Pompilinae

Anoplius suspectus (Saussure, 1904), North Africa, Algeria, Egypt; Arabia, Yemen; Asia, India, Nepal, Pakistan, Laos, Thailand, Sumba (Wahis, 2006) in present survey found east of the DDCR

Gonaporus israelicus Wolf, 1990, Israel, UAE, **DDCR**

Telostegus argyrellus (Klug, 1834), North Africa, Algeria, Tunisia, Morocco, Libya, Egypt; West Africa, Mauritania, Niger, Senegal; Turkey, Jordan, Israel, Iran; Asia, Pakistan, Turkmenistan, Kyrgyzstan; Europe, Portugal, Spain (insectoid.info/checklist/pompilini/ and Gahari et al. 2014) UAE, **DDCR**

Ceropalinae

Ceropales kriechbaumeri Magretti, 1884, Burkina Faso, Nigeria, South Africa, Zimbabwe, Uganda (http://www.waspweb.org/Vespoidea/Pompilidae/Ceropalinae/Ceropales/index.htm), UAE, **DDCR**

Tiphiidae: Thynninae
In present survey one specimen of one species west of the DDCR

Mutiliidae
To light in **DDCR**

Scoliidae

Campsomerinae
Campsomeriella thoracica (Fabricius, 1787), Sahel area of the Afrotropical Region, the Mediterranean area, Arabian Peninsula, including UAE (Schulten 2007) **DDCR**
Micromeriella hyalina (Klug, 1832), Sahel area of the Afrotropical Region, the Mediterranean area, Arabian Peninsula, including UAE (Schulten 2007) **DDCR**

Scoliinae
Scolia flaviceps Eversmann, 1846, Crete, Iraq, Tajikistan, Turkmenistan, Uzbekistan, Central Asia, Cyprus, Transcaucasia, Greece, southern France, Italy, Balkans to the eastern Mediterranean Region, including Egypt to the Caspian Sea, Turkey, Turkmenistan (Samin, Bağriaçik and Gadallah 2014) **DDCR**

Apoidea - Spheciformes

Sphecidae

Sphecinae
Prionyx nigropectinatus Taschenberg, 1869, Libya, Algeria, Egypt, Israel, Mauritania, Tajikistan, Turkmenistan, Oman, Yemen, Iran (Pulawski 2016) **DDCR**

Sceliphrinae
Sceliphron madraspatanum pictum F. Smith, 1856, Mediterranean Region, Iraq, Arabian Peninsula including UAE (Schmid-Egger 2011) in the present survey found east of the DDCR (*Sceliphron madraspatanum* (Fabricius, 1781), India, Maldives, Malaysia, Thailand, Taiwan, Philippines, Japan, China, Kazakhstan, western Russia (Pulawski 2016)

Ammophilinae
Ammophila rubripes Spinola, 1838, widespread throughout Africa from north to south and west to east, Saudi Arabia, Yemen, Oman, UAE, Israel, Syria (Pulawski 2016) in the present survey found east of the DDCR

Crabronidae

Astatinae

Astata prosii Schmid-Egger, 2014, UAE (Pulawski 2016) **DDCR**

Crabroninae: Larrini

Gastrosericus moricei E. Saunders, 1910, North Africa (Algeria, Libya and Egypt), Arabia (Saudi Arabia, Oman and UAE), Israel, Sinai Peninsula, Sri Lanka, Uzbekistan, Tajikistan and Kazakhstan (Pulawski 2016) **DDCR**

Gastrosericus waltlii Spinola, 1839, South western Africa (Namibia), North Africa (Western Sahara, Algeria, Morocco, Libya, Egypt), south east Western Russia, southern France, Cyprus, Turkey, Israel, Iran, Arabia (Saudi Arabia, Kuwait, Oman, UAE), Sri Lanka, Central Asia, Tajikistan, Kazakh, Uzbekistan, China (Pulawski, 2016) in present survey found west of the DDCR

Prosopigastra globiceps Morice, 1989, Mali, Sudan, Egypt, Israel to Central Asia and northwest China, and Arabian Peninsula, including UAE (Schmid-Egger 2011) **DDCR**

Tachysphex erythropus (Spinola, 1839), Morocco, Libya, Spain, Portugal, Italy, Greece, Bulgaria, Turkey, Egypt, Saudi Arabia, Turkmenistan, Kazakhstan, Uzbekistan, Sri Lanka (Pulawski 2016) **DDCR**

Tachysphex micans (Radoszkowski, 1877), Morocco, Libya, Egypt, Turkmenistan, Tajikistan, Kazakhstan (Pulawski 2016) **DDCR**

Tachysphex quadrifurci Pulawski, 1971 = *brevipennis* Mercet, 1909, Spain, Portugal, Greece, Algeria, Morocco, Egypt, Turkey, Ukraine, Crimea, Kazakhstan, Turkmenistan, Iran, UAE, India, Zimbabwe, South Africa (Pulawski 2016) **DDCR**

Tachytes comberi Turner, 1917, Libya, Mauritania, Pakistan, Arabian Peninsula, including Saudi Arabia, Oman, UAE (Pulawski 2016) **DDCR**

Crabroninae: Oxybelini

Oxybelus lamellatus Olivier, 1811, From Southwest Europe and North Africa to Northwest India, southwards to Mali, Nigeria and Niger, Arabian Peninsula, including UAE (Schmid-Egger 2011), West Africa (Mauritania), North Africa (Morocco, Tunisia, Algeria, Libya, Egypt, Sudan, Eritrea, Ethiopia, Somalia), Mediterranean Europe (Spain, Italy, Greece, Cyprus), Turkey, Jordan, Syria, Iraq, Iran, Arabia (Saudi Arabia, UAE), Turkmenistan, Afghanistan, Pakistan, India, Uzbekistan, Kazakhstan, Tajikistan, China (Pulawski 2016), **DDCR**

Crabroninae: Palarini

Palarus bisignatus F. Morawitz, 1890, Central Asia, Saudi Arabia, UAE (Schmid-Egger 2011 and Pulawsi 2016) **DDCR**

Palarus dongalensis Klug, 1845, North Africa (Egypt and Sudan), Iran, Saudi Arabia, Oman, UAE (Schmid-Egger 2011 and Pulawski 2016) **DDCR**

Palarus laetus Klug, 1845, North Africa (Tunisia, Morocco, Egypt, Djibouti), Iraq, Iran, Arabia (Kuwait, Oman, UAE), India (Schmid-Egger 2011 and Pulawski 2016) **DDCR**

Palarus parvulus de Beaumont, 1949, North Africa (Algeria, Egypt) Israel, Arabian Peninsula, including UAE (Pulawski 2016) **DDCR**

Crabroninae: Miscophini

Plenoculus vanharteni Schmid-Egger, 2011, Northeast Coast of UAE (Schmid-Egger 2011 and Pulawski 2016) **DDCR**

Bembicinae: Alyssontini

Didineis bucharica Gussakovskij, 1937, Uzbekistan, Kazakhstan, UAE (Schmid-Egger 2011 and Pulawski 2016) in the present survey found east of the DDCR

Bembicinae: Bembicini

Bembix arenaria Handlirsch, 1893, Tunisia, Egypt, Saudi Arabia, Turkey, Iran, Palestine, UAE (Pulawski 2016) in present survey found east of the DDCR

Bembix chopardi Berland, 1950, North west Africa (Niger), North Africa (Egypt), Arabia (Saudi Arabia, UAE (Pulawski 2016) in present survey found east of the DDCR

Bembix freygessneri Morice, 1897, North-west Africa (Mauritania, Chad), North Africa (Algeria, Libya, Egypt, Sudan), Arabia (Saudi Arabia, Yemen, UAE) (Pulawski 2016) **DDCR**

Bembix gazella Guichard, 1989, Oman (Muscat) and UAE (Pulawski 2016) **DDCR**

Bembix hameri Guichard, 1989, UAE (Pulawski 2016) **DDCR**

Bembix hauseri Schmid-Egger, 2011, Saudi Arabia, Oman, UAE (Pulawski 2016) **DDCR**

Bembix kohli Morice, 1897, Egypt, Iran/Baluchistan and UAE (Schmid-Egger 2011) **DDCR**

Bembix oculata Panzer, 1801, Europe (Germany, Austria, Portugal, Spain, France, Italy, Greece, Hungary, Croatia, Serbia, Bulgaria), Ukraine, Russia, North Africa (Western Sahara, Algeria, Tunisia, Libya, Egypt, Sudan), Cyprus, Albania, Turkey, Syria, Israel, Iran, Arabia (Saudi Arabia, UAE), Afghanistan, Turkmenistan, Kazakhstan, Tajikistan, China (Mongolia), (Pulawski 2016) in present survey found east of the DDCR

Bembix rochei Guichard, 1989, North-west Africa (Mali), North Africa (Algeria, Tunisia), Arabia (UAE), India (Pulawski 2016) **DDCR**

Bembix saadensis Guichard, 1989, Arabia (UAE) (Pulawski 2016) **DDCR**

Stizoides assimilis Fabricius, 1787, North Africa (Algeria, Morocco, Egypt, Sudan), Palestine, Israel, Arabia (Saudi Arabia, Yemen, UAE), India, Turkmenistan, Kazakhstan, Tajikstan, (Pulawski 2016) east of the DDCR

Eremiaspheciinae: Eremiaspheciini
Laphyragogus sp. (a new species to be described by Christian Schmid-Egger) **DDCR**

Philanthinae: Philanthini
Philanthus coarctatus Spinola, 1839, North west Africa (Mauritania, Chad), North Africa (Western Sahara, Libya, Egypt, Sudan, Ethiopia), Italy, Turkey, Jordan, Israel, Iraq, Iran, Asia (Kazakhstan), Arabia (Saudi Arabia, Oman, UAE) (Pulawski 2016) **DDCR**
Philanthus pallidus Klug, 1845, North-west Africa (Mauritania), North Africa (Morocco, Egypt, Sudan, Ethiopia, Eritrea, Arabia (Saudi Arabia, Oman, UAE), Iran (Pulawski 2016) **DDCR**
Philanthus triangulum Fabricius, 1775, Widespread in Europe from north to south, Africa from north to south, Middle East, Arabia including UAE, Western and central Asia (Pulawski 2016) **DDCR**

Philanthinae: Cercerini
Cerceris albicincta Klug, 1845, North-west Africa (Chad), North Africa (Western Sahara, Algeria, Morocco, Egypt, Sudan) Palestine, Arabian Peninsula including Saudi Arabia and UAE (Pulawski 2016) **DDCR**
Cerceris chromatica Schletterer, 1887, North Africa (Algeria, Egypt) Israel, Arabia (Saudi Arabia, Oman, UAE) (Pulawski 2016) **DDCR**
Cerceris sp. **DDCR**

Apoidea – Apiformes

Halictidae

Halictinae
Halictus (*Seladonia*) *lucidipennis* (Smith, 1853), Southern Palaearctic and Oriental Regions, including North Africa, Asia from Palestine, Arabian Peninsula, Asia Minor, Iran, Iraq, Central Asia to Mongolia and N China, south to Sri Lanka, Cape Verde Islands, northern part of Afrotropical Region, south to Kenya, Central Thailand, UAE (Dathe 2009) in present survey found east of the DDCR
Sphecodes sp. UAE, **DDCR**

Nomiinae
Nomia (*Crocisaspidia*) *vespoides* (Walker, 1871), Sudan, Eritrea, Iran, Pakistan, Oman, UAE (Distribution Map at www.discoverlife.org) in present survey found east of the DDCR
Pseudapis (*Pseudapis*) *nilotica* (Smith, 1875), North Africa to Pakistan (Egypt, Ethiopia, Sudan, Djibouti, Saudi Arabia, Qatar, Oman, UAE, Turkmenistan, Afghanistan) (Dathe 2009) **DDCR**

Nomioidinae

Ceylalictus (*Ceylalictus*) *punjabensis* (Cameron, 1907), Cape Verde Islands, North Africa, Arabian Peninsula, including UAE), Israel, Jordan, S Iran, S Afghanistan, Pakistan, NW India (Dathe 2009) **DDCR**

Ceylalictus (*Ceylalictus*) *variegatus* (Olivier, 1789), warm habitats in Central and Southern Europe, North Africa, steppes and deserts of western Asia to China, northern India and Mongolia, Saudi Arabia, Yemen, Oman, Bahrain, UAE (Dathe 2009) **DDCR**

Ceylalictus (*Meganomioides*) *karachiensis* (Cockerell, 1911), Mauritania, Oman, S Pakistan, UAE (Dathe 2009) **DDCR**

Nomioides (*Nomioides*) *klausi* Pesenko, 1983, North Africa, Arabian Peninsula (Saudi Arabia, Oman, UAE), SW Iran (Dathe 2009) **DDCR**

Colletidae

Undertermined, **DDCR**

Megachilidae

Megachilinae

Megachilini

Megachile (*Euchtricharea*) *concinna* Smith, 1879, USA, Azores, Spain, France, Corscia, Italy, Sicily, Slovenia, Greece, Morocco, Egypt, Sudan, Israel, Turkey, Yemen, UAE (Distribution Map at www.discoverlife.org) **DDCR** sub-species *leucostoma*

Megachile (*Euchtricharea) minutissima* Radoszkowski, 1876, Egypt, Eritrea, Saudi Arabia, Pakistan, UAE (Dathe 2009) **DDCR**

Megachile (*Euchtricharea*) *patellimana* Spinola, 1838, widely distributed in western Palaearctic, particularly in the Mediterranean, Asia Minor, Egypt and UAE, also south-western Africa, Sudan, Niger and Mozambique (Dathe 2009) **DDCR**

Megachile (*Maximegachile*) *maxillosa* Guérin-Méneville, 1845, Senegal, Namibia, Botswana, South Africa, Zimbabwe, Malawi, Kenya, Sudan, Ethiopia, Saudi Arabia, Yemen (Distribution Map at www.discoverlife.org) **DDCR**

Coelioxys indica Friese, 1925, India, West Africa, East Africa, UAE (Distribution Map at www.discoverlife.org) **DDCR**

Osmiini

Haetosmia circumventa (Peters, 1974), Canary Islands, Morocco, Libya, Sudan, UAE (Dathe 2009) **DDCR**

Anthidiini

Icteranthidium n. sp. (to be described by Jessica Litman) **DDCR**

Pseudoanthidium (*Pseudanthidium*) *ochrognathum* (Alfken, 1932), Egypt, Israel, UAE (Dathe 2009) **DDCR**

Apidae

Xylocopinae

Xylocopini

Xylocopa (*Ctenoxylocopa*) *fenestrata* (Fabricius, 1798), Palestine to India, Iraq north to Bagdad, south coast of Iran, UAE (Dathe 2009) **DDCR**

Xylocopa (*Koptortosoma*) *aestuans* Linnaeus, 1758), SE Asia to Mediterranean (Morocco, Mauritania, S Sahara, Egypt, Turkey, Iran), UAE (Dathe 2009) **DDCR**

Ceratinini

Ceratina (*Ceratinula*) *parvula* Smith, 1854, Circum-Mediterranean (Crete), near East, Turkey, Turkmenistan, UAE (Dathe 2009) **DDCR**

Ceratina (*Pithitis*) *tarsata* Morawitz, 1872, Eastern Mediterranean (Crete), Egypt, Sudan, Ethiopia, Yemen, UAE (Dathe 2009) **DDCR**

Apinae

Anthophorini

Amegilla (*Micramegilla*) *byssina* (Klug, 1845), Desert areas from Algeria to eastern Arabia, including UAE, Egypt, Pakistan (Dathe 2009) **DDCR**

Anthophora (*Heliophyla*) *tenella* (Klug, 1845) Algeria, Egypt (Distribution Map at www.discoverlife.org) **DDCR**

Apinini

Apis (*Apis*) *mellifera* Linnaeus, 1758, Worldwide, **DDCR**

Apis (*Micrapis*) *florea* Fabricius, 1787, NW India to Borneo, Afghanistan, Iran, Oman, UAE (Dathe 2009) **DDCR**

Melectini

Thyreus elegans (Morawitz 1878), North Africa from Mauritania to Egypt, Palestine, Turkey, Pakistan, Central Asia, Saudi Arabia, UAE (Dathe 2009) **DDCR**

Thyreus hyalinatus (Vachal, 1903) Senegal, Mauritania, Nigeria, Chad, Egypt, Sudan, Eritrea, Djibouti, Tanzania, Israel, Saudi Arabia, Iran UAE (Distribution Map at www.discoverlife.org) **DDCR**

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RESEARCH ARTICLE

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Discovery of *Trichopria keralensis* (Hymenoptera, Diaprioidea, Diapriidae) in South Korea and Japan, a review of the *keralensis* species group of *Trichopria* and the nomenclature and synonymy of *Alareka*

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Abstract

Trichopria keralensis is recorded for the first time from South Korea and Japan and a detailed redescription and photographs of this species are given. The genus *Alareka* is a junior synonym of *Trichopria* **syn. n.** *Alareka keralensis* is transferred to *Trichopria keralensis* **comb. n.** *T. keralensis* and closely related species are referred to the *keralensis* species group of *Trichopria*. The *keralensis* species group is recorded here for the first time from the East Palaearctic, West Palaearctic, Afrotropical and Australian (Oceanian) regions. The multiple original spellings of *Alareka*, *Alarika*, *Alareka keralensis* and *Alareka keralaensis* are resolved.

Keywords

Diapriinae, Diapriini, multiple original spellings, new combination, new distribution records, synonymy

Introduction

Alareka, a monotypic genus of subfamily Diapriinae, was established Rajmohana and Narendran (2000) for a single Oriental species, *A. keralensis*, described on the basis of one male specimen collected in Kerala, India. Rajmohana and Narendran (2000) distinguished *Alareka* from other Diapriinae genera using a range of characters, most notably including: nasiform head; rim of frontal shelf serrated and with small median prominence; and opisthognathous mouthparts. The female of *A. keralensis* (as *A. keralaensis*) was recently described by Liu and Xu (2011) from Southern China. Specimens agreeing with *A. keralensis* were discovered during the present study and the known range is extended from India, China to Japan (Oriental) and South Korea (East Palaearctic) and a detailed redescription and photographs of this species are given.

Detailed examination of the new material showed that the genus *Alareka* is a junior synonym of *Trichopria* syn. n. and consequently *Alareka keralensis* is transferred to *Trichopria keralensis* comb. n. The synonymy is discussed in the light of the repeated and rapid evolution of a linked character suite of head characters: elongate head, opisthognathous mouthparts and projections of the frons and antennal shelf, which has arisen frequently and repeatedly in Diapriidae and other microhymenoptera; also the existence of species of *Trichopria* evidently closely related to *T. keralensis* but with some head characters intermediate between *Alareka* and other *Trichopria*.

There are a number of species which are closely related to *T. keralensis* which share the extreme nasiform condition of the head and so *T. keralensis* and these closely related species are referred to the *keralensis* species group of *Trichopria.* This species group is defined here. The *keralensis* species group is recorded here for the first time from the East Palaearctic, West Palaearctic, Afrotropical and Australian (Oceanic) regions.

Unfortunately Rajmohana and Narendran (2000) gave multiple original spellings of *Alareka*, *Alarika*, *Alareka keralensis* and *Alareka keralaensis* which are resolved below in the interests of nomenclatural consistency and stability.

Materials and methods

The terminology used in the present study follows that of Nixon (1980) and Masner and García (2002). The images were captured with an Axiocam HRc camera through a Discovery V20 stereomicroscopy (Carl Zeiss, Oberkochen, Germany) and were produced with AxioVision40AC software (Carl Zeiss, Oberkochen, Germany). Final plates were prepared in Adobe Photoshop CS6 (Adobe Systems Incorporated, San Jose, United States of America).

The following abbreviations are used throughout the text: POL, distance between the inner edges of the two lateral ocelli; OOL, distance from the outer edge of a lateral ocellus to the compound eye; MT, Malaise trap.

Taxonomy

Order Hymenoptera
Family Diapriidae Haliday, 1833

***Trichopria* Ashmead, 1893**

Phaenopria Ashmead, 1893
Planopria Kieffer, 1906
Xyalopria Kieffer, 1907
Orthopria Kieffer, 1911
Ashmeadopria Kieffer, 1912
Rhopalopria Kieffer, 1912
Abothropria Kieffer, 1913
Scapopria Kieffer, 1913
Neodiapria Kieffer, 1916
Alareka Rajmohana & Narendran, 2000 syn. n.; Rajmohana and Narendran 1999; 178, 180, **nomen nudum**; Rajmohana and Narendran 2000a: 193, **nomen nudum**; Rajmohana and Narendran 2000b: multiple original spellings *Alareka* pp. 21, 22, 23, fig, 22 and *Alarika*, p. 27, of which *Alareka* is the **correct original spelling** (ICZN 1999, Art. 32.5.1); Rajmohana 2006: iv, 8, 23, 26; Liu, Chen and Xu 2011: 181; Nielsen and Buffington 2011: 613; Rajmohana and Bijoy 2012: 4 **unpublished work**; Rajmohana, Poorani, Shweta and Malathi 2013 **unpublished work.**

Remarks. Before continuing further with a review of the morphology and classification of this taxon it is first necessary to clarify the confused nomenclatural history and spelling of the name *Alareka*: firstly it was published as a nomen nudum twice by Rajmohana and Narendran (1999, 2000a); it was first made available by Rajmohana and Narendran (2000b) but with the multiple original spellings *Alareka* and *Alarika* - the stated etymology was that it is an anagram of Kerala, and it was given feminine gender, so it can be assumed that this includes the feminine gender ending –a, i.e. the intended spelling was *Alareka* and that *Alarika* was a lapsus calami. *Alareka* Rajmohana & Narendran, 2000 is therefore available and *Alarika* is an incorrect original spelling (ICZN 1999, Art. 32.5.1) must be corrected, and is not available.

New material of this genus was discovered the collections of Yeungnam University and The Natural History Museum, London showing that *Alareka keralensis* was more widespread than previous known and prompting a review of the status of the genus. A detailed redescription was made for *Alareka* (see *Trichopria* species group *keralensis* – Description) below, which showed that some significant features had previously been missed or misinterpreted. A number of significant characters place this genus within *Trichopria*, specifically close to, if not within the group of species with males having whorled hairs on the antenna. These characters are: whorled hairs on the male antenna; male a3 and a4 normally articulated; slender fore-tibial spine present; mesoscutal hairs

arranged in (1-)3 pairs. *Alareka* is highly derived in many ways but its derived features are extreme developments of characters already noted for *Trichopria*, such as: foamy structures made of large hyaline scales, which are found in e.g. *T. drosophilae* (Perkins, 1910); strongly compressed antennal scape found in e.g. *T. vulgaris* (Kieffer, 1912) and *T. drosophilae*; strongly laterally compressed flagellum in both sexes found in e.g. *T. drosophilae*.

The most significant difference from *Trichopria* is the nasiform head and opisthognathous mouthparts; however there are several undescribed species of *Trichopria* from s. e. Asia which have subtriangular heads intermediate between *Alareka* and the normal subround head found in most *Trichopria*. Such differences in the degree of development of a nasiform head, and especially opisthognathous mouthparts, are not unusual in diapriids, even within the same genus. There is a linked character suite of head characters: elongate head, opisthognathous mouthparts and projections of the frons and antennal shelf which has arisen rapidly and repeatedly in Diapriidae and other microhymenoptera (Nielsen and Buffington 2011). There are a number of diapriid genera including both opisthognathous and hypognathous species for example: *Synacra* Förster, 1856, *Basalys* Westwood, 1833, *Aneuropria* Kieffer, 1905 all of which include both opisthognathous and hypognathous species, and *Vadana* Rajmohana & Narendren, 2000 (hypognathous) is just a *Calogalesus* Kieffer, 1912 (opisthognathous). While it may be easy to recognize small groups of derived opisthognathous species, and both practical and useful to key them separately for the purposes of identification, it does not serve the purposes of classification to split these off as separate genera if it leaves larger genera paraphyletic as appears to be the case of *Alareka* and closely related *Trichopria*. In any case, other more senior generic names are already available for the group of *Trichopria* having males with whorled hairs, should the genus be divided in future. We conclude therefore that *Alareka* is just a small derived subgroup of *Trichopria* probably close to or from within the group of species having males with whorled hairs on the antenna as exemplified by *T. verticillata* (Latreille, 1805). Hence the genus *Alareka* is considered here to be a junior synonym of *Trichopria* syn. n. As a consequence of the new generic synonymy *Alareka keralensis* is transferred to *Trichopria keralensis* comb. n. Other generic synonymy given above is based on Johnson (1992) and Notton (2004, 2014).

There are a number of undescribed species which are closely related to *T. keralensis* and so *T. keralensis* and these closely related species are referred to here as the *keralensis* species group of *Trichopria*. This species group is defined here:

Trichopria species group *keralensis*

Description. Head nasiform; antennal shelf strongly prominent, its anterior margin with a small median prominence, and with small subtriangular lateral projections; face with strong medial carina in upper third; clypeus narrow but prominent, convex; tentorial pits deep and close together; malar sulcus absent; compound eyes with

long, sparse hairs. Mouthparts strongly opisthognathous, mandibles elongate, together beak-like, with tips serrated. Female antenna 12-segmented; scape strongly flattened in basal 3/5; basal flagellar segments strongly laterally compressed, particularly the base of the segments; clava gradually incrassate apically, and distinctly to weakly laterally compressed; multiporous hair sensilla present on a7-12; a12 about as long as, or very slightly longer than the subapical. Male antenna 14-segmented; scape strongly flattened in basal 3/5; flagellar segments clavate, strongly laterally compressed, with a whorl of long hairs on each node, near the apex of the flagellum the nodes become subapical to medial; fourth segment usually not or weakly modified, occasionally with apical expansion and lateral emargination; a8, or a8 and a9, each with a comb of short fine hairs. Mesoscutum smooth, weakly concave laterally; notauli and humeral sulci absent; propodeum with a strong medial keel, which is raised anteriorly; dorsal propodeal areas with serried, adpressed hairs; metapleuron with small glabrous patch anteriorly. Wings well developed; subcostal, marginal and stigmal veins present, tubular, the stigmal vein very short, pointed; wing lamina densely hairy, with a small bare patch just apical of the marginal vein. Femora strongly laterally compressed basally; slender spine present at apex of fore tibia. Petiole slightly swollen medially; large tergite basally unnotched; apex of gaster slightly upturned; tip of ovipositor exserted at rest. Body colour variously blackish-brown, reddish-brown, yellowish-brown, largely smooth and shiny. Large hyaline scales (with the appearance of foam) present on anterior pronotum, propleuron, axillae, a small patch medioventrally in front of the mid coxae, and ventrally between the mid and hind coxae, and dorsal petiole; postgenal hair cushion dense, but without large transparent scales; mesoscutum of female with usually with 3 pairs of hairs, a lateral pair (next to tegula) an anterior pair and a medial pair, the male usually with only the laterals. Body length 1.80–2.84 mm.

Remarks. The *keralensis* species group is distinguished from other *Trichopria* by the extreme nasiform, opisthognathous form of the head and mouthparts.

Distribution. The *keralensis* species group is recorded here for the first time from the East Palaearctic (South Korea, Japan), West Palaearctic (Saudi Arabia, Yemen), Afrotropic (Kenya, Malawi, Nigeria, Zimbabwe) and Australian – Oceanian regions (Solomon Islands). Specimens from South Korea and Japan are identified as *Trichopria keralensis* and a detailed redescription is provided below.

Trichopria keralensis **(Rajmohana & Narendran, 2000), comb. n.**

Figs 1–8

Alareka keralensis : Rajmohana & Narendran, 1999; 178, **nomen nudum**

Alareka keralensis Rajmohana & Narendran, 2000b: multiple original spellings *keralensis* pp. 21, 23, figs 1–6 and *keralaensis*, p. 21, of which *keralensis* is the correct original spelling following first reviser action by Rajmohana, 2006

Alareka keralaensis : Rajmohana and Narendran 2000b: 21, incorrect original spelling

Alareka keralensis : Rajmohana 2006: iv, 8, 25, 26

Alareka keralaensis: Liu, Chen and Xu 2011: 181, 182, 183, incorrect subsequent spelling
Alareka keralensis: Rajmohana and Bijoy 2012: 4, unpublished work
Alareka keralensis: Rajmohana, Poorani, Shweta and Malathi 2013, unpublished work

Material examined (4♀♀6♂♂**).** SOUTH KOREA: 1♂, Chungcheongnam-do, Seosan-si, Daegok-ri, Hanseo Univ., 18 Jul.–14 Aug. 2006 (MT), J.W. Lee; 1♂, Gangwon-do, Hongcheon-gun, Bukbang-myeon, Nature Environment Research Park, 35°45'15.6"N, 127°51'1.7"E, 21 Jun.–4 Jul. 2011 (MT), J.O. Lim; 1♂, *ditto*, 16–31 Jul. 2012 (MT), J.O. Lim; 1♀, *ditto*, 1–8 Aug. 2011 (MT), J.O. Lim; 1♀, *ditto*, 5–18 Aug. 2011 (MT), J.O. Lim; 1♂, Gangwon-do, Wonju-si, Heungeop-myeon, Maeji-ri 234, Yonsei University, 28 Aug.–27 Sep. 2013 (MT), H.Y. Han; 1♀, Gyeongsangbuk-do, Cheongdo-gun, Gakbuk-myeon, Mt. Biseulsan, 15–19 Aug. 2015 (MT), J.W. Lee; 2♂♂, Jeju-do, Ara 1-dong, 33°27'14"N, 126°33'56.4"E, 1–15 Jun. 2009 (MT), J.W. Lee. JAPAN: 1♀, Okinawa, Yona, Rhykyu Univ. Res. Station., May 1999, B.J. Sinclair. (all specimens housed in the collection of the Department of Life Sciences, Yeungnam University).

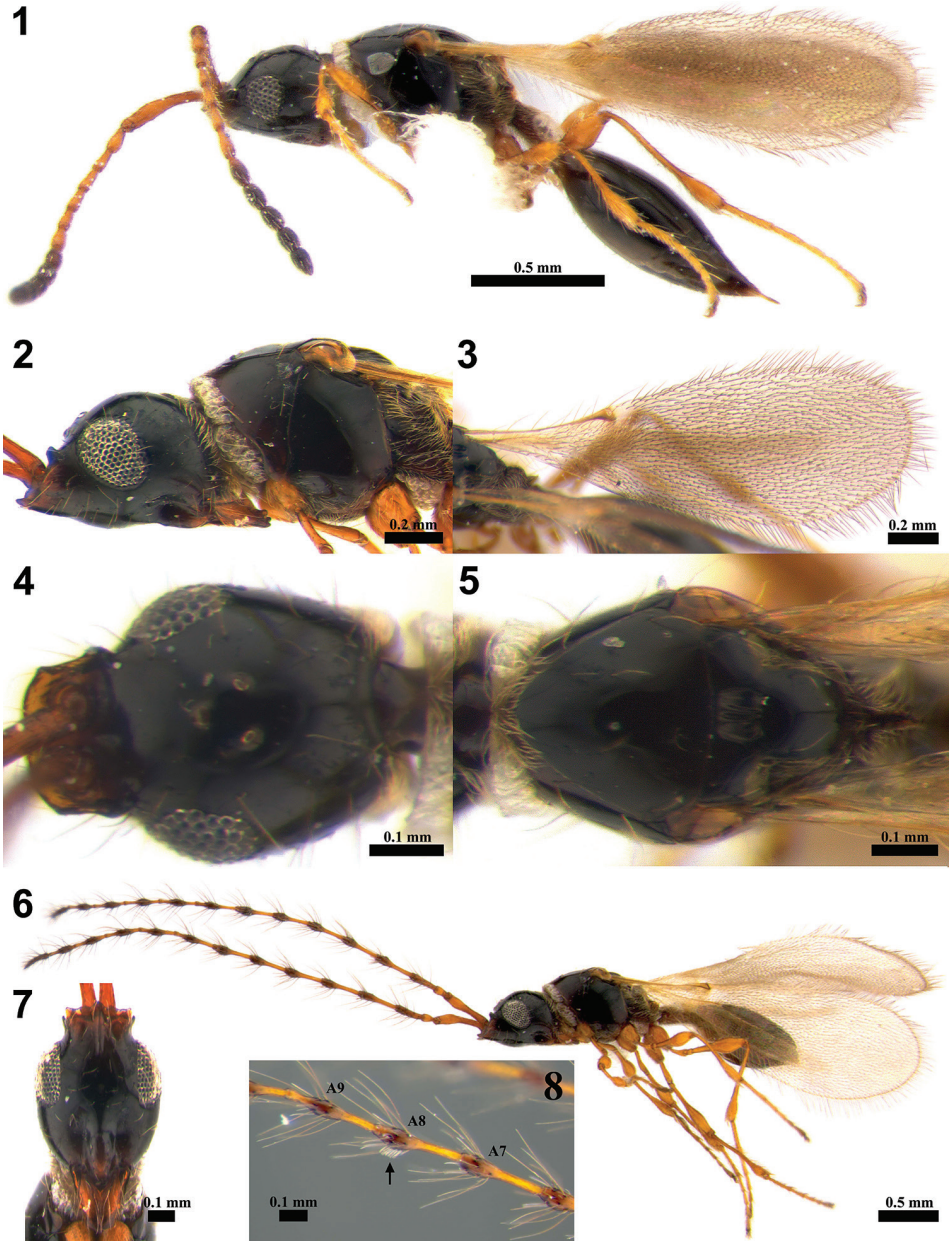
Redescription. Female. Head. Head smooth with long sparse hairs, in dorsal view longer than wide (19: 15), in lateral view slightly longer than high (19: 18); distinctly nasiform, antennal shelf sharply projecting, anteriorly with small medial projection, and lateral subtriangular projections; upper third of face with a median longitudinal carina, POL:OOL=3:7; eye moderately small, with sparse long hairs, distinctly shorter than postgena (3: 5); eye height much shorter than malar space (15: 22); postgenal cushion well developed; mandibles elongate, beak-like projecting, with serrated tips; antenna much shorter than body length (3: 5), gradually expanded 6-segmented clava; antennal segments a1-12 respectively in following proportions (length: width): 34: 5; 9: 4; 9: 3; 8: 3; 10: 3; 10: 4; 9: 4; 9: 5; 9: 5; 8: 6; 7: 6; 10: 5.

Mesosoma. Mesosoma in dorsal view equal to width of head and much shorter than long (7: 3); cervix long and smooth; pronotum and propleura with dense cushions; mesoscutum smooth, notauli, parapsidal impressions and humeral sulci completely absent; anterior scutellar pit small and deep with longitudinal carinae at bottom, much smaller than remaining scutellar disc (6: 11); scutellar disc rectangular, without lateral and posterior pits; dorsellum with 3 keels, and the median keel distinctly raised; mesosoma in lateral view clearly longer than high (10: 7); lateral part of pronotum smooth; mesopleuron smooth, with sparse hairs, without sternaulus; metapleuron with long dense hairs; median propodeal keel moderately raised, not sharply pointed, not exceeding level of mesoscutum; nucha clearly visible in dorsal view.

Wing. Fore wing with subcostal, marginal and stigmal veins tubular, stigmal vein very short, pointed.

Metasoma. Petiole covered with dense hairs, in dorsal view elongate (10: 20); second tergite (T2) without hairs and median basal notch.

Colour. Body dark brown to blackish brown; antenna yellowish brown with A8–A12 dark brown; legs yellowish brown; tegulae yellowish brown, hyaline; wings hyaline with brown hairs, veins yellowish brown.



Figures 1–8. *Trichopria keralensis* (Rajmohana & Narendran, 2000). **1** Female habitus, lateral **2** Female head and mesosoma, lateral **3** Female fore wing, dorsal **4** Female head, dorsal **5** Female mesosoma, dorsal **6** Male habitus, lateral **7** Male head and face, frontal **8** Male antenna (A7–A9), lateral.

Measurements. Head length 0.43 mm, width 0.34 mm; mesosoma length 0.79 mm, width 0.34 mm; metasoma length 1.15 mm; fore wing length 2.63 mm; total body length 2.10–2.37 mm.

Male. Body length 1.80–2.84 mm. Differs from female as follows: Antenna 14-segmented, about 1.6 times the length of the body; flagellum elongate-knotted, with long hairs arranged in a whorl on each node, A8 with a comb of short fine hairs; antennal segments a1-12 respectively in following proportions (length: width): 34: 7; 8: 5; 18: 5; 26: 5; 29: 5; 28: 5; 26: 5; 29: 6; 29: 4; 26: 4; 25: 4; 24: 4; 23: 4; 30: 3; anterior scutellar pit usually almost smooth, some males have the anterior scutellar pit almost smooth to weak or strong longitudinal carinae at bottom.

Variations. The female of the type specimen has the antenna brown with the apical four segments blackish brown, but South Korean and Japanese female specimens have antenna brown with apical five segments dark brown.

Host. Unknown.

Distribution. South Korea (new record), Japan (new record), China (Guangdong, Hainan, Yunan), India (Kerala).

Nomenclature. Just as for the genus *Alareka* name above the nomenclatural history of the specific epithet *keralensis* is confused: firstly it was published as a nomen nudum by Rajmohana and Narendran (1999); it was first made available by Rajmohana and Narendran (2000b) but with the multiple original spellings *keralensis* and *keralaensis* - the stated etymology is that it was based on the collection locality Kerala, but this does not help as both spellings can be derived from this place name, *keralaensis* however appears to be an error since it is used only once. This unsatisfactory situation is resolved as follows; as one of the original authors, Rajmohana (2006) may be considered first reviser (ICZN 1999, Art. 24.2.4) since she used the spelling *keralensis*, this becomes the correct original spelling, and *keralaensis* becomes incorrect and unavailable (ICZN 1999, Art. 24.2.3).

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RESEARCH ARTICLE

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Aspilota ajara sp. n. (Hymenoptera, Braconidae, Alysiinae), the first species of the genus *Aspilota* Foerster from caves

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Abstract

Aspilota ajara **sp. n.**, a new species of the *A. miraculosa* (*fasciatae*) species group with very short upper tooth, was collected in a cave on La Palma, Canary Islands, Spain. This is the first *Aspilota* species known to occur in caves as well as the first record of *Aspilota* for the Canary Islands. The new species is described, illustrated and compared with related taxa.

Keywords

Braconidae, Alysiinae, *Aspilota*, parasitoid, caves, description, La Palma

Introduction

The Alysiinae is an extremely diverse subfamily of parasitoids of the family Braconidae (Dolphin and Quicke 2001) with about 2,300 already described species (Yu et al. 2012), which are divided in to two large and morphologically diverse tribes, Alysiini and Dacnusini (Shenefelt 1974). Members of the tribe Alysiini are parasitoids

of Diptera-Cyclorrhapha, usually inhabiting humid substrates (Wharton 1984; Yu et al. 2012). Dacnusini are almost exclusively specialized on leaf and stem miner flies, mainly from the families Agromyzidae, Chloropidae and Ephydridae (Belokobylskij 2005; Peris-Felipo et al. 2014).

The genus *Aspilota* Foerster, 1863 is one of the largest taxa of the *Aspilota* genus group (Alysiini) with approximately 250 species described almost from all zoogeographical regions. Species of *Aspilota* are well defined by the presence of the large paraclypeal fovea connecting with the inner margin of the eye and the presence of fore wing vein cuqu1 (2-SR) (van Achterberg 1988; Peris-Felipo and Belokobylskij 2016a).

A new species, *Aspilota ajara* sp. n., from the *A. miraculosa* (*fasciatae*) species group (characterized by the small size of the upper tooth of the mandible) is described and illustrated in this paper. This is the first record of an *Aspilota* species collected in caves and also the first record of the genus *Aspilota* for the Canary Islands.

Materials and methods

Area of study

La Palma Island (Canaries Islands) has a subtropical climate, with annual average temperature of 24.2°C (winters of 20–22 and summers of 25–28°C) and a low annual average rainfall of 135mm (AEMET 2016). The "Llano de Los Caños" cave is located in Villa de Mazo (La Palma, Canary Islands, Spain), close to the La Sabina and Tirimaga (Fig. 1). The cave is almost a linear tube with a length of 1,200 m and with several short branches. It has a single entrance at the mountain of La Horqueta (1365 m; UTM 28RBS262646). Recently, a new section called "Galerias de los Zapadores" was opened (Fernández et al. 2015). However, our area of study belongs to the classic section ("Tramo clásico").

Methodology

Samples were carried out at four sampling points (E) located in the main cave in complete darkness during 1995 (Fig. 2). At each point, four pitfall traps were placed at the beginning of each annual season and were checked two weeks later. Automobile antifreeze liquid was used as preservative and pieces of cheese were used as bait (García and González 1998).

The first sampling point (E1) was located at 20 m from the entrance in earthy-sandy soil. The second (E2) was placed at 70 meters from the entrance and has an earthy substrate and also a crack of 30 cm which divides the cave into two. The third point (E3) was situated at 90 meters from the entrance, in earthy substrate. The last

Figure 1. Location of studied cave in Canary Islands (Spain) and in La Horqueta Mountain.

sampling point (E4) was located at 190 m. from the entrance in a substrate built up from the remains of demolition (García and González 1998). Climatic conditions and distance from the cave entrance are given in Table 1.

For terminology of morphological features, sculpture and measurements, see Peris-Felipo et al. (2014); for wing venation nomenclature, see Peris-Felipo et al. (2014) and, in parentheses, van Achterberg (1993). The keys by Fischer (1976, 1978), Belokobylskij and Tobias (2007) and Papp (2008) were used for the identification of

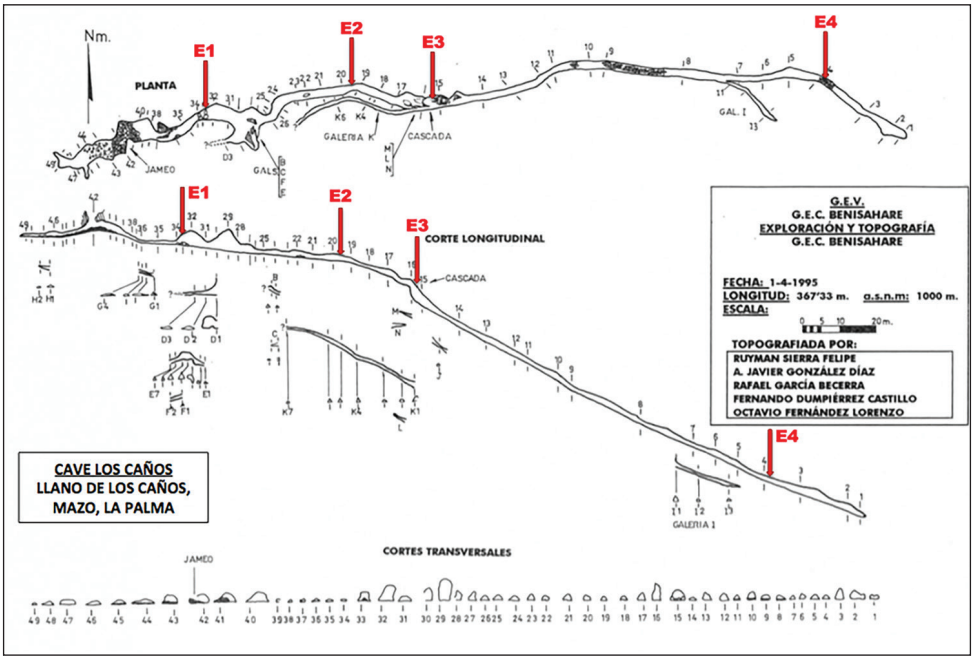

Figure 2. Map of the "Llano de Los Caños" cave with sampling points E1–E4 in red.

Table 1. Climatic conditions and distance from the cave entrance for the sampling points.

Sampling points (E)	Distance from cave entrance (m)	Temperature (°C)	Relative Humidity (%)
E1	20	-	-
E2	70	14.5	92.3
E3	90	13.9	-
E4	190	16.3	94.3

Aspilota species. The material was imaged using Digital Microscope Keyence® VHX-2000 and Adobe Photoshop® imaging system.

Type specimens are deposited in the following collections: holotype in the Natural History Museum of Tenerife (Tenerife, Canary Islands, Spain; MNHT); paratypes in the Entomological Collection at University of Valencia (Valencia, Spain; ENV), Museo Nacional de Ciencias Naturales (Madrid, Spain; MNCN), Entomological Collection at University of La Laguna (La Laguna, Canary Islands, Spain; CULL), Natural History Museum of Tenerife (Tenerife, Canary Islands, Spain; MNHT), Zoological Institute RAS (St Petersburg, Russia; ZISP), and in the private collection of Rafael García Becerra (La Palma, Canary Islands, Spain; RGB).

Taxonomic part

Order Hymenoptera
Family Braconidae
Subfamily Alysiinae
Genus *Aspilota* Foerster, 1863

***Aspilota ajara* Peris-Felipo, sp. n.**
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Figs 3, 4

Type material. Holotype: female, **Spain**: Canary Islands, La Palma, Villa de Mazo, Llano de los Caños cave, 15.iii.1995 (R. García-Becerra leg.) (MNHT).

Paratypes. **Spain**, 27 females, same data as holotype, but iii, vi, ix & xii.1995 (CULL, ENV, MNCN, MNHT, RGB, ZISP).

Description. Female (holotype). Head. In dorsal view twice as wide as its median length, 1.3 times as wide as mesoscutum, with rounded temples behind eyes. Head at level of temple (dorsal view) as wide as at level of eyes. Eye in lateral view 1.6 times as high as wide and 0.9 times as wide as temple medially; in dorsal view about as wide as temple. POL 1.5 times OD; OOL 4.7 times OD. Face 1.7 times as wide as high; inner margins of eyes subparallel. Clypeus slightly curved ventrally, 2.3 times as wide as high. Mandible weakly widened towards apex, 1.4 times as long as maximum width. Upper tooth of mandible distinctly shorter than middle and lower teeth, develop as rounded lobe; middle tooth long, narrow and pointed; lower tooth longer than upper tooth, wide, rounded apically. Antenna thick, 19-segmented, 1.1 times as long as body. Scape 2.1 times as long as pedicel. First flagellar segment 3.2 times as long as its apical width, 1.1 times as long as second segment; second segment 3.0 times as long as its maximum width, third to ninth segments 2.8 times, 10th to 14th 2.6 times, 15th segment 2.2 times, 16th segment 2.5 times, and 17th (apical) 2.75 times as long as their maximum width accordingly.

Mesosoma in lateral view about 1.2 times as long as high. Mesoscutum 1.1 times as long as maximum width. Notauli mainly absent on horizontal surface of mesoscutum. Mesoscutal pit absent. Prescutellar depression smooth, only with median carinae. Precoxal suture present, not reaching anterior and posterior margins of mesopleuron. Posterior mesopleural furrow crenulate in upper part and smooth below. Propodeum sculptured, with pentagonal areola. Propodeal spiracle small.

Legs. Hind femur 4.7 times as long as its maximum width. Hind tibia slightly widened towards apex, 12.0 times as long as its maximum subapical width, as long as hind tarsus. First segment of hind tarsus 2.6 times as long as second segment.

Wings. Length of fore wing 2.8 times its maximum width. Radial (marginal) cell ending at apex of wing, 1.5 times as long as its maximum width. Vein cuqu1 (2-SR) present and sclerotized. Vein r2 (3-SR) 2.7 times as long as vein cuqu1 (2-SR); vein r3 (SR1) 2.1 times as long as vein r2 (3-SR). Nervulus (cu-a) strongly postfurcal. Brachial

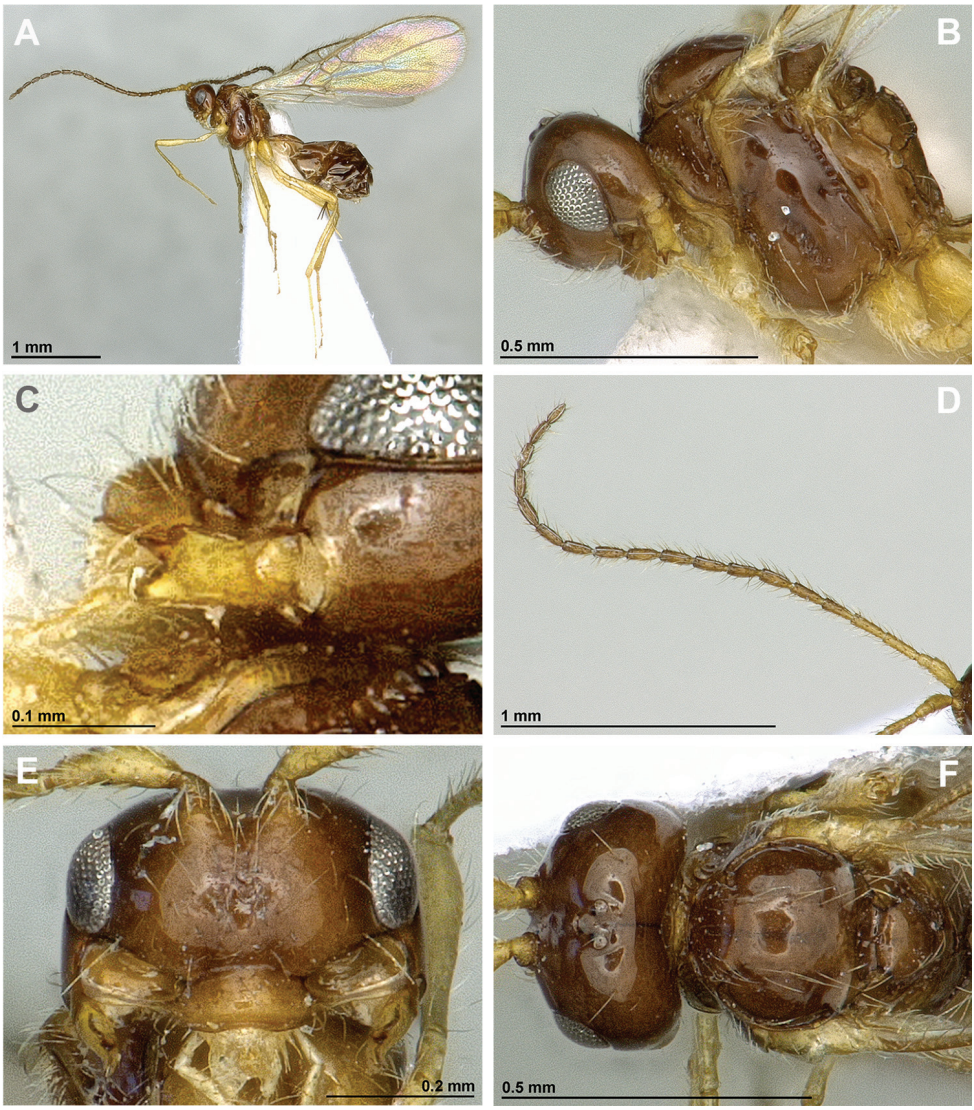

Figure 3. *Aspilota ajara* sp. n. (female). **A** Habitus, lateral view **B** Head and mesosoma, lateral view **C** Mandible **D** Antenna **E** Face, front view **F** Head and mesonotum, dorsal view.

(subdiscal) cell closed distally, 2.3 times as long as its maximum width. Hind wing 6.3 times as long as its maximum width.

Metasoma. Distinctly compressed. First tergite smooth medially, weakly rugulose laterally, widened towards apex, 2.3 times as long as its apical width. Ovipositor 1.3 times as long as first tergite, distinctly shorter than metasoma, 0.8 times as long as hind femur.

Colour. Body reddish brown, metasoma paler. Antenna mainly pale brown, four basal segments yellow. Mandible and legs yellow. Wings hyaline.

Length. Body – 2.0 mm; fore wing – 2.4 mm; hind wing – 1.7 mm.

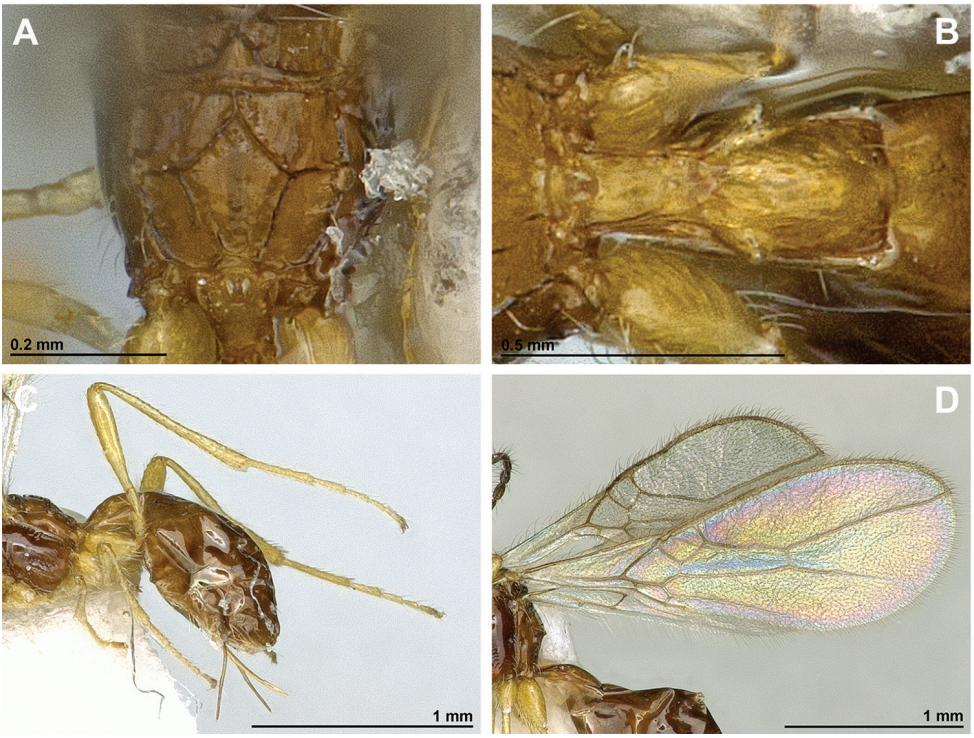

Figure 4. *Aspilota ajara* sp. n. (female). **A** Propodeum, dorsal view **B** First metasomal tergite **C** Metasoma, hind leg and ovipositor, lateral view **D** Fore and hind wings.

Variation. Body length 1.9–2.5 mm; fore wing length 2.3–2.7 mm; hind wing length 1.6–1.9 mm. Otherwise similar to holotype.

Etymology. The name is derived from Canary dialect "ájara" meaning "be fortunate", referring to the difficulty in finding this genus in the caves.

Comparative diagnosis. This new species is similar to *A. insolita* (Tobias, 1962) (U.K., Ireland, Denmark, Spain, Hungary, former Czechoslovakia, European part of Russia, Iran: Peris-Felipo et al. 2016) as they share the sculptured, pentagonal areola on the propodeum, eye in lateral view 0.9–1.0 times as wide as the temple medially, mandible 1.4 times as long as its maximum width, and sixth flagellar segment 2.6–2.8 times as long as its maximum width.

Aspilota ajara sp. n. differs from *A. insolita* in having the head in dorsal view twice as wide as its median length (1.8 times in *A. insolita*), head in dorsal view 1.3 times as wide as mesoscutum (1.6 times in *A. insolita*), face 1.7 times as wide as high (1.9 times in *A. insolita*), clypeus 2.3 times as wide as high (1.6 times in *A. insolita*), head at level of eyes in dorsal view about as wide as head at level of temple (1.2 times in *A. insolita*), the first flagellar segment 3.2 times as long as its maximum width (4.7–5.3 times in *A. insolita*), and hind femur 4.7 times as long as its maximum width (4.0–4.1 times in *A. insolita*).

In Belokobylskij's (Belokobylskij and Tobias 2007) key, *A. ajara* sp. n. runs to the Eastern Palaearctic *A. tshirikovi* Belokobylskij, 2007 (Russian Far East and Japan), but differs in having the lower mandibular tooth long (short in *A. tshirikovi*), middle and apical antennal segments slender and long (thick and short in *A. tshirikovi*), face 1.7 times as wide as high (1.2–1.4 times in *A. tshirikovi*), and paraclypeal fovea wide (rather narrow in *A. tshirikovi*).

General distribution. Canary Islands (Spain).

Remarks. Specimens were found in all traps but mainly in E2 and E3 sampling points. One specimen was captured in each of March and June, five in September and 21 in December. Unfortunately, it is not possible to report precise collection data for sampling points and dates because the notes with this complete information were destroyed in a flood. The following Diptera were sampled in the same traps: *Calliphora vicina* Robineau-Desvoidy, 1830 (Calliphoridae), *Megaselia* sp. (Phoridae) and *Aptilotus martini* Wheeler & Marshall, 1989 (Sphaeroceridae) (García and González 1998). However, it is impossible to establish any biological relationships between them.

Discussion

Subterranean ecosystems have always interested people and there has been great scientific interest in cave fauna. Proof of this is in the significant number of animal species found and described from these peculiar localities. However, only nine species of Braconidae, belonging to the genera *Aleiodes* Wesmael, 1838 (Rogadinae), *Apanteles* Foerster, 1863 (Microgastrinae), *Aulosaphes* Muesebeck, 1935 (Lysiterminae), *Dinotrema* Foerster, 1863 (Alysiinae), *Ontsira* Cameron, 1900 and *Spathius* Nees, 1819 (Doryctinae) have been cataloged from subterranean environments (Peris-Felipo and Belokobylskij 2016b). The description of *Aspilota ajara* sp. n. provides the first record of *Aspilota* for the cave biota.

It is possible that most braconids collected in subterranean environments (caves, galleries or chasms) found their way there accidentally, searching for host refuges (Peris-Felipo and Belokobylskij 2016b). However, hosts of Alysiini (Alysiinae), which include also sarcophagous and necrophagous Diptera, as well as parasitoids (Calliphoridae, Muscidae, Sarcophagidae, and Phoridae), are common and distinct elements of cave fauna and we suggest that they have acquired stable parasitoid faunas in these peculiar subterranean conditions. Interestingly, no braconid parasitoids known from subterranean environments have any outstanding morphological characters (including colour) associated with subterranean life. Either these insects have relatively recently penetrated these environments, with insufficient time for major morphological adaptations, or they have regular contact with areas outside caves. To conclude, further studies on caves are recommended in order to improve our knowledge of these parasitoids from caves, which remain largely unknown.

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SHORT COMMUNICATION

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Comparative nesting success of the keyhole mud-dauber (Hymenoptera, Crabronidae, *Trypoxylon nitidum*) in different substrates

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Abstract

The solitary wasp *Trypoxylon nitidum* F. Smith nests in a variety of existing cavities. Nesting success – the fraction of completed, provisioned cells that produced adult offspring – can be estimated by examination of old cells. We estimated nesting success of *T. nitidum* in new and old (previously utilized by *T. nitidum*) bamboo traps nests, old nests of solitary wasps (*Sceliphron fistularium* (Dahlbom), *Trypoxylon albitarse* Fabr. and *Zeta argillaceum* (L.)) and social wasps (*Polistes lanio* (Fabr.) and *P. versicolor* (Olivier)) in Trinidad, West Indies. Success was markedly higher (61.4%) in new trap nests and significantly lower (5.6%) in old trap nests than in other substrates. Mean success in old nests of other wasps varied from 10.0% to 28.8%, with no general difference between those of solitary and social wasps. We infer that a) rented (reutilized) nests are more easily located by parasites than are new trap nests, and b) old trap nests have a higher load of parasites and disease organisms than substrates not previously utilized by *T. nitidum*.

Keywords

Nesting success, *Polistes lanio*, *Polistes versicolor*, *Sceliphron fistularium*, *Trypoxylon albipes*, *Zeta argillaceum*

Introduction

Trypoxylon Latr., 1796 (Hymenoptera: Crabronidae) is a worldwide genus of more than 300 known species of spider-hunting wasps (Bohart and Menke 1976). All studied species mass provision with paralyzed spiders. Some species build free-standing mud nests, while others nest in pre-existing cavities. Many of these latter will accept artificial tubular cavities known as trap nests (Medler 1967, Griswold and Coville 1986).

The keyhole mud-dauber, *Trypoxylon* (*Trypargilum*) *nitidum* F. Smith, is common about houses in Trinidad, West Indies. It constructs no free-standing nest but utilizes various existing cavities, which it divides with mud partitions into a linear series of cells (Richards 1934: 347). Cavities include such human-made structures as nail holes, keyholes and book backs, as well as old nests of various solitary and social wasps. When a cell is fully provisioned with spiders, the female lays an egg, seals the cell with mud, and has no further contact with the cell. The cocoon is dark brown, hard and brittle, more or less cylindrical, with the front end round and slightly swollen.

Provision of sufficient food does not guarantee that the larva will develop to adulthood. Brood and their provisions attract a variety of parasites, parasitoids and pathogens. Nesting success is the fraction of fully provisioned, closed cells that give rise to mature offspring. In the one review of the subject to date, Weaving (1995) reported figures from about 50 solitary-wasp species in various parts of the world. These are mostly between 45–75%, although figures below 30% or above 90% are not rare. Among the wasps treated are five *Trypoxylon* species, with nesting success between 56–76%. Tormos et al. (2005) and Musicante and Salvo (2010) give figures of 45–87% for a further six species with nesting habits similar to those of *T. nitidum*.

As a rule, nesting success of mud-nesting solitary wasps can be estimated with considerable confidence by examining old cells. In the case of *T. nitidum*, emerging adults leave a distinctive emergence hole. This proffers the opportunity to compare success rates in the various types of nest substrates. In this paper we test the hypothesis that choice of a nest substrate is a significant factor in nesting success.

Materials and methods

The main part of this study was carried out in the St Augustine area of Trinidad, West Indies during September-November 1999, with some auxiliary study in later years. Our material comprised 2620 *T. nitidum* cells from 288 nests.

Nest sites were of three types. We made trap nests from bamboo stems of 5–11 mm inner diameter, each about 30cm long. These were split longitudinally, plugged midway along their length with tissue paper, resealed and placed in sheltered areas on buildings that *T. nitidum* was known to frequent. Many of these trap nests were reconstituted after they had been utilized by *T. nitidum* and were set out again the following year.

The second type comprised old nests of the mud-nesting solitary wasps *Sceliphron fistularium* (Dahlbom) (Sphecidae), *Trypoxylon* (*Trypargilum*) *albitarse* Fabr. (Cra-

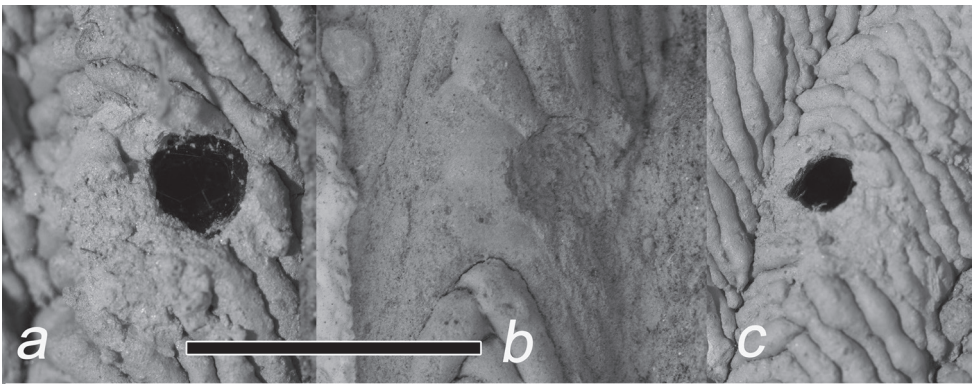

Figure 1. Stages in the reutilization of old *Trypoxylon albitarse* cells by *T. nitidum*. **a** Without reutilization (note *T. albitarse* emergence hole) **b** Reutilized with no emergence by *T. nitidum* (note closure without emergence hole) **c** Reutilized with emergence by *T. nitidum* (note smaller emergence hole). Scale bar = 1 cm. Figure by Terry Sampson.

bronidae) and *Zeta argillaceum* (Linn.) (Vespidae: Eumeninae). *T. albitarse* is much larger than *T. nitidum* and constructs free-standing nests (Fig. 1). The third type was old nests of the common social wasps *Polistes lanio* (Fabr.) and *P. versicolor* (Olivier) (Vespidae: Polistinae). These open combs of uniform paper cells are presumably a very convenient substrate for *T. nitidum*.

We opened and examined *T. albitarse* and *Z. argillaceum* nests in-situ. All other substrate types were brought into the laboratory. The fate of *T. nitidum* brood could be inferred by searching the nest exterior and cell contents for such evidence as emergence holes, empty pupal cases, dead pupae, frass and exuviae of parasitic organisms. The effects of parasites and parasitoids are often evident long after the fact from their signature exit holes. Emergence holes of *T. nitidum* in cells of the other mud-nesting wasps are consistently smaller (about 4 mm diameter) than those of the original builders (5–7 mm). Where a *T. nitidum* cell had failed in one of these other mud nests, this was evident externally by a species-characteristic mud closure to the host cell.

Results

T. nitidum utilized 103 new traps nests, accepting none with an inner diameter greater than 10 mm. Those with inner diameter of 6 mm were utilized with the greatest frequency. Brood cells had a mean length of 13 mm, intercalary cells a mean length of 16 mm, and vestibular cells a mean length of 17 mm.

Table 1 shows nesting success of *T. nitidum* in seven different substrates. There were significant differences among substrates (Table 2). We identify four groups of substrates, in increasing order of nesting success: a) old trap nests, b) old nests of *S. fistularium*, c) old nests of other wasps, and d) new trap nests.

Table 1. Nesting success of *Trypoxylon nitidum* in different substrates. In new trap nests, the number of successes is estimated from the number of known successes (349) and the projected fate of 80 live pupae, as explained in the text. In all other substrates, the number of successes is directly known. Old trap nests are those that were previously utilized by *T. nitidum*.

Substrate nest	Total nests	Total cells	Number of successes	Success rate (%)
New trap nests	103	675	415	61.4
Old trap nests	92	502	28	5.6
Sceliphron fistularium	35	159	16	10.0
Trypoxylon albitarse	21	76	15	28.8
Zeta argillaceum	12	45	11	24.4
Polistes lanio	31	808	149	18.4
Polistes versicolor	16	361	78	21.6
Total	288	2626	712	

Table 2. Differences in nesting success of *Trypoxylon nitidum* among different substrates, based on Table1. Results of Fisher's exact test of successes and failures among pairs of substrates, based on Table 1. NS, p>0.05. *, p<0.05. **, p<0.01.

	old trap nests	*Sceliphron fistularium*	*Trypoxylon albitarse*	*Zeta argillaceum*	*Polistes lanio*	*Polistes versicolor*
new trap nests	**	**	**	**	**	**
old trap nests		*	**	**	**	**
Sceliphron fistularium			*	*	*	**
Trypoxylon albitarse				NS	NS	NS
Zeta argillaceum					NS	NS
Polistes lanio						*

Discussion

The results corroborate the hypothesis that type of nest substrate affects nesting success. The observed variation among substrates – from 10.0 to 61.4% – is mostly within the range reported in the literature for other solitary wasps and bees. New bamboo trap nests give rise to much greater success than any other substrate, while old trap nests give much lower success. Success in the intermediate group – old nests of solitary and social wasps – shows no striking differences or pattern of variation. In particular, the solitary (mud-nesting) and social (paper-nesting) species do not separate as distinct groups. The presumed greater ease with which parasites can penetrate thin paper cell walls than thicker mud walls does not produce the expected lower nesting success in the former.

Given the clear superiority of virgin substrates, why does *T. nitidum* often reutilize old nests of other wasps? There is almost certainly a trade-off between these two types of substrates. Old nests of some wasps are presumably easy to find and provide ready-made cavities that require very little modification. By searching under the eaves of buildings (as we did), a female may within minutes find an old *Polistes* nest with enough cells for her lifetime reproduction. Substrate-search time is probably a major

factor in the number of cells she can provision. However, this kind of substrate is presumably relatively easy for nest parasites to find. Similarly, Wcislo (1996) concluded from a comparison of nesting success in a broad range of wasps and bees that the clustering of trap nests into bundles facilitates the discovery by parasites of several nests at once. For this reason and because they would seem relatively easy for parasites to penetrate, nesting success in old *Polistes* nests (around 20%) seems surprisingly high.

Utilization of old trap nests, in contrast, appears to be a very poor choice with no evident trade-off. This may be due to residual disease organisms from the previous season and/or residual odour of *T. nitidum* to which parasites can orient.

The very low nesting success in old *S. fistularium* nests is puzzling. This solitary wasp builds thick-walled nests that are presumably hard for any nest parasite to penetrate. Possible explanations include a) brood failure due not to nest parasites but to fungi and other pathogens, which may do better in a denser, moister nest, and b) penetration of cells before they are closed, so that nest-wall thickness is not a factor.

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