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A photo-based assessment of wild bees in a filled-up gravel pit in Riem, Munich – with a species list of bees found in Central European gravel pits

(Hymenoptera, Apiformes)

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Gravel pits, both in active use and restored, provide important replacement habitats and nesting requisites for wild bees formerly specialized in nesting in dynamic fluvial landscapes. Species inventories in six Central European gravel pits report 245 species of wild bees, and this study found 48 species of wild bees and the domesticated *Apis mellifera* in the refilled section of the Obermayr gravel pit in Riem, Munich. The tested inventory method of in-situ photo-documentation, instead of voucher specimen collection, was feasible for most bee families, but is not applicable for Halictidae and some small nomad bees (genus *Nomada*) or mini-miners (*Andrena* subgenus *Micrandrena*), as well as species complexes in the genus *Bombus*.

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Introduction

Dynamic riverside landscapes are an important habitat for various wild bee species (Völkl et al. 2002), but became increasingly rare in Central Europe. An assessment of more than 76 000 km of watercourses in Germany, conducted by the water management authorities of the federal states, showed that only 1.6 % of the rivers are in their natural state, another 6.2 % are only slightly modified and 11.9 % moderately changed, the rest falls in the classes considerably, strongly, very strongly or completely changed (Arle et al. 2017). Thus, many of the bee species naturally specialized on riverside habitats are nowadays found in sand and gravel pits instead (Escher 1974, Westrich 2018), as these provide manifold different niches, like deep and shallow ponds, accumulations of

clay, sand, gravel, rocks, shrubland and steep faces (Krebs & Wildermuth 1976) – especially for many soil-nesting bees species, the presence of open, poorly vegetated, freshly exposed soils is an essential habitat demand (Westrich 1989, Falk & Lewington 2015). The continuous de-novo succession of the habitat through ongoing gravel extraction simulates landscape dynamics typically induced in erosion banks and river landscapes by flooding events and fluvial erosion cycles (Meisterhans & Heusser 1970, Krebs & Wildermuth 1976). Inventories conducted in actively used and restored gravel pits in Central Europe identified 245 species of wild bees for this habitat (see Results section, Tables 1 and 2 for references).

The gravel pit of the Obermayr Company in the East of Munich offers both, renatured areas and areas which are still mined for sand and gravel.



Fig. 1. The study site “Kiesgrube Obermayr” (modified from www.google.de/maps/@48.1462044,11.7084456,606m/data=!3m1!1e3; last accessed 19.02.2019).

This study focused on a living bee inventory in the non-active parts of the gravel pit, applying a standardized in-situ photo-documentation, and vouchers were only collected for those taxonomically critical genera where determination in the field was not possible. Besides producing a species inventory for the Obermayr gravel pit in Riem, this study aimed to test the feasibility of using a non-invasive species determination based on bee specimen photography in the field instead of voucher collection. With current projects like the “Bundesprogramm Biologische Vielfalt – Schwerpunkt Sichern von Ökosystemdienstleistungen” of the Federal Office for Nature Conservation (BfN) and the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), non-invasive monitoring methods become increasingly important and the possibility of reliable, reproducible documentation fulfilling scientific standards without specimen collection needs to be tested.

Material and methods

Species list for Central European gravel pits

We are aware of five published studies which have monitored wild bees in gravel pits (Table 1). Additionally, we requested an unpublished report (Dubitzky 2015) for another Munich gravel pit located in the East of Munich (Trudering). The species lists within these studies were compiled and a list of 239 species recorded in gravel pits was generated (Table 2). The honey bee *Apis mellifera* was excluded from the analyses, as this is a domesticated and ubiquitous species. Each found study was scanned for the following information: (i) Where and when was the study conducted? (ii) Which sampling technique was used? (iii) Which taxa were found? If the information was not directly clear from the published material, the authors were contacted via e-mail.

Study site “Kiesgrube Obermayr”

“Kiesgrube Obermayr” is situated in the East of Munich, in Riem at N 48°8.833140' E 11°42.608280' 520 m a.s.l. While the southern part is still an active gravel pit, the northern part is refilled and maintained as an open-soil and nutrient-poor grassland site. The area is not open

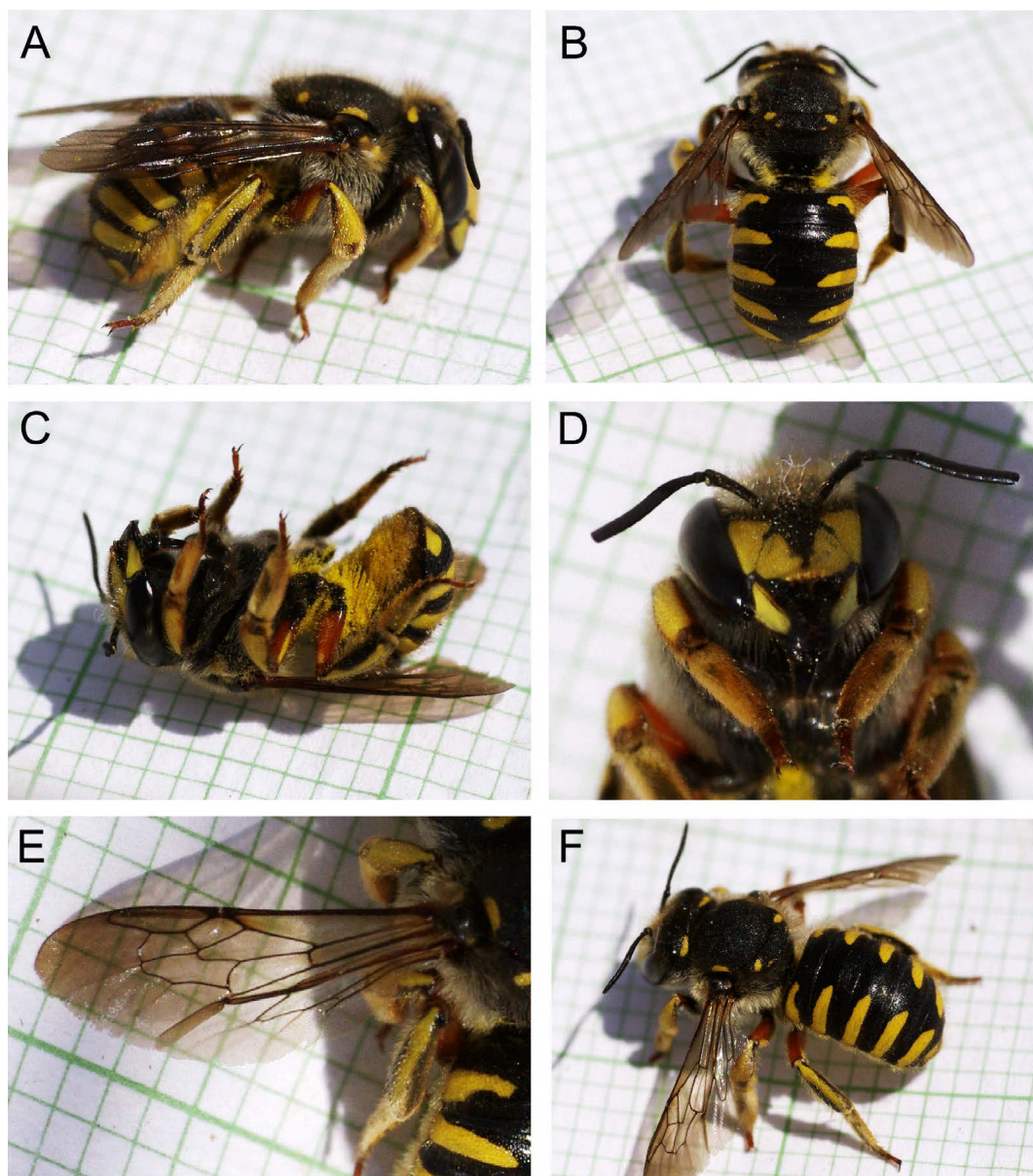


Fig. 2. Picture plate of an *Anthidium manicatum* female: **A.** lateral view; **B.** dorsal view; **C.** ventral view; **D.** detail face and front legs; **E.** detail wings; **F.** thorax and abdomen pattern. Images A-E: individual immobilized by chilling; F: recovering from paralyzation. Square grid = 1 mm. All photographs by M. Hofmann.

to the public and is maintained by the Landesbund für Vogelschutz (LBV) and the municipal department (Kommunalreferat). It borders to the Munich Trade Fair Center in the Southwest, a transshipment station in the West and arable fields to all other directions. Until 2004, the northern area had still been in active use as gravel pit, and then was refilled with several soil types. There

are two experimental fields with washed dry mud (middle and eastern part), a fine sediment resulting from washing gravel, and washed sand, a sandy material also resulting from the washing process with fine cohesive components (H. Sedlmeier, pers. com.). The steep face in the northern part of the biotope consists of this washed sand. Unwashed gravel had been piled up to

several walls and hills at the site. There is also a south-east-facing wall of demolished concrete that is not covered by vegetation. In the middle of the biotope there is railroad basalt disposed from the railroad tracks of former Neuaußing station. The bigger stones probably originated from the alpine upland. Loamy gravel derived from the topsoil removed for gravel extraction forms the hills in the south and the smaller walls in the northeastern and northern part of the biotope, these artificial hills are sparsely covered by woody vegetation, mainly consisting of willows (*Salix* spp., Salicaceae). The rest of the area is covered by a thin, compressed loam-gravel-layer on building rubble. Flat areas, hills, and ponds create a highly-structured area (Fig. 1). The area's flora (>545 documented species found during species monitoring from 2003–2016; a list excluding threatened taxa is available via the LBV administration) and its butterfly, grasshopper, and beetle fauna (see biotope reports available via the LBV administration) are extremely rich. Herbaceous plants and grasses were reintroduced by autochthonous transfer of mowed material from nearby dry grassland habitats of Munich, and *Hippophae rhamnoides*, *Sorbus aucuparia* and various *Rosa* sp., all of Munich provenance, had been actively planted by the LBV. Hundreds of trees and shrubs of eight *Salix* species have established by themselves (H. Sedlmeier, pers. com.).

Species inventory

Between the 14th of March and the 8th of August 2017, the Obermayr gravel pit was visited by the first author in regular intervals (every 2–3 weeks), the initial spring species survey was conducted by both authors. Monitor-

ing walks were conducted between 10 am and 4 pm on sunny, warm days with little or no wind. The mapping did not follow a strict route, but bees were searched for on flowers and nesting requisites. If possible, species were identified directly in the field and were documented via macro-photography in a standardized setup: for detailed pictures, the bees were caught with an insect net and cooled down for 10 minutes in an Eppendorf cupped plastic vial stored on ice in a cooled box. When the bees fell into rigor of cold, they were transferred onto scale paper (using a small box lined with millimeter paper on its bottom) and photographed from all sides (SLR camera: Pentax K-x; Lens: Sigma DG 17–70 mm, 1:2.8, macro), carefully turning them by hand or using a pair of watchmaker's tweezers. Within one to two minutes, they warmed up again and were released at the location they were also caught. For species that are taxonomically difficult to distinguish by morphology alone, like most members of the genera *Sphécodes*, *Lasiglossum* or *Halictus*, voucher specimens, preferably males (for morphological re-identification by genitalia preparations), were collected and identified morphologically and via DNA barcoding (methods and primers as described in Hofmann et al. 2018). Photo vouchers are accessible via the Diversity Workbench (DWB) server, DNA barcodes were uploaded to NCBI GenBank (see Table 3 for GenBank Accession Numbers and DWB Accessions). The voucher specimens are deposited in the Zoologische Staatssammlung Munich (ZSM).

Additionally, we included species records from 2016 provided by M. Bräu in the species list. The domesticated honey bee *Apis mellifera* was abundantly observed at the Kiesgrube Obermayr, but not included in the species list.

Table 1. Inventories of active and renatured gravel pits in Central Europe, with study period and sampling method.

Site	Study period	Sampling method	Number of species	Publication
inactive gravel pit complex in Leverkusen	2000–2005	net sampling	98	[1] Cölln et al. 2012
former gravel pit Roth in Trudering, Munich	4 monitoring walks in 2015; one additional investigation day in 2008	net sampling	70	[2] Dubitzky, A. (2015) and Schuberth, J. (unpublished)
Ramsar area “Baggerweieren” at “Haff Réimech”, Luxembourg	1997 to 2004; 209 monitoring walks	net sampling	110	[3] Feitz et al. 2006
gravel pits between Rhine and Lake Zurich	N/A	N/A	14	[4] Krebs & Wildermuth 1976
closed gravel pit Rutzendorf, Lower Austria	2003–2005 and 2007–2008; four-weekly rhythm	net sampling	82	[5] Pachinger & Prochazka 2009; with additional data from B. Pachinger for 2009 and later (personal communication)
gravel pit “am Hardtwald Durmersheim” south of Karlsruhe	1993 to 2005	net sampling	41	[6] Schiel & Rademacher 2008; with additional data from A. Schanowski for 2007 (personal communication)

Table 2. List of wild bees reported for Central European gravel pits. The numbers in squared brackets indicate the studies where the species was reported (numbers refer to Table 1). Species marked in bold were also found in this study.

Species	Family	Study
<i>Andrena agillissima</i> (Scopoli, 1770)	Andrenidae	[3]
<i>Andrena apicata</i> Smith, 1847	Andrenidae	[2]
<i>Andrena barbilabris</i> (Kirby, 1802)	Andrenidae	[1,6]
<i>Andrena bicolor</i> Fabricius, 1775	Andrenidae	[1,2,6]
<i>Andrena carantonica</i> Pérez, 1902	Andrenidae	[1,6]
<i>Andrena chrysopus</i> Pérez, 1903	Andrenidae	[6]
<i>Andrena chrysoseles</i> (Kirby, 1802)	Andrenidae	[3,5]
<i>Andrena clarkella</i> (Kirby, 1802)	Andrenidae	[2]
<i>Andrena cineraria</i> (Linnaeus, 1758)	Andrenidae	[2,3,6]
<i>Andrena denticulata</i> (Kirby, 1802)	Andrenidae	[6]
<i>Andrena dorsata</i> (Kirby, 1802)	Andrenidae	[1,5,6]
<i>Andrena flavipes</i> Panzer, 1798	Andrenidae	[1,2,5,6]
<i>Andrena fulva</i> (Müller, 1766)	Andrenidae	[1,3]
<i>Andrena fulvata</i> Stoeckhert, 1930	Andrenidae	[2]
<i>Andrena gelriae</i> van der Vecht, 1927	Andrenidae	[6]
<i>Andrena grävada</i> Imhoff, 1832	Andrenidae	[2]
<i>Andrena haemorrhoa</i> (Fabricius, 1781)	Andrenidae	[1,3,5,6]
<i>Andrena hattorfiana</i> (Fabricius, 1775)	Andrenidae	[3]
<i>Andrena helvola</i> (Linnaeus, 1758)	Andrenidae	[2]
<i>Andrena impunctata</i> Pérez, 1895	Andrenidae	[5]
<i>Andrena intermedia</i> Thomson, 1870	Andrenidae	[2]
<i>Andrena labiata</i> Fabricius, 1781	Andrenidae	[1,6]
<i>Andrena lathyri</i> Alfken, 1899	Andrenidae	[6]
<i>Andrena minutula</i> (Kirby, 1802)	Andrenidae	[1,2,3,6]
<i>Andrena minutuloides</i> Perkins, 1914	Andrenidae	[1,5]
<i>Andrena mitis</i> Schmiedeknecht, 1883	Andrenidae	[6]
<i>Andrena nigroaenea</i> (Kirby, 1802)	Andrenidae	[5]
<i>Andrena nitida</i> (Müller, 1776)	Andrenidae	[3]
<i>Andrena nobilis</i> Morawitz, 1873	Andrenidae	[5]
<i>Andrena oralis</i> Morawitz, 1876	Andrenidae	[5]
<i>Andrena ovatula</i> (Kirby, 1802)	Andrenidae	[1,5,6]
<i>Andrena pilipes</i> Fabricius, 1781	Andrenidae	[1,5,6]
<i>Andrena praecox</i> (Scopoli, 1763)	Andrenidae	[1,2,6]
<i>Andrena propinqua</i> Schenck, 1853	Andrenidae	[5]
<i>Andrena proxima</i> (Kirby, 1802)	Andrenidae	[1]
<i>Andrena pusilla</i> Pérez, 1903	Andrenidae	[6]
<i>Andrena ruficrus</i> Nylander, 1848	Andrenidae	[2]
<i>Andrena schencki</i> Morawitz, 1866	Andrenidae	[3]
<i>Andrena scita</i> Eversmann, 1852	Andrenidae	[5]
<i>Andrena similis</i> Smith, 1849	Andrenidae	[6]
<i>Andrena simontornyella</i> Noskiewicz, 1939	Andrenidae	[5]
<i>Andrena strohmeilla</i> Stoeckhert, 1928	Andrenidae	[2]
<i>Andrena subopaca</i> Nylander, 1848	Andrenidae	[2,3,6]
<i>Andrena symphyti</i> Schmiedeknecht, 1883	Andrenidae	[5]
<i>Andrena vaga</i> Panzer, 1799	Andrenidae	[1,2,3,4,6]
<i>Andrena ventralis</i> Imhoff, 1832	Andrenidae	[2]
<i>Andrena viridescens</i> Viereck, 1916	Andrenidae	[6]
<i>Andrena wilkella</i> (Kirby, 1802)	Andrenidae	[1,6]
<i>Anthidiellum strigatum</i> (Panzer, 1805)	Megachilidae	[3,4,6]

Table 2. (continued).

Species	Family	Study
<i>Anthidium manicatum</i> (Linnaeus, 1758)	Megachilidae	[2,3]
<i>Anthidium nanum</i> Mocsary, 1881	Megachilidae	[3,5]
<i>Anthidium oblongatum</i> (Illiger, 1806)	Megachilidae	[3]
<i>Anthidium punctatum</i> Latreille, 1809	Megachilidae	[2,3,5]
<i>Anthophora bimaculata</i> (Panzer, 1798)	Apidae	[6]
<i>Anthophora plumipes</i> (Pallas, 1772)	Apidae	[1,2,3,4]
<i>Anthophora quadrimaculata</i> (Panzer, 1798)	Apidae	[1]
<i>Anthophora retusa</i> (Linnaeus, 1758)	Apidae	[1,3,6]
<i>Bombus hortorum</i> (Linnaeus, 1761)	Apidae	[1,2,5]
<i>Bombus humilis</i> Illiger, 1806	Apidae	[5,6]
<i>Bombus hypnorum</i> (Linnaeus, 1758)	Apidae	[1,3]
<i>Bombus lapidarius</i> (Linnaeus, 1758)	Apidae	[1,2,5,6]
<i>Bombus lucorum</i> (Linnaeus, 1761)	Apidae	[1,2,5]
<i>Bombus pascuorum</i> (Scopoli, 1763)	Apidae	[1,2,3,5,6]
<i>Bombus pratorum</i> (Linnaeus, 1761)	Apidae	[1,2]
<i>Bombus rupestris</i> (Fabricius, 1793)	Apidae	[1,2,6]
<i>Bombus soroeensis</i> (Fabricius, 1776)	Apidae	[2]
<i>Bombus sylvarum</i> (Linnaeus, 1761)	Apidae	[3,5,6]
<i>Bombus terrestris</i> (Linnaeus, 1758)	Apidae	[1,3,5]
<i>Bombus vestalis</i> (Geoffroy, 1785)	Apidae	[1,2,5]
<i>Camptopoeum frontale</i> (Fabricius, 1804)	Andrenidae	[5]
<i>Ceratina chalybea</i> Chevrier, 1872	Apidae	[5]
<i>Ceratina cucurbitina</i> (Rossi, 1792)	Apidae	[1,3,5,6]
<i>Ceratina cyanea</i> (Kirby, 1802)	Apidae	[1,2,3,4,5,6]
<i>Chelostoma campanularum</i> (Kirby, 1802)	Megachilidae	[1,6]
<i>Chelostoma distinctum</i> (Stöckert, 1929)	Megachilidae	[2,3,6]
<i>Chelostoma florissomne</i> (Linnaeus, 1758)	Megachilidae	[3]
<i>Chelostoma rapunculi</i> (Lepeletier, 1841)	Megachilidae	[1,2,3,6]
<i>Coelioxys afra</i> Lepeletier, 1841	Megachilidae	[3,6]
<i>Coelioxys aurolimbata</i> Förster, 1853	Megachilidae	[3]
<i>Coelioxys elongata</i> Lepeletier, 1841	Megachilidae	this study
<i>Coelioxys inermis</i> (Kirby, 1802)	Megachilidae	[2]
<i>Coelioxys mandibularis</i> Nylander, 1848	Megachilidae	[1]
<i>Coelioxys quadridentata</i> (Linnaeus, 1758)	Megachilidae	[1,3]
<i>Colletes cunicularius</i> (Linnaeus, 1761)	Colletidae	[1,2,3,6]
<i>Colletes daviesanus</i> Smith, 1846	Colletidae	[1,4,5]
<i>Colletes fodiens</i> (Geoffroy, 1785)	Colletidae	[1,6]
<i>Colletes hederæ</i> Schmidt & Westrich, 1993	Colletidae	[3]
<i>Colletes similis</i> Schenck, 1853	Colletidae	[1,6]
<i>Dasypoda hirtipes</i> (Fabricius, 1793)	Melittidae	[3,4,5,6]
<i>Dioxys tridentata</i> (Nylander, 1848)	Megachilidae	[3]
<i>Epeoloides coecutiens</i> (Fabricius, 1775)	Apidae	[3]
<i>Epeolus variegatus</i> (Linnaeus, 1758)	Apidae	[1,3,6]
<i>Eucera longicornis</i> (Linnaeus, 1758)	Apidae	[3,5]
<i>Eucera nigrescens</i> Pérez, 1879	Apidae	[3,5,6]
<i>Eucera pollinosa</i> Smith, 1854	Apidae	[5]
<i>Halictus confusus</i> Smith, 1853	Halictidae	[6]
<i>Halictus eurygnathus</i> Blüthgen, 1931	Halictidae	[3]
<i>Halictus gavaranicus</i> Pérez, 1903	Halictidae	[5]

Table 2. (continued).

Species	Family	Study
<i>Halictus kessleri</i> Bramson, 1879	Halictidae	[5]
<i>Halictus langobardicus</i> Blüthgen, 1944	Halictidae	[3,6]
<i>Halictus leucaheneus</i> Ebmer, 1972	Halictidae	[6]
<i>Halictus maculatus</i> Smith, 1848	Halictidae	[3,5,6]
<i>Halictus pollinosus</i> Sichel, 1860	Halictidae	[5]
<i>Halictus quadricinctus</i> (Fabricius, 1777)	Halictidae	[5,6]
<i>Halictus rubicundus</i> (Christ, 1791)	Halictidae	[1,3,6]
<i>Halictus scabiosae</i> (Rossi, 1790)	Halictidae	[1,3,6]
<i>Halictus seladonius</i> (Fabricius, 1794)	Halictidae	[5]
<i>Halictus sexcinctus</i> Fabricius, 1775	Halictidae	[4,5,6]
<i>Halictus simplex</i> Bluethgen, 1923	Halictidae	[5,6]
<i>Halictus smaragdulus</i> Vachal, 1895	Halictidae	[6]
<i>Halictus subauratus</i> (Rossi, 1792)	Halictidae	[3,5,6]
<i>Halictus tumulorum</i> (Linnaeus, 1758)	Halictidae	[1,2,3,5,6]
<i>Heriades crenulatus</i> Nylander, 1856	Megachilidae	[6]
<i>Heriades truncorum</i> (Linnaeus, 1758)	Megachilidae	[1,2,3,5,6]
<i>Hoplitis acuticornis</i> (Dufour & Perris, 1840)	Megachilidae	[3]
<i>Hoplitis adunca</i> (Panzer, 1798)	Megachilidae	[5]
<i>Hoplitis claviventris</i> (Thomson, 1872)	Megachilidae	[2,3]
<i>Hoplitis leucomelana</i> (Kirby, 1802)	Megachilidae	[1,2,3,4,5]
<i>Hoplitis tridentata</i> (Dufour & Perris, 1840)	Megachilidae	[3,6]
<i>Hylaeus angustatus</i> (Schenck, 1859)	Colletidae	[3,6]
<i>Hylaeus annularis</i> (Kirby, 1802)	Colletidae	[1,3,6]
<i>Hylaeus brevicornis</i> Nylander, 1852	Colletidae	[1,5,6]
<i>Hylaeus cardioscapus</i> Cockerell, 1924	Colletidae	[5]
<i>Hylaeus clypearis</i> (Schenck, 1853)	Colletidae	[3]
<i>Hylaeus communis</i> Nylander, 1852	Colletidae	[1,2,6]
<i>Hylaeus confusus</i> Nylander, 1852	Colletidae	[1,2,6]
<i>Hylaeus cornutus</i> Curtis, 1831	Colletidae	[1,2,3,5]
<i>Hylaeus difformis</i> (Eversmann, 1852)	Colletidae	[3]
<i>Hylaeus dilatatus</i> (Kirby, 1802)	Colletidae	[5]
<i>Hylaeus gibbus</i> Saunders, 1850	Colletidae	[5,6]
<i>Hylaeus gredleri</i> Foerster, 1871	Colletidae	[1,3,5,6]
<i>Hylaeus hyalinatus</i> (Smith, 1842)	Colletidae	[1,3,5]
<i>Hylaeus nigritus</i> (Fabricius, 1798)	Colletidae	[3]
<i>Hylaeus punctatus</i> (Brullé, 1832)	Colletidae	[3]
<i>Hylaeus punctulatissimus</i> Smith, 1842	Colletidae	[1]
<i>Hylaeus signatus</i> (Panzer, 1798)	Colletidae	[1,3]
<i>Hylaeus variegatus</i> (Fabricius, 1798)	Colletidae	[3,6]
<i>Lasioglossum aeratum</i> (Kirby, 1802)	Halictidae	[5,6]
<i>Lasioglossum albipes</i> (Fabricius, 1781)	Halictidae	[2,6]
<i>Lasioglossum brevicorne</i> (Schenck, 1869)	Halictidae	[6]
<i>Lasioglossum calceatum</i> (Scopoli, 1763)	Halictidae	[1,2,3,5,6]
<i>Lasioglossum clypeare</i> (Schenck, 1853)	Halictidae	[5]
<i>Lasioglossum costulatum</i> (Kriechbaumer, 1873)	Halictidae	[3,6]
<i>Lasioglossum</i> aff. <i>cupromicans</i> (Pérez, 1903)	Halictidae	[2]
<i>Lasioglossum discum</i> (Smith, 1853)	Halictidae	[5]
<i>Lasioglossum fulvicorne</i> (Kirby, 1802)	Halictidae	[3,6]
<i>Lasioglossum glabriusculum</i> (Moraw., 1872)	Halictidae	[3]
<i>Lasioglossum intermedium</i> (Schenck, 1869)	Halictidae	[1,3]

Table 2. (continued).

Species	Family	Study
<i>Lasioglossum interruptum</i> (Panzer, 1798)	Halictidae	[5]
<i>Lasioglossum laticeps</i> (Schenck, 1869)	Halictidae	[1, 3, 6]
<i>Lasioglossum lativentre</i> (Schenck, 1853)	Halictidae	[3, 5, 6]
<i>Lasioglossum leucopus</i> (Kirby, 1802)	Halictidae	[1, 2, 6]
<i>Lasioglossum leucozonium</i> (Schränk, 1781)	Halictidae	[1, 2, 3, 6]
<i>Lasioglossum limbellum</i> (Morawitz, 1876)	Halictidae	[3, 6]
<i>Lasioglossum lucidulum</i> (Schenck, 1861)	Halictidae	[6]
<i>Lasioglossum malachurum</i> (Kirby, 1802)	Halictidae	[3, 4, 5, 6]
<i>Lasioglossum minutissimum</i> (Kirby, 1802)	Halictidae	[1, 6]
<i>Lasioglossum monstificum</i> (Morawitz, 1891)	Halictidae	[1]
<i>Lasioglossum morio</i> (Fabricius, 1793)	Halictidae	[1, 2, 3, 5, 6]
<i>Lasioglossum nigripes</i> (Lepelletier, 1841)	Halictidae	[5]
<i>Lasioglossum nitidulum</i> (Fabricius 1804)	Halictidae	[2]
<i>Lasioglossum nitidiusculum</i> (Kirby, 1802)	Halictidae	[3]
<i>Lasioglossum pauperatum</i> (Brullé, 1832)	Halictidae	[6]
<i>Lasioglossum pauxillum</i> (Schenck, 1853)	Halictidae	[1, 3, 6]
<i>Lasioglossum politum</i> (Schenck, 1853)	Halictidae	[5, 6]
<i>Lasioglossum punctatissimum</i> (Schenck, 1853)	Halictidae	[1, 6]
<i>Lasioglossum puncticolle</i> (Morawitz, 1872)	Halictidae	[3]
<i>Lasioglossum quadrinotatum</i> (Schenck, 1861)	Halictidae	[3, 6]
<i>Lasioglossum quadrinotatum</i> (Kirby, 1802)	Halictidae	[5, 6]
<i>Lasioglossum rufitarse</i> (Zetterstedt, 1838)	Halictidae	[2]
<i>Lasioglossum semilucens</i> (Alfken, 1914)	Halictidae	[2, 3]
<i>Lasioglossum sexnotatum</i> (Kirby, 1802)	Halictidae	[5, 6]
<i>Lasioglossum sexstrigatum</i> (Schenck, 1869)	Halictidae	[1, 2, 6]
<i>Lasioglossum trichopygum</i> (Blüthgen, 1923)	Halictidae	[5]
<i>Lasioglossum villosulum</i> (Kirby, 1802)	Halictidae	[1, 2, 3, 6]
<i>Lasioglossum xanthopus</i> (Kirby, 1802)	Halictidae	[5, 6]
<i>Lasioglossum zonulum</i> (Smith, 1848)	Halictidae	[5, 6]
<i>Macropis europaea</i> Warncke, 1973	Melittidae	[3]
<i>Megachile alpicola</i> Alfken, 1924	Megachilidae	[6]
<i>Megachile centuncularis</i> (Linnaeus, 1758)	Megachilidae	[1, 2, 6]
<i>Megachile circumcincta</i> (Kirby, 1802)	Megachilidae	[1, 2, 3]
<i>Megachile ericetorum</i> Lepelletier, 1841	Megachilidae	[1, 2, 3]
<i>Megachile lagopoda</i> (Linnaeus, 1761)	Megachilidae	[5]
<i>Megachile ligniseca</i> (Kirby, 1802)	Megachilidae	[3]
<i>Megachile nigriventris</i> Schenk, 1869	Megachilidae	[2]
<i>Megachile parietina</i> (Geoffroy, 1785)	Megachilidae	[4]
<i>Megachile pilidens</i> Alfken, 1924	Megachilidae	[1, 3, 6]
<i>Megachile rotundata</i> (Fabricius, 1787)	Megachilidae	[6]
<i>Megachile versicolor</i> Smith, 1844	Megachilidae	[1, 2, 5]
<i>Megachile willughbiella</i> (Kirby, 1802)	Megachilidae	[1, 2, 3, 4, 5]
<i>Melecta albifrons</i> (Forster, 1771)	Apidae	[4]
<i>Melitta leporina</i> (Panzer, 1799)	Melittidae	[1, 3, 5, 6]
<i>Melitta nigricans</i> Alfken, 1905	Melittidae	[3]
<i>Nomada alboguttata</i> Herrich-Schäffer, 1839	Apidae	[1, 3, 5, 6]
<i>Nomada bifasciata</i> Olivier, 1811	Apidae	[3]
<i>Nomada fabriciana</i> (Linnaeus, 1767)	Apidae	[1, 2, 3, 6]
<i>Nomada ferruginata</i> (Linnaeus, 1767)	Apidae	[2, 3]
<i>Nomada flava</i> Panzer, 1798	Apidae	[1, 3, 6]

Table 2. (continued).

Species	Family	Study
<i>Nomada flavoguttata</i> (Kirby, 1802)	Apidae	[1,2,3,6]
<i>Nomada flavopicta</i> (Kirby, 1802)	Apidae	[3]
<i>Nomada fucata</i> Panzer, 1798	Apidae	[1,3,6]
<i>Nomada fulvicornis</i> Fabricius, 1793	Apidae	[1,6]
<i>Nomada fuscicornis</i> Nylander, 1848	Apidae	[6]
<i>Nomada goodeniana</i> (Kirby, 1802)	Apidae	[6]
<i>Nomada lathburiana</i> (Kirby, 1802)	Apidae	[2,3,6]
<i>Nomada leucophthalma</i> (Kirby, 1802)	Apidae	[3]
<i>Nomada marshamella</i> (Kirby, 1802)	Apidae	[1,3]
<i>Nomada obscura</i> Zetterstedt, 1838	Apidae	[6]
<i>Nomada panzeri</i> Lepeletier, 1841	Apidae	[2,6]
<i>Nomada rufipes</i> Fabricius, 1793	Apidae	[6]
<i>Nomada sexfasciata</i> Panzer, 1799	Apidae	[3]
<i>Nomada sheppardana</i> (Kirby, 1802)	Apidae	[6]
<i>Nomada signata</i> Jurine, 1807	Apidae	[3]
<i>Nomada succincta</i> Panzer, 1798	Apidae	[1,3]
<i>Nomada zonata</i> Panzer, 1798	Apidae	[1]
<i>Osmia aurulenta</i> (Panzer, 1799)	Megachilidae	[3,4]
<i>Osmia bicolor</i> (Schränk, 1781)	Megachilidae	[1,3,4]
<i>Osmia bicornis</i> (Linnaeus, 1758)	Megachilidae	[1,3]
<i>Osmia brevicornis</i> (Fabricius, 1798)	Megachilidae	[3]
<i>Osmia caerulea</i> (Linnaeus, 1758)	Megachilidae	[6]
<i>Osmia gallarum</i> Spinola, 1808	Megachilidae	[3,6]
<i>Osmia rufohirta</i> Latreille, 1811	Megachilidae	[3]
<i>Osmia spinulosa</i> (Kirby, 1802)	Megachilidae	[3,5]
<i>Panurgus calcaratus</i> (Scopoli, 1763)	Andrenidae	[1,5,6]
<i>Rhopitoides canus</i> (Eversmann, 1852)	Halictidae	[5]
<i>Sphecodes albilabris</i> (Fabricius, 1793)	Halictidae	[1,3,6]
<i>Sphecodes crassus</i> Thomson, 1870	Halictidae	[1,2,6]
<i>Sphecodes cristatus</i> Hagens, 1882	Halictidae	[6]
<i>Sphecodes ephippius</i> (Linnaeus, 1767)	Halictidae	[1,5,6]
<i>Sphecodes ferruginatus</i> Hagens, 1882	Halictidae	[1]
<i>Sphecodes geoffrellus</i> (Kirby, 1802)	Halictidae	[1,6]
<i>Sphecodes gibbus</i> (Linnaeus, 1758)	Halictidae	[1,2,5,6]
<i>Sphecodes hyalinatus</i> (von Hagens, 1882)	Halictidae	[2]
<i>Sphecodes longulus</i> Hagens, 1882	Halictidae	[1,6]
<i>Sphecodes marginatus</i> Hagens, 1882	Halictidae	[2]
<i>Sphecodes miniatus</i> Hagens, 1882	Halictidae	[1,2,5,6]
<i>Sphecodes monilicornis</i> (Kirby, 1802)	Halictidae	[1,2,5,6]
<i>Sphecodes niger</i> Hagens, 1874	Halictidae	[1]
<i>Sphecodes pellucidus</i> Smith, 1845	Halictidae	[1,6]
<i>Sphecodes puncticeps</i> Thomson, 1870	Halictidae	[1,6]
<i>Sphecodes reticulatus</i> Thomson, 1870	Halictidae	[1,6]
<i>Sphecodes rufiventris</i> (Panzer, 1798)	Halictidae	[6]
<i>Stelis odontopyga</i> Noskiewicz, 1925	Megachilidae	[3]
<i>Stelis ornatula</i> (Klug, 1807)	Megachilidae	[1]
<i>Tetraloniella dentata</i> (Germar, 1839)	Apidae	[5]
<i>Trachusa byssina</i> (Panzer, 1804)	Megachilidae	[3]

Results

We found six studies with wild bee species lists for Central European gravel pits (Table 1). In these studies, 245 species were documented (Table 2). Of these, 110 species were reported by only one study, while 135 were reported in at least two different studies (two studies: 56 spp., three studies: 48 spp., four studies: 22 spp., five studies: 8 spp., all six studies: 1 spp.). Of the 245 species with records published from gravel pits, 190 are also native in the Munich area (M. Bräu, pers. com.).

A total of 48 species were found in the survey area (see Table 3). 29 were documented via standardized in-situ photography, eight via DNA-barcoding, and 3 species were observed. Eight of these have also been recorded by M. Bräu in 2016, and an additional six species had been documented in 2016, but were not seen in 2017. Amongst the observed species, four were oligolectic, 33 polylectic and eleven were cuckoo bees. Of the non-parasitic bees eleven nested above ground, five above and below ground and 21 below ground. A *Megachile* female could not be identified to species level, as the pollen brush

was full and the colours relevant for determination were not visible. A *Megachile* male voucher (KGO-00081) was unclear, as coxa 1 and tergite 6 were not visible. Most likely it was a *Megachile rotundata* male, but it cannot be excluded that it was another species, thus we did not include it in our list. The photo voucher of *Megachile* cf. *versicolor* could also be *Megachile centuncularis*, as a definite separation of these two species is only possible via examination of the genitalia, but the redish tarsal segments hint towards *M. versicolor* (KGO-00021). The same applies for the *Halictus confusus/tumulorum* complex, the photo voucher was not unambiguous, but here we can confirm the presence of *H. tumulorum* via DNA barcoding (voucher MG792009). For one *Hylaeus* voucher, we strongly suspect it to be *H. nigrinus*, but we lack a photo of sufficient quality of the face in frontal view to say for sure (KGO-00039). For *Andrena*, we had photo vouchers of one male and three females, where relevant features were not visible and they thus could not be identified. In total, 12 % of the photo vouchers (excluding *Halictus*, *Lasioglossum* and *Sphex* pictures) were not identifiable to species level.

Table 3. Species list for gravel pit Obermayr. The record type refers to the mode of documentation (o, observation; p, photodocumentation; b, barcoding of voucher specimen; ext, external data from M. Bräu), the record ID gives the GenBank or Biodiversity Workbench accession numbers for barcoded or photographic vouchers, lecty describes the foraging preference and nest site preference whether a bee builds its nest below or above the surface or is parasitic. Species where determination was not sure on the photograph are printed in grey.

Species	record type	record ID	lecty	nest site preference
<i>Andrena bicolor</i> Fabricius, 1775	o	observation on 28.03.2017	polylectic	ground
<i>Andrena chrysosceles</i> (Kirby, 1802)	p	KGO-00099	polylectic	ground
<i>Andrena dorsata</i> (Kirby, 1802)	ext	M.Bräu, 21.04.2016	polylectic	ground
<i>Andrena flavipes</i> Panzer, 1798	ext, p	M.Bräu, 21.04.2016 KGO-00028	polylectic	ground
<i>Andrena gravida</i> Imhoff, 1832	p	KGO-00097	polylectic	ground
<i>Andrena haemorrhoa</i> (Fabricius, 1781)	p	KGO-00084	polylectic	ground
<i>Andrena vaga</i> Panzer, 1799	ext, p	M.Bräu, n. d. KGO-00096 KGO-00106	oligolectic	ground
<i>Andrena viridescens</i> Viereck, 1916	ext	M.Bräu, 21.04.2016	oligolectic	ground
<i>Anthidium manicatum</i> (Linnaeus, 1758)	p	KGO-00035	polylectic	above
<i>Anthidium oblongatum</i> (Illiger, 1806)	p	KGO-00014	polylectic	above
<i>Anthidium punctatum</i> Latreille, 1809	p	KGO-00073	polylectic	above
<i>Bombus hortorum</i> (Linnaeus, 1761)	p	KGO-00082	polylectic	above and ground
<i>Bombus hypnorum</i> (Linnaeus, 1758)	p	KGO-00074	polylectic	above
<i>Bombus lapidarius</i> (Linnaeus, 1758)	p	KGO-00069 KGO-00100	polylectic	above and ground
<i>Bombus lucorum</i> (Linnaeus, 1761)	p	KGO-00065	polylectic	ground
<i>Bombus pascuorum</i> (Scopoli, 1763)	p	KGO-00067	polylectic	above and ground
<i>Bombus pratorum</i> (Linnaeus, 1761)	o	observed 28.03.2017	polylectic	above

Table 3. (continued).

Species	record type	record ID	lecty	nest site preference
<i>Bombus rupestris</i> (Fabricius, 1793)	p	KGO-00070	parasitic	parasitic
<i>Bombus sylvarum</i> (Linnaeus, 1761)	p	KGO-00002 KGO-00068	polylectic	above and ground
<i>Bombus terrestris</i> (Linnaeus, 1758)	p	KGO-00079	polylectic	ground
<i>Bombus vestalis</i> (Geoffroy, 1785)	ext, p	M.Bräu, 21.04.2016 KGO-00101	parasitic	parasitic
<i>Coelioxys elongata</i> Lepeletier, 1841	p	KGO-00080		
<i>Colletes cunicularius</i> (Linnaeus, 1761)	parasitic ext, p	parasitic M.Bräu, n.d. KGO-00107	polylectic	ground
<i>Colletes daviesanus</i> Smith, 1846	o	observed 14.08.2017	oligolectic	ground
<i>Halictus eurygnathus</i> Blüthgen, 1931	p	KGO-00022 KGO-00034	polylectic	ground
<i>Halictus rubicundus</i> (Christ, 1791)	p	KGO-00103	polylectic	ground
<i>Halictus scabiosae</i> (Rossi, 1790)	p	KGO-00006	polylectic	ground
<i>Halictus subauratus</i> (Rossi, 1792)	b	MG792004	polylectic	ground
<i>Halictus tumulorum</i> (Linnaeus, 1758)	b	MG792009	polylectic	ground
<i>Hylaeus cf. nigritus</i> (Kirby, 1802)	p	KGO-00039	polylectic	above
<i>Hylaeus communis</i> Nylander, 1852	p	KGO-00027 KGO-00050 KGO-00052	polylectic	above
<i>Lasioglossum laticeps</i> (Schenck, 1869)	b	MG791965 MG791966 MG791967	polylectic	ground
<i>Lasioglossum leucozonium</i> (Schränk, 1781)	b	MG791993 MG791991	polylectic	ground
<i>Lasioglossum morio</i> (Fabricius, 1793)	b	MG791969 MG791970 MG791971 MG791972	polylectic	ground
<i>Lasioglossum pauxillum</i> (Schenck, 1853)	b, ext	M.Bräu, 21.04.2016 and 20.05.2016 MG791980 MG791981 MG791983	polylectic	ground
<i>Megachile cf. versicolor</i> Smith, 1844	p	KGO-00021	polylectic	above
<i>Megachile willughbiella</i> (Kirby, 1802)	p	KGO-00036 KGO-00037	polylectic	above and ground
<i>Nomada flavoguttata</i> (Kirby, 1802)	ext	M.Bräu, 21.04.2016	parasitic	parasitic
<i>Nomada goodeniana</i> (Kirby, 1802)	ext	M.Bräu, 21.04.2016	parasitic	parasitic
<i>Nomada lathburiana</i> (Kirby, 1802)	ext	M.Bräu, 21.04.2016	parasitic	parasitic
<i>Osmia aurulenta</i> (Panzer, 1799)	ext, p	M.Bräu, 20.05.2016 KGO-00071 KGO-00104	polylectic	above
<i>Osmia bicolor</i> (Schränk, 1781)	p	KGO-00105	polylectic	above
<i>Osmia spinulosa</i> (Kirby, 1802)	p	KGO-00072	oligolectic	above
<i>Sphecodes crassus</i> Thomson, 1870	b	MG845959	parasitic	parasitic
<i>Sphecodes ephippius</i> (Linnaeus, 1767)	ext	M.Bräu, 21.04.2016	parasitic	parasitic
<i>Sphecodes gibbus</i> (Linnaeus, 1758)	ext	M.Bräu, 21.04.2016	parasitic	parasitic
<i>Sphecodes monilicornis</i> (Kirby, 1802)	ext	M.Bräu, 21.04.2016	parasitic	parasitic
<i>Sphecodes puncticeps</i> Thomson, 1870	b	MG 845968	parasitic	parasitic

Discussion

With at least 48 species, the gravel pit Obermayr is an important wild bee habitat in the East of Munich, especially for ground-nesting species. In Germany, Austria and Switzerland, 50 % of the bees are nesting in self-burrowed tunnels in the ground and 19 % in hollow spaces (Zurbuchen & Müller 2012, p.57; Westrich 2018), but for the gravel pit the proportion ranges at 54 % ground-nesters (both self-burrowed or in existing cavities), and ten of the eleven parasitic species rely on the nests of ground-nesting species. This should be considered when it comes to the refill of idle gravel pits. By maintaining some open soil sites, they can enrich the landscape by providing nesting sites for wild bees. Moreover, if hollows and puddles hold the water, renatured gravel pits are important spawn habitats for amphibians (Escher 1974), and steep walls can serve swallows as nest sites (Wagner 1969), and such sites also have a high conservation value for butterflies (Lenda et al. 2012). With some planning effort, the conservation value of abandoned gravel pits can be strongly increased.

Photo-documentation in-situ instead of voucher collection proved feasible for most wild bee genera, but nevertheless taxonomic skills are necessary to be able to recognize bee sex and genera in the field, to be aware which different features need to be photographed or focused on in males and females and in different genera (see Table 4 for examples). The method is problematic for species from the Halictidae genera *Sphecodes*, *Lasioglossum* and *Halictus*, but also in certain groups of *Andrena*, *Nomada* or *Bombus*, as some species in these groups differ only in minute texture features difficult to document by photography. Generally, small individuals (<7 mm) can be problematic for another reason, as the rigor of cold only lasts for about a minute, thus time often is not sufficient to get all details documented. Moreover, another limitation to the photo-based identification of bee females is that individuals with pollen load usually cannot be identified, as the pollen generally obscures the colour of the scopae – hence we chilled down only foraging females without pollen load, and did not consider those carrying pollen.

Table 4. Species features for photo-documentation. This list is not attempting to be comprehensive and must be adapted depending on time and region of the monitoring and should be in accordance with the respective keys of determination.

General features	
Overview photograph from top, side and bottom size, colours, body shape	
Frontal view of the face	shape, colours, hairs, mandibles, clypeus, labrum
Details of thorax from above	sculpturation of scutum and potential rugosity of propodeum
Detail of abdomen from above	tergite bands and sculpturation
For females	
Pollen brush or scopae with flocci	colour(s), extension
For males	
Sternites	spines, shape of last sternite
Genus-specific features	
<i>Andrena</i> males	frontal and side view of the head, detail of antennae (front view)
<i>Anthophora</i> males	mid-tarsi and mid-basitarsi, hind tibiae and basitarsi
<i>Bombus</i> females	sternite 6, head in front and side view, hind tibiae and basitarsi
<i>Bombus</i> males	detail of antennae, hind tibiae and basitarsi
<i>Chelostoma</i> males	sternites 2 and 4
<i>Coelioxys</i> females	tergite 6 and sternites 5 and 6
<i>Coelioxys</i> males	tergite 5 (edges) and sternite 4
<i>Colletes</i> females	hind margin of tergite 1, dorsal fringe of hind tibiae, galeae, clypeus
<i>Colletes</i> males	sternite 6, galeae
<i>Hylaeus</i>	frontal face and antennal view, pronotal collar; additionally for males: mandibles and labrum
<i>Megachile</i> females	tergite 6 in side view
<i>Megachile</i> males	front tarsi, front coxae
<i>Nomada</i>	frontal and side view of head, labrum and tip of mandibles, detail of antennae, detail of hind femora and tibiae
<i>Osmia</i>	spurs of hind tibiae

Macro photographs need to be of sufficient quality, brightness and especially depth of field and resolution to be able to identify microstructures and sculpture on the thorax and tergites, thus a good macro lens is required, and if the weather is cloudy, an additional light source improves picture quality.

The big advantages of in-situ bee photo-documentation are the preservation of live individuals' colour information (which is often lost in specimens) and the possibility to share voucher information (e.g. with taxonomic specialists) via a cloud, thus it is not necessary to send fragile specimens per mail, if the determination needs to be confirmed by a second person. However, in comparison with collecting voucher specimens, this method certainly has certain limitations and also some disadvantages: firstly, the photographer needs to be quick in taking pictures of all relevant features, because the rigor of cold does not last long. Secondly, if pictures are not good enough to see the characters you need, there is no chance to go back to the original individual, after it was released. Moreover, the time effort in the field is increased compared to specimen collection, thus only smaller or fewer sites can be monitored at a time.

Although photo-documentation cannot replace voucher collection completely, it can be an approach towards non-invasive species documentation (especially in larger bees and easier to recognize groups), which becomes increasingly important in times of drastic decreases in many insect taxa worldwide (Sánchez-Bayo & Wyckhuys 2019). That bee identification from photographs is possible to a certain degree (considering above-mentioned limitations to the method), at least in the larger genera (especially Megachilidae), has been repeatedly shown in recent times in numerous web-based insect identification forums and discussion groups (including social media), where good macro-photographs have enabled specialists to securely identify bee taxa to genus and even species level, sometimes contributing new regional records with this method (e.g., BWARS.com 2018, Wildbienen-Forum 2019, Hummelforum 2019, BugGuide.net 2019).

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