DEPARTMENT OF BIOLOGICAL AND
ENVIRONMENTAL SCIENCES

OLIGOLECTIC BEE SPECIES:

An understudied group in Global Change impacts?

Monika Böttcher

Degree project for Bachelor of Science with a major in biology
BIO 603, Bachelor´s degree project, 30 higher education credits
First cycle
Semester/year: 2023
Supervisor: Julia Osterman, Deptartment of Biology and. Environmental Science
Examiner: Åslög Dahl, Deptartment of Biology and. Environmental Science

Andrena vaga ♀ *Photo: Julia Osterman*

Content

Abstract

Global change is considered the primary cause of the decline in bees worldwide, posing a significant threat to crucial pollination services they provide, carrying negative economic and ecological implications. Despite the extensive research conducted on the responses of bee communities to anthropogenic impacts, the focus has predominantly been on commercially interesting bees. In contrast, studies on solitary wild bees are notably scarce, especially on oligolectic bees (i.e. pollen specialists), despite their significant representation, accounting for up to 30% of species in some regions. This study seeks to address important knowledge gaps surrounding oligolecty and the responses of oligolectic bee species to global change. Objectives include providing a comprehensive explanation of "oligolecty"; provide a revised list of Swedish oligolectic species; reviewing current knowledge on global change impacts, indications of the potential vulnerability of oligolectic bees, and quantitatively presenting the distribution of research studies on global changes and bees. Existing knowledge has been drawn from scientific articles via global databases, reports, and experts. The used method is partly qualitative and partly quantitative. This study also reveals obscurities and misleading generalizations. Possible reasons for the sparse number of studies, what consequences this may have and what can be done to change this are discussed to some extent.

Key words: Solitary bee, global change, oligolecty, red list, taxonomy

Introduction

Global Change

Global changes are a large variety of anthropogenic drivers (figure 1A) and different authors' points out the main stressors with some slight differences. Five major global change stressors: landscape alteration, agricultural intensification, climate change, invasive species, and spread of pathogens have been identified as the main drivers of wild bee declines and extinctions (Gonza´ lez-Varo et al. 2013). Although LeBuhn & Luna (2021) mention that the drivers of pollinator declines vary, they also specifies enhancing recognition of important drivers such as; impacts of pollution, notably lead and other heavy metals, pesticide use and diseases, leading to reduced species richness and abundances. Rasmussen and colleagues (2022) highlights habitat destruction, changed (intensified) land use in agriculture, the use of plant protection products, climate change and invasive species as the broad-scale threats to the diversity of pollinators.

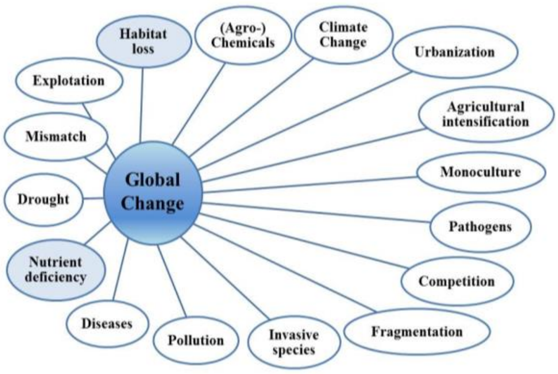

Figure 1A: Global change stressors

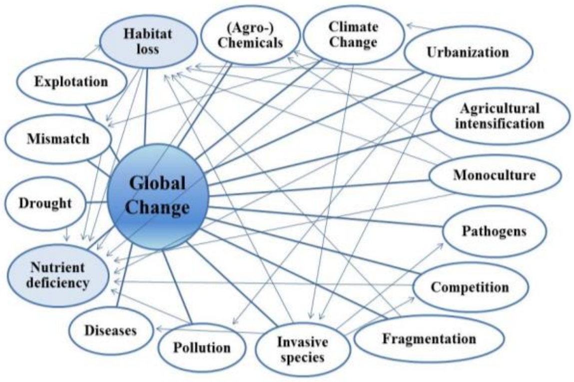

Figure 1B: Global change interactions

Global change consists of multiple factors, and while it involves various factors, it is essential to understand the impact of individual drivers (figure 1A). Therefore, clarity of the interaction effects (figure 1B) of the decline in wild bee populations with multiple natural and anthropogenic stressors is crucial (Meeus et al. 2018).

Anthropogenic alterations in modern landscapes encompass a mix of stressors that synergistically affect various species. Many of these species play pivotal roles in ecosystem functionality. The combined impact of these stressors can diminish reproduction and survival rates in beneficial insects such as bees, potentially resulting in population decline. Additionally, these stressors may influence behaviours related to resource acquisition and nesting (Stuligross et al. 2023).

Apiformes - Bees

Bees (Apiformes) are insects belonging to the order Hymenoptera and there are seven bee families in the world, of which six are found on all continents except Antarctica, the seventh family is endemic to Australia (Hanson, 2018). At species level there are around 20 000 bee species worldwide (Raine & Rundlöf 2023). In Sweden there are 280 bee species spread over the six families mentioned above and 68 (24 %) of them are specialized in their pollen foraging, they are so called oligolectic bees (pers. comm. with Björn Cederberg).

The six families, where and how they live (Falk & Lewington 2015) is shortly presented here:

- Family Megachilidae; various nesting, but cavity nesting dominates,
- Family Andrenaidae; typically ground nesting, solitary
- Family Colletidae; solitary, *Colletes* - mostly ground nesting, *Hylaeus* – cavity nesting
- Family Melittidae; typically ground nesting, solitary
- Family Apidae; various nesting, contains both solitary and eusocial species
- Family Halictidae; usually ground nesting, contains both solitary and eusocial species

Oligolectic bees

Among solitary bees, there exist "thousands" of species classified as oligolectic (pollen specialists), as elucidated by Cane in 2011. The term "thousands" denotes the extensive diversity within this category. Michener's classification identifies 69 out of 443 genera across six bee families as exhibiting oligolecty. Extrapolating from these figures, the global average of oligolectic bee species stands at approximately 9% (1491 out of 17187 bee species) as per Michener's data from 2007. Geographically, the prevalence of oligolectic species is highest in the southernmost regions of Europe, gradually diminishing as one move northward (Pekkarinen 1998) [166]. Many oligolectic bees also exhibit dependency on specific habitat types, with their limitations primarily dictated by the availability of suitable habitats and nest sites rather than host plants. Additionally, these bees may manifest preferences within their chosen habitat, necessitating heterogeneity. This preference for diverse habitat features accommodates the distinct needs of these species, which utilize different parts of the habitat for pollen collection and nest construction, as indicated by Bogusch et al. in 2020 [40].

Oligolectic bees and their host plants

Oligolectic bees and their host plants are linked elements in biological communities. One important factor is the host plant´s role in bee reproduction. It is common for female bees of the genus *Andrena* (sand bees) to become so closely associated with flowers of a specific species that it is the only place males can, with relative certainty, find his female counterpart (Hanson 2018). For oligolectic wild bees to be able to maintain viable local populations, the plants from which they collect their pollen must be abundant (Linkowski et al. 2004). These bees disappear from their habitats if their forage plants disappear or if the populations become so scarce that they no longer constitute a secure food resource (Rasmussen et al. 2022). Biesmeijer and colleagues (2006) studied bee (and hoverfly) assemblages in Britain and the Netherland and their results showed clearly that pollen specialists and their obligate outcrossed hostplants were declining in parallel. If a pollen specialist disappears from an area where its host plant exists, it does not necessarily mean that its host plant also disappears, instead the pollination network can change (i.e. another species takes over, usually a generalist). An example is the areas with arable heath in Uppsala County where the diversity and frequency of flower visitors is dominated by *Apis mellifera* (honey bee) and flies (order Diptera). In that case, the honey bee and the fly indicate a disturbed ecology where specialists are missing (Larsson & Sjödin 2010). Burkle and colleagues (2013) looked at the changes in pollination networks, and found that about 50% of the species of bees that existed 120 years ago no longer existed. Moreover, more specialists than generalists disappeared, despite their host plant still remaining (Burkle et al. 2013).

Objectives of this study

This study aims to; provide a comprehensive explanation of the terminology "oligolecty", quantitatively presenting and reviewing current knowledge, identify deficiencies and knowledge gaps of global change stressors on oligolectic bees, present indications of the potential vulnerability of oligolectic bees, and suggest explanations to the limited knowledge in the field. Additional to that, a revised list of the oligolectic bee species in Sweden is provided, as appendix 2.

Methods

Descriptions of how this study is performed are here presented stepwise, additional aspects can be found in Method discussion (page 20) and specifications are attached as appendixes.

Collection of data

A large number of published studies and reports related to wild bees, oligolecty and global change have been read. Scientific articles have been searched via global databases; Web of Science (WoS), ScienceDirect, Google Scholar, etc. Some facts originate from established institutions or authorities such as Sweden Observation Species Centre (Artportalen) & Artfakta) and the Swedish University of Agricultural Sciences (SLU). Personal communication with the Swedish entomologist Björn Cederberg (part of the Swedish expert committee of Hymenoptera) has also formed the basis for certain parts of this study. Studies, other than those that were the result of the quantitative search, have been selected in slightly different ways, mainly because the relevance to this study, but certain prioritization has taken place for articles written by authors whose studies within the subject in question I have read and judged to be reliable (Potts, Biesmeijer, Cane, Westrich, Müller, Kuhlmann, Westerfelt and Bogusch among others). References studies included in these articles have also been used. Some studies have been recommendations from Björn Cederberg or my supervisor Julia Osterman. Other studies have been selected for other reasons, for example their choice of terms, methods or results descriptions made me question them.

It should be emphasized that the quantitative results, regarding the extent to which studies on the effects of global change include oligolectic bees, should be viewed only as an indication rather than actual fact. This then; 1) the overall interpretation of the studies is largely based only on the title and abstract of the study and, i.e. for many of these studies no qualitative assessment has been made in this study; 2) it cannot be excluded that if the database search is performed using a different method, it could generate more results; 3) more studies have been discovered that were not included in the results list from the database searches, even though the choice of keywords should have included them; 4) during the course of the study, several new studies in the field have been published. Some of those who were not included (3 & 4) in the search, as well as additional studies extracted from reference lists mentioned earlier, are however, included and discussed in the study. In the result section they are referred to as additional studies.

Oligolectic species

This study also provides a updated list of the Swedish oligolectic species, their hostplants and a refined degree of their oligolecty. The revised compilation (appendix 2) of oligolectic species occurring in Sweden is based on the lists Pettersson and colleagues (2004) and Linkowski and colleagues (2004) presented in their reports. Sources used to update these lists are; Swedish Observation Species Center (Artportalen, Artfakta), Bees Wasps & Ants Recording Society (BWARS), Steven Falk's book; Field Guide to the Bees of Great Britain and Ireland (2015), the Norwegian Biodiversity Information Center (Artsdatabanken), Finnish Biodiversity Info Facility (Artdatacenter), Global Biodiversity Information Facility (GBIF) and Denmark's national Artportal. The list has then been fact-checked by the Swedish entomologist Björn Cederberg. The species included in the updated list of oligolectic bees in Sweden, were searched in the other countries' red lists, some could not be found, which could mean that; 1) they do not appear in the country 2) they can go by a different name. Sources of oligolectic current prevailing red list status in Scandinavian countries are the Biodiversity Information Centers of; Sweden (Artportalen); Norway (Artsdatabanken); Finland (Finnish Biodiversity Info Facility) and Madsen`s “Den danske Rødliste 2019” and the complete list is attached as appendix 3. It should be emphasized that some species might be considered as polylectic by other researchers. The revised list of oligolectic bees is used as a reference in this study for which bees are oligolectic, it should then be noted that it is based on the oligolectic bees found in Sweden. In some sections of this study, the classification of polylecty/oligolecty that has been made is questioned and in those cases bees, in Sweden considered broadly oligolectic are not included, as they could also be considered polylectic.

Database searches

All database searches described here were performed in; Web of Science Core Collection, all editions, and in all of the searchable fields using one query. Web of Science will henceforth be referred to as WoS. All searches were performed between 2023-10-10 and 2023-10-24; specific dates are included in Appendix 4.

The database searches to see if the number of hits differs depending on the choice of term and the search combinations were as follows:

- "bee*" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*")
- "bee*" AND ("oligol*" OR "pollen speciali*")
- "bee*" AND ("food speciali*" OR "diet speciali*") NOT ("oligol*" OR "pollen speciali*")

- "bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*")
- "bee" AND ("oligol*" OR "pollen speciali*")
- "bee" AND ("food speciali*" OR "diet speciali*") NOT ("oligol*" OR "pollen speciali*")

Quantitative search – global change effects

For the quantitative distribution of global change effects, different keywords have been pooled together in into different groups. The reality is different as global change effects, to varying degrees, are interactive and directly or indirectly affect other areas. The Land alteration group includes search terms related to land use or changes in the landscape or the layout of the land. Chemicals (mainly linked to agriculture) itself have been placed in the group; (Agro-) chemicals, Invasive species and Pathogens are included in the same group and climate-related keywords are placed in the group; Climate Change. Competition, Mismatch and Nutritional deficiency are a separate group as they, more or less, are indirect effects of other impacts. The searches were performed with the search combination: ("bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("global change search term"), where the "global change search term" was exchanged for every new search, some examples are; habitat loss; urbanization; pesticide; invasive species etc. (all search combinations, can be found in Appendix 4). There are also two additional search groups where words related to Synergism and Threats, respectively, is included; These two groups were added due to the fact that there are interactive effects within global impacts and pollen specialist bees are threatened. All these search results (268 studies) were pooled together as a marked list in Web of Science.

Selection of data

In the earlier mentioned marked list in Web of Science, all doublets were automatically excluded. The marked list (169 studies) was then exported as a full record (available in Appendix 1). Not to potentially be affected by keywords, author or other records, two columns relevant to the examination; the title and the abstract, were copied to another work book. Then all irrelevant studies were excluded and the rest (69 studies) were read through (the abstracts) and classified after what kind of global change the study focused. Some of the studies were read in full as the abstract raised questions and others because they appeared to be of special interest.

In the result section, where the found studies are reviewed, these classifications are slightly different as the content of many studies did not really fit the groups used in the search. Several studies employing expressions such as "oligolectic bees/species" in their conclusions, presented in the abstracts, were analyzed by scrutinizing the supplementary material to identify the specific species encompassed within each study. Appendix 1 is, additional to present all the studies that resulted from the search, serving as a reference list of the selected studies reviewed herein, when reviewed or referred to in the study, a reference number is marked with square brackets [number] that correlates with the underlined number in the appendix. In the appendix all numbers of selected studies are underlined. Studies considered irrelevant are written with grey text. Assessed classification (what study field) can be read in a separate column, as can also the result of the analyses, where red textboxes indicates misleading abstracts, found bias, orange

Results

Oligolecty

Oligolecty and polylecty are terms used in bee species facts to describe the degree of specialization for pollen collection. Bees collecting pollen from species within a single plant family are oligolectic (="few-gathering") and those collecting from two or more plant family are polylectic (="poly-gathering") (Nilsson 2013). In the article "Oligolectic bee species in northern Europe" (1989), Pekkarinen discusses the concepts of poly-, oligo- and monolecty. The terms oligolecty and polylecty were introduced by Robertson in 1925 to describe the degree of specialization for pollen collection in bees. Oligo- is a prefix indicating few/a small number (of something)/a few/small and comes from the Greek combining form of olígos. The suffix -lectic comes from the Greek lektos, which means chosen/selected (noun) or légō, "to choose; to arrange; to gather"), from Proto-Indo-European *leǵ- ("to collect, gather") (Wikipedia 2023).

Although the term oligolectic has existed for almost 100 years, the word specialist (mostly in a combination) is often used instead. It is then important to reflect on what the author actually means by specialist. If you look up the word specialized in a biology dictionary, the definition is; "having special adaptation to a particular ecological niche which often results in wide deviation from the presumed ancestral form. Such specializations evolve and may result in niche limitations" (Thain & Hickman 2004). A bee can be a pollen specialist as well as a habitat specialist; therefore would the word specialist not be accurate. It is common with combinations such as; diet specialist and food specialist but these terms might give the impression that the bee is selective in its diet for nutritional reasons or tastes of the pollen. Oligolecty is a term that refers to the collection of pollen, not to which food a bee eats or to which diet it goes (diet = "a specific allowance or selection of food, to control weight or for health reasons" (Collins 2003)). The term "oligolecty" specifically refers to the *behaviour* of being specialized in collecting pollen from a limited range of plant species. Oligolectic bees often have specific requirements for larval development, and collect specific types of pollen to provision their larvae and the choice of pollen is linked to meeting those requirements (and to some extent the specific plant species' availability). Oligolecty is an example of how bees have evolved specialized behaviours to maximize their reproductive success in their respective environments. By focusing their foraging efforts on specific plant species, these bees ensure that their offspring receive optimal nutrition while also contributing to the pollination and reproduction of their preferred plants. It's more accurate to use "pollen specialist" or "host plant specialist" to convey the idea that the bee specializes in collecting pollen from specific plant species for the purpose of provisioning its larvae. This terminology reflects the biological and ecological aspects of oligolecty more accurately.

Different forms of the word oligolecty

- As a noun for the phenomenon itself; oligolecty (Robertson 1925) points out that oligolecty is the correct word and not oligolectism, (monolecty, oligolecty, polylecty).
- As a noun for a bee with this degree of pollen specialization: oligolege (plural oligoleges), it is the word that is most common in English (monolege, oligolege, polyleges)
- As an adjective for the quality of a bee; oligolectic (monolectic, oligolectic, polylectic).

Monolecty, oligolecty or polylecty

The terms monolecty, oligolecty, and polylecty have conventionally served as a classification framework for categorizing bee species based on the number of plant taxa from which they collect pollen. Unfortunately, these terms have not been consistently applied, primarily due to challenges in compiling the taxonomic spectrum of pollen use, insufficient data regarding the host plants utilized by different bee species, and limitations in certain analytical methods that hinder valid comparisons. It is crucial to emphasize that these classifications are ultimately about the fidelity of bees to specific plants and should not be conflated with floral constancy—a dynamic attribute exhibited by individual bees. Even in the case of highly polylectic bees, each bee, during individual rounds of pollen collection, consistently gathers pollen from a single plant species without switching to another (Cane & Sipes 2006). This behavior, as elucidated by Michener in 2007, does not constitute oligolecty but rather represents an efficient strategy for pollen collection. The variable specialization of bees in collecting pollen within a taxonomic range of host plants, distinct from floral constancy, is an intrinsic and species-specific trait (Cane & Sipes 2006). Another way to put it: while the specialization of bees in relation to flora is likely influenced by inherent neural or morphological constraints, floral constancy is a learned behavior unique to each individual bee. This constancy has the potential to shift with new opportunities or vary among individuals of the same species at the same time and location (Michener 2007).

Monolecty is employed when a bee exclusively gathers pollen from a single flower species or a few closely related flower species, as outlined by Westrich in 1990. However, a perspective articulated by Linkowski and colleagues (2004) introduces the term "narrow oligolecty" as a preferable alternative to monolecty, asserting that "mono" specifically conveys the notion of collecting from only one species, a behavior observed in very few bee species. This rarity of pollen specialization to a single plant species is corroborated by additional studies, such as Rasmussen et al. in 2021. Crone et al. (2023) employs the term "strict foraging specialists" for bee’s exclusively foraging on one plant species. Pekkarinen (1998) [166] further highlights the fluidity in distinguishing between oligolectic and polylectic species, noting the presence of intermediate species and spatial variations in pollen specialization within the same species. The terminology for these intermediate species varies among authors; Linkowski and colleagues (2004) use "narrow oligolecty" along with "moderate" and "broad oligolecty” while Praz and colleagues (2008) uses “strictly oligolectic” and “broadly oligolectic”. It should be mentioned that there is a fourth term; mesolecty, although the use of it is not as widespread as the others. Rasmussen and colleagues (2020) utilize the term "mesolecty" for bees that forage pollen across a narrow range of plant families, as seen in their work and in the study by Praz et al. (2008). However, Cane and Sipes (2006) consider the term mesolectic to be a substitute for “broadly oligolectic”. Apart from the term monolectic (defined as pollen specialized on one plant species), it is difficult to specify exactly where the boundary is between oligolecty and polylecty. The division is more or less arbitrary and has been the basis of endless debates (Cane & Sipes 2006).

Most oligoleges are univoltine (having one generation per year) thus adult emergence and bloom of their hostplant are and have to be synchronized. In case of desynchronization, different oligolectic species appears to acts either as; obligate oligoleges, refusal of provisioning or nesting as long as the hostplant is unavailable or as facultative oligoleges, turning to some substitutional pollen source. There is some advantages by await hostplant bloom such as reduced risk of predation, nest invasion and general wearness (Cane & Sipes 2006).

Even though some oligolectic bees display a remarkable specialization in their pollen preferences to the extent that their larvae can only thrive on pollen derived from a limited pool of plant families or genera (Cane 2011) the classification of pollen specialization is essentially of an ethological character and visible morphological qualifications are not necessarily required when compared to other related bee species (Pekkarinen 1998) [166]. Behavioural specializations can serve as a driving force in the evolutionary process and often encompass various aspects such as the daily timing of floral visits, the preparation of pollen grains through moistening and packing for return flights to the nest, or the vibration of flowers (buzzing) to effectively release pollen grains. Morphological specialization encompasses features such as the density and type of hairs tailored for the collection of different-sized pollen grains, the presence of flattened spatulate hairs adapted for gathering oil, and the development of extremely elongate mouthparts designed to access hidden nectar sources (Rasmussen et al. 2020).

After accounting the classification criteria for monolecty, oligolecty, and polylecty, the subsequent sections of this study will use "oligolecty", encompassing monolectic species, unless other is stated.

Disproportionalities in Red lists

Already in 1998 Pekkarinen pointed out that 32 of the oligolectic bee species in Finland were listed as threatened in England, southwestern Germany or Poland (Pekkarinen 1998), and in 2004 Pettersson and his colleagues presents the fact that the red-listed oligolectic species (and their parasitic bees) are greatly over-represented in the Swedish national Red list of threatened wild bee species (Pettersson et al. 2004). A more recent study shows that in the Red List of bees of Czechia, a larger proportion is comprised of oligoleges (97 of 166; 58%) than that of polyleges (139 of 306; 45%) (Bogusch et al. 2020) [40]. Swedish oligolectic species and their listings in the National Red List of Sweden; Norway; Denmark; Finland and the listing in IUCN Red List are presented in Table 1.

Table 1: Listing of oligolectic bees in National Red Lists and in the IUCN Red List. Red listed (%) is the part of red listed oligolectic bees out of the total number of oligolectic bees. The species lists are attached as appendix 3.

Country	Sweden	Denmark	Norway	Finland	IUCN
Year	2020	2019	2021	2019	2012-14
LC	39	30	29	32	31
NT	9	5	3	2	10
VU	6	6	6	3	1
EN	5	5	3	6	3
CR	3	1	2	2	0
DD	-	-	-	-	23
RE	3	4	3	2	-
Total*	67	58	46	47	68
Red listed	23	17	14	13	14
Red listed (%)	34 %	29 %	30 %	28 %	21 %

LC = Least concern
NT = Near Threatened
VU = Vulnerable
EN = Endangered
CR = Critical endangered
DD = Data deficiency
RE = Regionally extinct

* = number of all found species in respectively country including species not assessed (NE) and species listed as not appliable (NA)
Sources: https://www.artportalen.se/Occurrence/TaxonOccurrence/16/2002991 [Visited 2023-10-10]
https://artsdatabanken.no/lister/rodlisteforarter/2021 [Visited 2023-10-18]
https://ecos.au.dk/forskningraadgivning/temasider/redlistframe/soeg-en-art [Visited 2023-10-27]
https://punainenkirja.laji.fi/sv/results?type=species&year=2019&redListGroup= [Visited 2023-10-28]
https://www.iucnredlist.org/ [Visited 2023-11-05]

Oligolectic bees and Global Change impacts

A first search in WoS with a combination of words related to; Threat, Nutrient deficiency and Climate change was used (see more in Methods) generated 928,030 result hits. Therefor the search terms had to be pooled into different hypothetical groups, which in WoS generated all together 289 results (Figure 2). After removal of doublets and screening of the abstracts of which studies that classified as relevant, a total of 69 studies remained. The specified search terms within each group, as well as search combination groups are available in Appendix 4. These remaining studies were then reclassified after topics, to better serve the purpose of this study. The new classifications are quantitatively presented in Figure 3 and will in various extensions be reviewed in the subsequent sections, following the same topic order as in the figure. As there are very few studies or not cover the subject enough in some of the sections, other studies are included for an enhanced understanding of the different global change impacts. These studies are placed after the reviewed hit results as, "additional studies" in the headline.

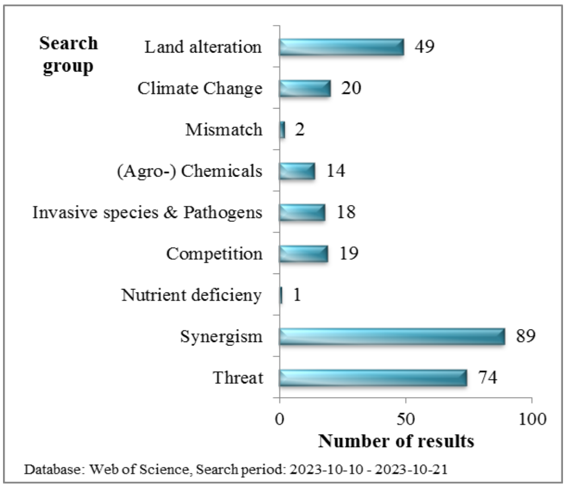

Figure 2: Number of results generated from data base searches in the different groups of pooled search terms.

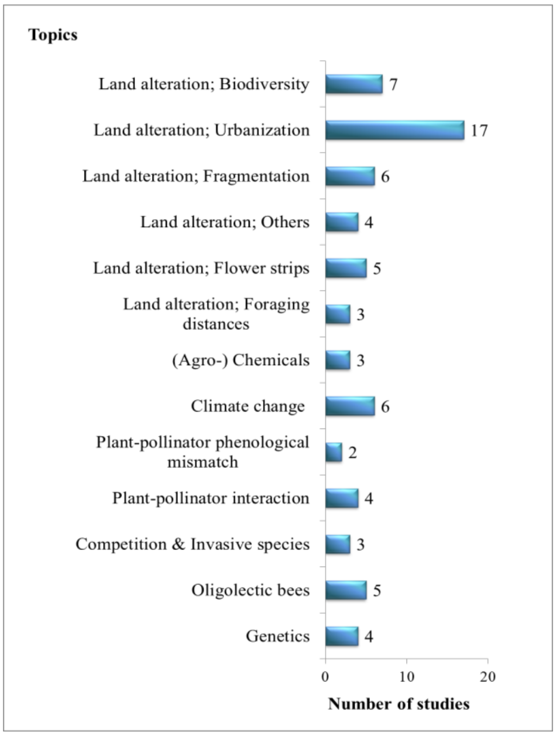

Figure 3: The quantitative distribution after re-classification based on studied topic.

Topics

Land alteration; Biodiversity

Seven studies had assessed bee diversity in their study. One was performed in a scrub oak barrens and concluded in the abstract that: increased visibility of nectar resources and sandy patches post-treatment may have promoted sand specialist and oligolectic bee species (Bried & Dillon 2012) [124]. In the study that investigated the bee community in wet meadows near Krakow, in Poland, showed that the least abundant species were disproportionately represented by oligolectic bees. Their over representation clearly indicates that species having a close association to wet meadow plant, are particularly at risk (Moron et al. 2008) [143]. Species richness in a sand steppe habitat in Eastern Austria was found to have decreased with over 50% (Dominique et al. 2023) [3]. When the composition of bee communities was compared between restored and remnant prairies, the results showed pronounced differences, and that oligolectic bees occurred more in remnant prairies (Lane et al. 2022) [27]. Not reviewed: [17], [21], [36]

Land alteration; Urbanization

Urbanization studies dominate, comprising seventeen, with a notable exclusion [14]. A Finnish study highlights oligolectic bee preference for less urbanized areas, emphasizing the importance of focusing on oligolectic and terrestrial bee species for biodiversity preservation (Venn et al. 2023) [7]. In Brazil, a 40-year evaluation of grassland bee fauna reveals a 22% decline in species richness and abundance, attributed to intense land occupation and lack of natural area preservation (Martins et al. 2013) [119]. Urban intensity's impact on European cities' bees is explored, revealing broader pollen generalization as less sensitive to severe urbanization (Casanelles-Abella et al. 2022) [26]. Springfield's sub-urban yards house around half solitary species, noting lower abundance for oligolectic species (~10%) (Lerman & Milam 2016) [96]. Vegetation appeal for bees in wasteland areas, early-season polylectic and kleptoparasitic bees favor sub-urban, while summer emerging bees prefer urban sites (Twerd et al. 2021) [34].Bengaluru's 20 ha urban green area study estimates native bee fauna diversity and abundance, including a probable misspelling of "oligolectic" (Bhatta & Kumar 2020) [37]. Paris reveals positive associations between pollinator diversity and green space size, flowering plant richness, while impervious surfaces correlate negatively (Zaninotto et al. 2023) [8]. Berlin's urban garden study links wild bee diversity to garden and landscape traits (Felderhoff et al. 2023) [10]. Cities with fragmented green spaces exhibit reduced oligolectic species, increased social and large-bodied bees. Greater impervious surfaces relate to fewer below-ground-nesting bees. Warmer cities show lower richness, with optimal functional diversity at intermediate precipitation levels (Ferrari & Polidori 2022) [15]. A Czech study uncovers a bee and wasp biodiversity hotspot on bare loess exposed by anthropogenic activities (Heneberg & Bogusch 2020) [55]. Lastly, in Pennsylvania, ornamental plants attract polylectic bee species despite the coexistence of oligolectic species (Ericksson et al. 2020) [57].

Not reviewed: [51]; [80]; [81]; [83]; [150]. [80]; [81] are included in the discussion

Land alteration: Fragmentation

Five studies explored fragmentation's effects on bee populations. One focused on functional traits in the Hungarian Great Plain's natural forest steppe, revealing a close connection between fragment size and larval feeding preferences, positively impacting oligolectic bees (Török et al. 2022) [22]. Franzén et al. (2007) investigated *Andrena hattorfiana* behavior in small populations, finding a 2% patch emigration rate with a maximum distance of 900 m. Notably, 10% crossed areas lacking pollen plants, such as unpaved roads and stone walls, suggesting sedentary behavior and increased vulnerability to local extinction (Franzén et al. 2007) [142]. Gonçalves et al. (2014) proposed Orchid bees as ecological indicators, noting abundance increases in Apinae and oligolectic bees with larger fragment sizes, while richness of Augochlorini bees decreased (Gonçalves et al. 2014) [111]. Slagle and Hendrix (2009) found that fragmentation did not affect *Andrena quintilis*, an oligolectic bee species (Slagle & Hendrix 2009) [139]. In a 2008 study comparing mesic and xeric regions in North America, Minckley found higher species richness in the xeric region, with xeric habitats richer in oligolectic species. They suggested a comprehensive approach integrating phylogeny, historical biogeography, and bee-plant ecology to understand bee fauna differences (Minckley 2008) [145]. Cane et al. (2006) investigated a desert bee guild in Arizona's response to fragmentation, targeting 120 bees, including 21 pollen-specialized on the creosote bush *Larrea tridentata* (Cane et al. 2006) [151].

Land alteration: Others

Sixteen studies fitted within the field Land alteration, where seven is placed in the sub-field Biodiversity and five in the sub-field Flower strips. The four remaining should be reviewed here, however, due to lack of time two of them have not been reviewed. A positive illustration of human-made modifications in the environment that is of benefit for both civilization and the conservation of biodiversity, are railway embankments, when managed appropriately was presented in a study by Moron and colleagues (2017) [89]. Another study presented a similar positive illustration, but in Gatewick Airport where *Eucera longicornis* thrives (Hennessy et al. 2020) [42].

Not reviewed: [69], [132], although [132] is included in the discussion.

Land alteration; Flower stripes

Five studies from the comprehensive search specifically delve into flower strips. One study highlights that the composition of plant species in flower strips, commonly used to enhance pollinator-friendly agricultural landscapes, is often dictated by logistics rather than direct knowledge of bee-plant interactions. They identify 34 herbaceous key plant species crucial for attracting wild bees, contributing significantly to sustaining diverse bee populations, including 2% to 32% oligolectic or red-listed bees (Kuppler et al., 2023) [13]. Another study compares habitat patches with sown flower strips, finding that while flower strips offer abundant flowers, their species composition and flowering timing exhibit uniformity, potentially favoring only a subset of pollinator species. In contrast, existing semi-natural habitat patches along slopes, fences, or ditches have the potential to support additional species for pollinator conservation, albeit with limited political promotion. Notably, these patches attract different pollen-specialized bees than sown flower strips (von Konigslow et al., 2021) [31]. A third study in Belgium assesses bee and hoverfly abundance and diversity within flower strips, suggesting that intercropping systems with flower strips contribute to sustainable agro-ecosystems. The study documents 43 bee species, emphasizing the generalist character of the pollinator community, with the exception of the oligolectic bee *Andrena nitidiuscula* (Amy et al., 2018) [76]. The fourth study near Vienna focuses on flower-visiting insects, particularly wild bees, in semi-natural grassland patches and flowering strips within vineyards. It highlights the correlation between insect numbers and flower cover, underscoring the role of flowering plants in supporting pollinators. Grassland patches consistently supply nectar-producing plants, while flowering strips, dominated by short-lived sowed plant species, benefit oligolectic bees specializing in Brassicaceae or Fabaceae (Rasran, 2018) [75]. In the fifth long-term study, networks of perennial flower strips covering 10% of an agricultural landscape led to increased pollinator abundance, notably oligolectic bee species after the third year. This suggests the crucial role of diverse habitats, foraging resources, and nesting sites in supporting overall pollinator well-being (Buhk et al. 2020) [72].

Land alteration: Foraging distances

Three studies with focus on forage distances were found, where one had investigated forage distances for two polylectic *Osmia* spp. and four oligolectic species, specifically *Chelostoma florisomne*, *C. rapunculi*, *Heriades truncorum*, and *Hoplitis adunca*, all belonging to the family Megachilidae. This study, conducted at the Munich Botanic Garden, aimed to determine forage distances, a crucial factor for assessing the critical size of fragmented habitats and implementing conservation measures such as flower strips. The study's results suggest that flower strips and nesting sites should not be located more than 150 meters apart. Notably, it should be acknowledged that in this study, data collection was aided by public visitors who reported the sightings of numbered species (Hofmann et al., 2020) [47].

In another study they investigated impacts due to prolonged foraging distances, in two solitary oligolectic bee species; *Chelostoma rapunculi* and *Hoplitis adunca*. Forage distances prolonged with 500 and 600 m showed to reduce the number of brood cells produced by C. *rapunculi* per time unit, with 46% and 36% respectively. Forage distances prolonged with 150 m; 200 m; 300 m, showed to reduce the number of brood cells produced by *H. adunca* per time unit with 23%, 31% and 26% respectively. The findings underscore the critical importance of having suitable nesting and foraging habitats in close proximity for the persistence of populations and, consequently, the conservation of endangered solitary bee species (Zurbuchen et al. 2010) [137]. The last study investigated whether structures in the landscape function as impassable obstacles to pollen collecting bees. *Hoplitis adunca* showed no signs of such, as the bee passed both an intensely trafficked highway and a broad river. More than 130 m altitude differences did not hindered *Chelostoma florisomne*, neither did a dense, forest covering a distances above 450 m (Zurbuchen et al. 2010) [136].

(Agro-) Chemicals

Of the 14 result hits the majority of the studies only mentioned pesticides in a general concept and the only three dealt with pesticide impacts on oligolectic bees were about species within the family Megachilidae; *Osmia brevicornis, Osmia ribifloris* and *Heriades truncurum.* These three bee species are all cavity nesting and solitary. Hellström and his colleagues underscore the importance of aligning foraging preferences and crops in pesticide risk assessments. They contend that the existing model species may not always be appropriately matched to the crops investigated, potentially leading to erroneous conclusions regarding pesticide risks in pollen and nectar. To address this, they propose *Osmia brevicornis*, an oligolectic European wild bee species specialized in Brassicaceae pollen, as a new model organism suitable for assessing how pesticides can impact specialist pollinators, particularly in oilseed rape, a mass flowering Brassicaceae crop. The study outlines a method for housing and administering controlled oral solutions in the laboratory, facilitating future investigations into pesticide exposure. The researchers conclude that *O. brevicornis* is a viable model for assessing pesticide risks both in laboratory settings and in the field. Additionally, they advocate for diversifying the species used in agricultural ecology, emphasizing the inclusion of pollen specialists. They emphasize the importance of considering the foraging preferences and dietary needs of selected model species when evaluating pesticide exposure risks and effects (Hellström et al. 2023) [9]. An additional study, proposing an oligolectic model species, explored the repercussions of pesticides on sexual communication. The aboveground oligolectic bee, *Heriades truncorum*, serves as an excellent model for investigating the impact of pesticides on sexual communication, given that certain aspects of its mating behavior have been previously documented. In this study, males exhibited a quicker approach towards unexposed females compared to those exposed to insecticides. Females exposed to insecticides produced reduced amounts of sex pheromone candidates and displayed less selectivity than their unexposed counterparts. Their findings suggest that insecticide exposure has a discernible impact on sexual communication, influencing both male preference and the female's assessment of male quality (Boff & Ayasse 2023) [2]. The third study introduces a method for rearing the oligolectic mason bees *Osmia ribifloris* sensu lato "in vitro." This approach is proposed as a valuable tool for assessing the risks associated with fungicides. Specifically, in the context of Osmia species demonstrating oligolecty, wherein they exclusively consume pollen from a specific group of plants, their inability to utilize pollen from non-host plants may heighten their vulnerability to toxicity induced by fungicides (Dharampal et al., 2018) [78].

(Agro-) Chemicals – additional studies

Current knowledge of pesticides is limited to very few species and the majority of the research is upon neonicotinoid insecticides (under unrealistic conditions). Bees can be exposed to pesticides all way through life; in their larvae stage; during hibernation, as they forage, when they constructs their nest and during brood care. The exposure could be oral through nectar, pollen, oil, water or by contact with air, plants, soil and other material bees are in contact with of in the environment (Raine & Rundlöf 2023). Pesticides can remain in the environment for years resulting in double exposure; if pesticide residues remain in soil and they build their nests in the ground (Sponsler et al. 2019), which approx.75 % of the 20 000 species in the world does (Raine & Rundlöf 2023). Bees can also be exposed by contact or by drinking from the guttation emitted by a plant, whose seeds have been treated with e.g. Imidacloprid. This as systematic agent transports the substance within a plant via the xylem and can even reach the leaves of the plant (Tome´ et al. 2012). The problem with pesticides can also impact bees by indirect effects, herbicides as an example, reduces the amount of flowers that produce nectar and pollen as well as host plants for the larvae of certain pollinators (Sponsler et al. 2019).

There are plenty of studies on the effects of pesticides (unfortunately, these studies have mostly focused on the honey bee), and the most common sublethal effects are learning disabilities, poor memory, and aberrant foraging behavior. Learning and memory are controlled by special areas of the brain and one of them is the corpus callosum, which has the task of storing information. As the bee grows, this structure also expands and in adulthood it exhibits a high neural plasticity. Bees that consume small amounts of insecticide via either contaminated nectar or pollen can lose the ability to remember and to orient themselves in time and space (Tome´ et al. 2012). In the study Tome´ and his colleagues performed on stingless bees, the effects of imidacloprid did not appear immediately when the fully formed adult emerged, but after four days a changed walking behavior was noted. One of the study's conclusions was that if walking behavior is affected, it is likely that the bee's flying ability and foraging behavior will be even more affected. They also emphasized that the changes that may occur during larval development, induced by pesticides, may result in additional consequences (beyond the loss of adult bees) to the colony and should not be neglected. Moreover, when combinations of several different agents are used simultaneously or over time, in one and the same field, pollinators are exposed to these combinations of plant protection agents. In addition, pollinators visit many different areas (especially if the plant they prefer is not widely available) and might then be exposed to several different types of chemical preparations (Sponsler et al. 2019).

Climate change

Six of the results fitted best within the topic climate change. The newest published study provides long term baseline data on areas in the warm deserts of North America with minimal human impacts to be used for studies of areas where human impacts are graver and as climate change advances (Minckley & Radke 2021) [33]. In a study performed a couple of years earlier, the effects on German bees, of various factors such as habitat breadth, pollen specialization, body size, nesting sites, sociality, duration of flight activity, and time of emergence during the season, were statistically modelled and analyzed. The study exposed that a narrow habitat breadth and late-summer emergence increased vulnerability to extinction in Central European bees. Spring emergence and occurrence in urban areas, on the other hand, were found to reduce vulnerability, indicating that intensive land use particularly affects summer-active bees. The combination of these factors is currently leading to a shift in Germany's bee diversity towards warm-adapted, spring-flying, city-dwelling species (Hofmann et al. 2019) [66].

Dellicour with collegues (2015) is suggesting that food resource abundance has a potential role when current patterns of genetic variation in specialists are to be determined. They had studied the impacts of past climate changes on three oligolectic *Melitta* species. The study illustrates that current phylogeographic patterns may have been shaped by contributions of both demographic history and ecological factors, and even though it is not a study of present climate change, the result could be of use in modelling and predictions (Dellicour et al. 2015) [109]. The fourth study delved into the temperature-dependent aspects of nesting activity and lifetime reproductive output, revealing that the positive effects of higher temperatures on bee productivity were counterbalanced by indirect costs associated with heightened parasite activity (Forrest & Chisholm 2017) [93]. In the fifth study, analyses of the bee fauna in the Munich Botanical Garden were performed in 1997/1999 and again in 2015/2017. During this period, 12 polylectic species disappeared out of 62 and 23 were added, of the oligolectic ones two disappeared out of the total 17 and 10 were added (Hofmann et al. 2018) [79]. In the sixth and last study, the relationships between environmental abiotic conditions, length of adult life, and magnitude of foraging activity in two bee species, were studied. Studied bee species were the oligolectic *Andrena vaga* and the polylectic *Anthophora plumipes*. The study suggests that life span is influenced both directly by climate and indirectly through activity patterns that are dependent on climate (Straka et al. 2014) [112].

Plant-pollinator phenological mismatch

The search resulted in two studies, where one study was performed by Cerceau and colleagues (2019) [62]. They investigated the role of the oligolectic bee *Arhysosage cactorum* for the reproduction of *Parodia neohorstii* (Cactaceae) and were carried out in Brazil 2016 and 2017. Both bee and host plant are threatened, red listed species and a mismatch could substantially impact the reproductive success of both partners. Mating behaviour of *Arhysosage cactorum* – is associated with the pollen host plant, which is common for oligolectic bees, being a mating place where male bees wait and searches for females. But here they observed a special mating behaviour, only known for a few other species of Andrenaidae; during copulation they were flying together among cactus flowers, strongly enhance crosspollination (Cerceau et al. 2019) [62]. The other study was carried out by Schenk and colleagues (2016) where they tested the effect of temporal (0, 3 and 6 days) mismatches on fitness of three solitary bees emerging at spring; the early-spring species *Osmia cornuta*, the mid-spring species *Osmia bicornis* and the late-spring oligolectic species *Osmia brevicornis*. All of them exhibited severe reduced fitness after a mismatch of 6 days, as not many bees can survive without flowers that long. After a mismatch of 3 days, the two polyleges produced the same number of brood cells as under synchronized conditions, whereas the oligolectic *Osmia brevicornis* produced fewer brood cells. It should be mentioned that *O. cornuta* decreased the number of female offsprings and *O. bicornis* used fewer nests to spread the brood cells over, which could result in higher offspring mortality. Their conclusion was that short temporal mismatches can cause clearly reduced fitness in solitary bees. In temperate climates, the seasonal activity of most bee species is primarily regulated by temperature cues. Solitary bees that emerge early in spring have spent the winter as fully mature adults within their spacious cells. Consequently, a shortened period of warmth in the spring can trigger rapid responses in these bees, potentially resulting in temporal mismatches with their host plants. While the consequences of such mismatches on plants have been extensively studied, there is a notable paucity of research focusing on the fitness implications for the bees themselves. Temperate oligolectic bee species that exhibit early spring emergence or late autumn activity are postulated to face more pronounced negative repercussions stemming from temporal desynchronization. This elevated vulnerability is attributed to the heightened risk of emerging in the absence of their preferred interaction partners.

Moreover, during the early and late periods of the season, when plant biodiversity is comparatively lower, bees may encounter challenges in shifting to alternative interaction partners. They also pointed out that since metabolic functions are faster and that the total energy consumption is higher, in warm than in cold conditions, temporal mismatches in periods of warm weather could aggravate potential starvation compared to mismatches during cold periods. Whether this also applies to solitary bees remains to be seen, as the study referred to a study made by Vesterlund & Sorvari, 2014, that dealt with bumble bees (Schenk et al., 2016) [88].

Mismatch and oligolectic bees – additional studies

Consequences of phenological mismatches for five wood-nesting solitary bees, representing a broad gradient of oligolecty/polylecty, were assessed during 9 years. Their published results shows that; if climate change increases phenological mismatches, negative consequences of climate change for specialist bees can be expected; a negative population growth rate for the two most specialized bee was indicated in their demographic analysis as well as a greater, nonnegative growth rate for the other three species; oligolectic bees might have lower viability and could therefore experience a greater decline than polylectic bees, from phenological mismatches. It should be noted that the results should be interpreted with caution due to uncertainties of both the data and the analysis, but this type of analysis is still a useful tool for comparisons among populations and species and its results helps to elucidate the role of phenological mismatches for the demography of wild pollinators (Vázquez et al. 2023).

Plant-pollinator interaction

Of four studies that dealt with plant-pollinator interactions one was only pointing out need of comparable studies about solitary, pollen specialized bee species, where the interplays among the timing of floral resource availability, the foraging behavior of bees, and characteristics such as diet breadth, sociality, and body size is examined (Olgilvie & Forrest 2017) [91]. The insight that recommended plant selections mostly benefits polylectic bees and may not support rare specialist pollinators in the Northeast America, inspired Fowler (2016) to provide a catalogue of native specialist bees and their associated host plants. This as such populations are susceptible to harm from anthropogenic threats. Further he identifies and discusses vulnerable bee-plant association, suggests pronounced emphasis on research and restoration efforts and that conservation efforts practice specifically target specialist bees (Fowler 2016) [100]. The findings in the third study signified a strong relationship between bee population size and plant population size. Findings like this are useful tools in conservation efforts, as the critical resource levels can be estimated from a pollen budget calculation (Larsson & Franzén 2007) [148]. The fourth study reviews, summarize and compile the existing knowledge in plant-pollinator interaction and, in contrast to almost every other study that focusing on (honey-) bees exhibiting pollen generalisation, the highlights are upon two often negligated groups; oligolectic and nocturnal foraging bees. It is concluded that research needs to figure out how to restore lost interactions in degraded habitats may be restored, as a stable plant-pollinator network will be a pivotal goal for conservation biology (Scott-Brown & Koch 2020) [46].

Competition & Invasive species

Among the 69 search results, three studies focused on the concept of competition, with two addressing competition and invasive species, and the third examining competition within a native bee community. The first study concentrated on the endangered *Perdita meconis*, a specialized poppy pollinator. It revealed the invasive African honey bee's successful competition against native *P. meconis*, leading to the alarming absence of *P. meconis* and a potential local extinction in Utah. The study also noted reduced populations of another native bee species and a decline in European honey bee abundance, causing decreased fruit set in sparsely distributed poppy populations (Portman et al., 2018) [85].

In the French West Indies, the second study explored various bee species and their floral hosts, highlighting the dominance of the introduced European honey bee due to its overwhelming abundance. The competitive and aggressive behavior of the honey bee displaced native bees from flowers, although ecological data on its impact in the region were lacking (Meurgey, 2016) [98]. The third study investigated competition within a species-rich, native bee community visiting creosote bush flowers in North American warm desert regions. Findings indicated that competition for pollen resources was temporary and rarely limited the native bee population. The researchers emphasized the need for comprehensive, long-term assessments of population dynamics, considering both native and non-native bee species across areas with multiple measurable flowering plant species. They underscored the importance of fundamental ecological data, noting that without such information, competing hypotheses and questions regarding competition in bee ecology cannot be adequately evaluated or resolved (Minckley et al., 2003) [169].

Competition and oligolectic bees – additional studies

When it comes to competition between different species, opinions vary; many authors believe that the most sensitive to competition are the species that are oligolectic. Some other authors are of the opinion that since the oligolectic bees is so good at harvesting pollen (due to their specialization), they can handle competition with generalists. In the studies done up to 2004 on the competitive impact of the honey bee on wild bees, they have varied so much that no direct conclusion can be drawn, but it is also pointed out that competition can be important in terms of habitat shortage and fragmentation (Linkowski. et al. 2004). Roughly 50% of the plant species visited by both honey bees and wild bees are shared between the two groups. Nevertheless, existing studies predominantly highlight the shared utilization of flowers by wild bees and honey bees, without fully illustrating the extent of this overlap. There are indications that the level of resource overlap fluctuates over time and is contingent on the context; in certain environments, the overlap can be notably extensive. (Rasmussen et al. 2021). There are authors that emphasizes that honey bees quickly can exhaust forage resources due to their highly sophisticated system of recruitment and large perennial colonies (Robertson 1925). An example is in a research investigation exploring food overlap, it was observed that honey bees swiftly deplete forage resources, potentially resulting in the local extirpation of wild bee populations. These findings offer valuable parameters for decision-making in the management of honey bee colonies within regions inhabited by threatened species. Notably, the study identifies six distinct oligolectic bee species facing threats, demonstrating a food overlap exceeding 70% with honey bees. The endangered species are: *Andrena lathyri, Andrena marginata, Dasypoda suripes, Dufourea halictula, Dufourea inermis,* and *Hoplitis anthocopoides* (Rasmussen et al. 2021).

Oligolectic bees

Four studies specifically focus on oligolecty or oligolectic bees, standing apart from other categories. Two of these studies focus on European oligolectic bees, highlighting their disproportional occurrences in Red Lists. Pekkarinen (1989) [166] is accompanied by a study proclaiming the same announcement two decades later by Bogusch and colleagues (2020). The latter emphasizes that, regardless of the viability and abundance of host plants for specialized bees, these bees still face a higher risk of endangerment compared to polylectic bees (Bogusch et al. 2020) [40]. A study on the declining specialized bee *Andrena humilis* explores its pollen harvesting pattern and reproductive rate. The results reveal an exceptionally low reproductive rate, with 0.9 offspring per day and < 10 produced offspring in a lifetime, despite its efficiency as a forager. This low reproduction rate appears to be a common trait in pollen-specialized bees in the family Andrenidae, providing insight into the severe decline of these bees (Franzén & Larsson 2007) [146].

The third study addresses native bee diversity, emphasizing the urgent need for taxonomic research, especially for oligolectic bees, as many remain undescribed. Approximately half of Australia's native bees are in need of revision, with land clearing, agriculture, invasive plant species, and climate change identified as main threats to native Australian bees (Batley & Hogendoorn 2010) [141].The last study, while not explicitly about global change, investigates pollinator foraging bout specialization. Its conclusions about oligolectic bees could serve as valuable basic data in global change research or conservation efforts, potentially influencing decisions but warranting consideration for bias (Smith et al. 2019) [64].

Genetics

Among the four studies addressing genetic variation, a study led by Packer and colleagues (2005) revealed reduced genetic variation within smaller and more isolated populations of oligolectic bees compared to their polylectic counterparts. Examining phylogenetically independent pairs of species from various bee families, including Colletidae, Megachilidae, Andrenidae, and Apidae, the findings supported the hypothesis that oligolectic bees are more vulnerable to extinction due to a likely reduction in their effective population size. This vulnerability suggests potential threats to mutualistic relationships between oligolectic bees and their host plants from genetic and ecological factors (Packer et al., 2005) [154]. In a study by Zayed and Packer in 2007, the lack of available data on the population genetics of solitary bees, particularly focusing on oligolectic species, was highlighted. The study focused on the population genetics within the oligolectic bee *Lasioglossum oenotherae*, covering 455 females from 15 populations across the bee's North American range. Results indicated regional disparities in gene flow, drift, and inbreeding (Zayed & Packer, 2007) [147]. A third study, utilizing a quantitative comparative approach to predict population genetic structure, observed no discernible effect of diet specialization but identified significant impacts of sociality on population genetic structure. The study included representatives from six bee families but notably lacked species from the Megachilidae and Melittidae families. Oligolectic species in the study included solitary species like *Lasioglossum oenotherae*, *Peponapis pruinosa*, *Andrena fuscipes*, *Andrena vaga*, and *Macrotera portalis*, as well as social oligolectic species like *Halictus scabiosae* and *Bombus bifarius* (López-Uribe 2019) [65]. The fourth study asserted that understanding the population genetics of pollen-specialized bees is enhanced by their work. Analyzing the population genetic structure of *Colletes gigas*, the main pollinator of rapeseed, China's crucial oil crop, they used a population genomic approach to explore the roles of geography and climate in genetic diversity, structure, and demographic history of *C. gigas* (Su et al. 2022) [19].

Synergism and interactions – additional studies

Global change pressures exhibit variation in their biotic or abiotic nature, spatiotemporal scales, and potential non-additive interactions, occurring synergistically or antagonistically. However, studies on pollinator and/or pollination decline often overlook the collective consideration of these pressures (González-Varo et al., 2013). Despite yielding 89 hits, there were no studies with a primary focus on the synergism or interactions of Global Changes and oligolectic bees in the result list. This observation aligns with a previous study by Straub and colleagues (2022), who systematically assessed the interactive effects of pesticides and pathogens on wild bees, revealing a limited number of relevant studies conducted in one laboratory and solely on social bees (bumblebees and stingless bees) (Straub et al., 2022). Terrestrial ecosystems face various simultaneous pressures, highlighting the crucial need to understand the interactive effects between them. This knowledge is vital for biodiversity conservation and the preservation of ecosystem services, as the impact of one pressure can be magnified or mitigated by the effects of another (Gonza´ lez-Varo et al. 2013).

Modern landscapes undergo anthropogenic alterations that introduce a mix of stressors affecting various species synergistically. Many of these species, especially bees, play crucial roles in ecosystem functionality. The combined impact of these stressors may reduce reproduction and survival rates in beneficial insects, potentially leading to population decline. Additionally, these stressors can influence behaviors related to resource acquisition and nesting (Stuligross et al., 2023). The decline in wild bee populations is primarily attributed to human activities, particularly land use changes that significantly alter the composition and diversity of accessible plants and food sources (Parreño et al., 2022). Pesticides and the depletion of food resources from flowering plants are two stressors that often interact, jointly affecting bee fitness. The impact of these stressors on essential behaviors such as foraging and nesting can restrict pollination services and hinder population persistence. Therefore, understanding these sublethal effects is crucial for a comprehensive grasp of the challenges faced by bees (Stuligross et al., 2023).

Discussion

Method discussion

Trying to cover such a big field as Global change and its impacts has definitely proved to be a challenge. It is important to remember that this study has focus on a broader level, to point out the lack of research done in the field. This makes it difficult to present uncomplicated and clear results. Nevertheless, a serious attempt to split or break down the results into digestible parts has taken place within a defined time frame in many of the fields. It would of course be preferred if all 79 found studies were read in its whole, but that would call for some assistants or co-workers. By mostly using abstracts or number of search hits, trying to present the distribution of found studies between different topics and to what extent they cover global impacts on oligolectic bees, might have caused bias.

Terminology and subjectivity

Investigation of the term oligolecty revealed gradations of the term, all of which might not be included. Subjective values on the importance of clarity and correct definitions might have influenced; the accurate use and possible consequences of inaccurate use of the term oligolecty presented, and thus maybe not consistent with the generally accepted view. Explanations of why "inaccurate" words, e. g. food specialist, are used instead have not been investigated; in the majority of the cases, it is likely more due to other reasons than lack of comprehension. Well aware of a personal stand in that question, database searches have been conducted with diet- and food specialist included, all other variants has been excluded though (read more in "Selection of search terms").

Database searches and "know how"

To be sure of having all relevant studies within a field (in this case global change) require a high level in "knowhow". Original plans of what was to be sought and presented have had to be changed time after time as it turned out to be; far too many result hits (several thousands) or too many completely irrelevant studies have been included in the hit list. During the course of the work, new concepts and words, relevant to this study, have also appeared or a letter has been missed, resulting in searches having to be redone, time after time. Different databases also has different ways of conducting a search, e. g. some has limitations of how many search terms you can use and some can use * as a "flashcard" to get all variants of a certain word (oligol* gives you oligolectic, oligolecty, oligoleges etc.) while others uses a ‘ to do the same. This has resulted in "trial and error" repeatedly and took a lot of time that could have been spent in understanding of studies.

Selection of search terms

Versions of oligolectic: Exclusion of "plant specialist" has probably led to search result bias due to the "accurate" word combination; "host-plant specialist". The mistake was detected when there was not enough time to correct it. Other terms used than; oligolecty, oligolectic, oligolege, pollen specialist, food specialist and diet specialist, were excluded. Bias in search results, due to the exclusion of words such as; "specialized solitary bee" or "specialist bee" is more than likely, but that is done deliberately, to point out the importance of correct term usage. Possible bias in search result can have occurred due to the fact that it might be other "accurate" words or expressions that have been overseen or due to misspell. Overseen words that were realized before deadline of this study but too late to add: desertification, UV-increase, synchronization, etc.

Selection of studies

The use of abstract as a selective method, due to the attempt to cover a big field as global change impacts on oligolectic, turned out to be nearly an impossible mission as well as an eye-opener. As the insight of oligolectic bees and global change impacts expanded the more excluded studies, considered irrelevant, became to be of relevance due to the importance of basic understanding of oligolectic bees. Examples of such research are within the fields of; evolution, pollen ecology, visual and olfactory floral cues, nesting biology, bar-coding, plant-pollinator networks, reproduction, conservation and many more. However, studies within those fields are mainly excluded, and there might also be some overseen studies that ought to be included. Different point of views of what is of relevance has also played a part, and subjectivity might have influenced the selection of studies.

Terminology

There is also considerable uncertainty regarding the degree of specialization in bee species concerning their choice of pollen-collecting plants. A species considered oligolectic today may be reclassified as polylectic, and vice versa, due to a lack of reliable data. Many classifications are founded on older observations, some of which may be as simple as noting a bee on a particular plant. Such observations can be fallible, as female bees may interact with flowers for purposes other than pollen collection, such as feeding on nectar, mating, or resting. If the host plant from which an oligolectic species primarily collects pollen were to disappear, the species would adapt by collecting pollen from alternative plants (personal communication with B. Cederberg). The consequences of such a shift in larval food pollen sources can have adverse impacts on larval development though, potentially leading to increased mortality. In its fully developed state, the species may experience compromised overall health, rendering it more vulnerable to diseases and other stressors, or it may suffer from impaired reproductive capacity.

Correct term usage

When using the term oligolectic or pollen specialist, this ensures that the concept and its meaning are clear and cannot be misunderstood (Figure 4). If e.g. the word specialist is used, it can result in uncertainty about what the terms actually stand for and if there is no explanation or definition for them, this can lead to misinterpretation in the worst case. Oligolecty is also a word that occurs in many other languages, which facilitates translations and reduces the risk of incorrect translations.

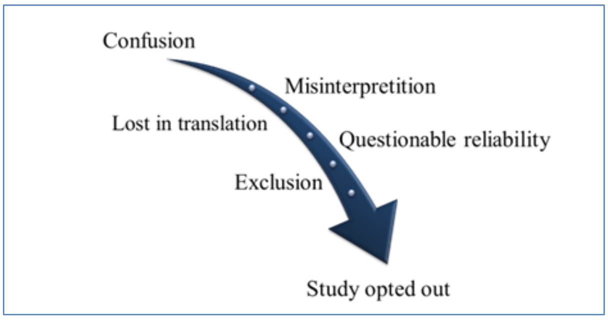

Figure 4: The figure shows some possible consequences of not using the correct term oligolectic alt. pollen specialist

Correctness and clarity in the use of terms in general also give increased credibility to the study being read, while incorrect terms could make the reader wonder to what extent the study is reliable; has the author really considered the true meaning of oligolecty and why is the correct term not used? This, in turn, can lead to the reader also opting out of other studies written by the same author.

Database search results - oligolecty

It may also happen that a study, where the correct term is not used, is excluded in a database search. Different databases use slightly different ways to specify certain words and include synonyms and not all of them have a comprehensive competence in that area, which means that the results can vary. The search on Web of Science with the word bee* and three different search variants showed a difference in the number of hits; oligolectic or pollen specialist together with food or diet specialist generated 704 results, when food or diet specialist where excluded the number of results was 492, while food or diet specialist and not oligolectic or pollen specialist generated 212 results. If * was removed from the word bee, 610, 287 and 21 results were generated respectively. This indicates that exclusion may be a reasonable assumption.

Global change impacts on oligolectic bees

There are studies that include oligolectic bees, albeit not to a large extent. This scarcity could be explained by one of the two aspects that have become most apparent during this review;

The first is the lack of taxonomic expertise, which has become evident in several of the reviewed studies. Oligolecty is not a static condition but can change over time or with new knowledge, meaning that classifications need to be revised. Many researchers use older lists where many species, previously misclassified as polylectic, have been reclassified as oligolectic through new observations. Ideally, these researchers should recognize that this could be the case, as demonstrated by, for example, Hofmann and colleagues (2019), who ensured that species' new classifications were updated before using them in statistical tests and modelling (Hofmann et al. 2019) [66]. The need for accurate taxonomic data is crucial to avoid introducing bias into the research. Taxonomy goes beyond mere nomenclature, serving practical purposes in diverse fields such as biodiversity studies, conservation efforts, and agriculture. It extends beyond the assignment of names, providing a systematic framework to understand the natural world. Through taxonomic revisions, valuable information is generated, documenting variations in colour and morphology, enhancing predictability by revealing shared behaviours and ecologies among closely related species. Additionally, it offers insights into distribution patterns, phenology, and the intricacies of associated organisms like parasites and food plants.

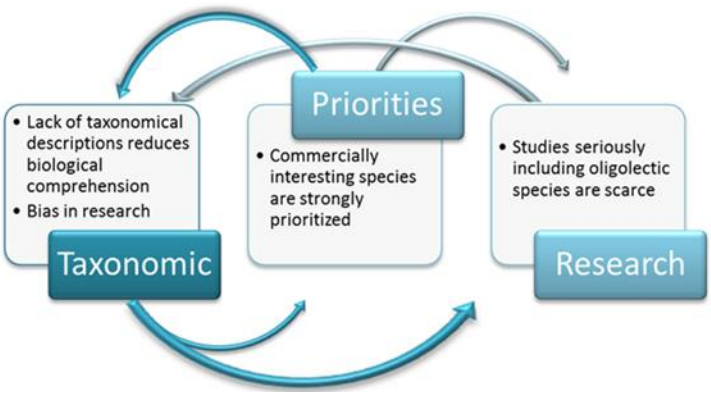

Figure 6: The main causes to oligolectic bees' scarce inclusion in research studies within the field of global change impacts

The second aspect is the oligolectic bees under study. The family that overwhelmingly dominates is Megachilidae, a commercially important group in agriculture. Unfortunately, the threat situation for the other families is significantly greater than that for Megachilidae. While the average threat in Europe is 9.2%, the family Megachilidae has a threat level of 1.1%, whereas the Melittidae and Colletidae families exhibit significantly higher levels; 18.9% and 12.8%, respectively (Nieto et al 2014).

These two aspects together imply that knowledge of oligolectic bees does not increase directly but only leads to increased knowledge of oligolectic bees belonging to the Megachilidae family (Figure 6).To what extent oligolectic bees are included in studies on global change impacts is obscure due to many factors that complicate an evaluation, especially when performed on a broader level. What has been identified is described in the subsequent sections.

Obscurity or generalization?

A conclusion read in one of the abstracts was; "*the diversity of plant pollen in oligolectic bee species nesting tubes were higher in residential gardens compared to bushland habitats*", but when looking into the full study it turns out that there were only three oligolectic species included in the investigation; Megachilidae; *Megachile canifrons, M. fabricator*, and *Rozenapis ignita* (Fernandes et al. 2022) [14]. One study performed in a scrub oak barrens and concluded in the abstract that; increased visibility of nectar resources and sandy patches post-treatment may have promoted sand specialist and oligolectic bee species. But a closer look in the study revealed that only four species had been found, namely; *Andrena braccata, A. hirticincta, A. placata*, and *A. simplex* (Bried & Dillon 2012) [124].

Another study employing a quantitative comparative approach to predict population genetic structure, no discernible effect of diet specialization was observed. However, the study identified significant impacts of sociality on population genetic structure. The representatives utilized in the study encompassed six bee families: Andrenidae, Apidae, Colletidae, Halictidae, Megachilidae, and Melittidae. Notably, upon scrutiny of the supplementary materials, it became apparent that species from the Megachilidae and Melittidae families were absent. Among the sampled families, Apidae predominated with 32 species, of which 14 belonged to the genus *Bombus*. The remaining families included two species of Colletidae, four of Halictidae, and three of Andrenidae. The oligolectic species identified in the study were as follows: solitary species encompassed *Lasioglossum oenotherae* (Halictidae), *Peponapis pruinosa* (Apidae), *Andrena fuscipes*, *Andrena vaga*, and *Macrotera portalis* (Andrenidae). Social oligolectic species comprised *Halictus scabiosae* (Halictidae) and *Bombus bifarius* (Apidae) (López-Uribe 2019) [65].

Another study, that investigated bee assemblages in cattle-grazed sites versus sites with high cheat grass cover in prairies proposed in their abstract that; "*sites with high grass cover tended to support oligolectic solitary bees*". Although, upon examination of the study it became clear that the oligolectic bees, covered by this proposition, (of nine) and one in the family Megachilidae: *Lithurgopsis apicalis* and the other eight in the family Apidae: seven Long horn bees (5 *Melissodes* spp., 2 *Svastra* spp) and *Diadasia enavata* (Thapa-Magar et al. 2020) [36]. Would it not be more correct to state that: "*sites with high grass cover tended to support Long horn bees*"? And if seventeen sites along a gradient (levels of urbanization) were studied and the total number of oligolectic species found were six, is a conclusion like: "*significant preference*", even possible then? (Venn et al. 2023) [7]. If you have a small dataset, caution should be exercised when making strong statements about preferences, as statistical significance may be harder to achieve with limited observations.

It ought to be possible to perform a quantitative estimation only based on abstracts, although some authors includes conclusion referring to oligolectic bees as a group in their abstracts, while in the study actually only found a smaller restricted number of oligolectic species. Authors should consider being more precise in their abstracts, specifying the scope of the study to avoid potential misinterpretations. By providing accurate and clear information in the abstract ensures that readers understand the context and limitations of your research from the outset. Using inclusive language might attract more attention or interest from a broader audience. However, it's crucial to balance this with accuracy. Certain terms or concepts might be commonly understood within a specific scientific community, but researchers should be mindful of potential misinterpretations by those outside the field.

Lack of informative material and misclassification

There were several studies where 1) species lists were missing or the species list could not be opened, 2) species lists without information about which species they classified as oligolectic, 3) narrowly oligolectic species incorrectly classified as polylectic.

1) Lane et al. 2022 [27], Lerman & Milam 2016 [96], Grundel et al. 2010 [132]
2) Felderhoff et al. 2023 [10], Buhk et al. 2018 [72], Gonçalves et al. 2014 [111]
3) Ferrari & Polidori 2022 [15], Twerd et al. 2021 [34] (read more of this in next section)

Taxonomic misclassification

There are huge knowledge gaps in taxonomic data available, and current taxonomic is often not updated. The need of correct taxonomic data is crucial not to introduce bias in the research. An example of this need is found in a study (Twerd et al. 2021) [34] performed as late as 2021, where 12 oligolectic species were wrongly considered polylectic; narrowly oligolectic species: *Andrena apicata, A. clarkella, A. curvungula, A. lapponica, A. nycthermera, Colletes cunicularius*; moderately oligolectic species: *Colletes daviesanus, C. fodiens, C. marginatus, C. similis*. If ten species out of 131 of the polylectic bees are found to be, upon further examination, not truly polylectic but rather oligolectic, when assessing the contributions of phenological groups of wild bees as an indicator of food availability in urban wastelands, this revelation could have significant implications for the study's results. The misclassification of these bees may introduce bias in the assessment of food availability, as the foraging behavior and resource utilization of oligolectic bees differ from polylectic ones. The findings may need to be re-evaluated and adjusted to account for this misclassification, ensuring the accuracy and reliability of the study's conclusions regarding food resource availability in urban wastelands.

In another study they explored how city traits affect both taxonomic and functional profile of urban bee communities in 55 cities around the world and when screening the list of included bee species in the study, six species that are narrowly oligolectic was classified as polylectic: *Andrena clarkella, A. curvungula, A. lapponica, A. nycthermera, A. praecox, Colletes cunicularius (*Ferrari & Polidori 2022) [15]. A study that caused doubtfulness is Lerman & Milam 2016 [96] where they referred to oligolectic as a "*specialists on a single plant*".

Questionable studies

One study that concluded positive results of oligolectic bee occurrence was read more thoroughly and possibly their conclusions could be questioned. The study took place in Munich, consisting of three study sites; a - the area of the Allacher Lohe, has a marshalling yard (continuous operational since 1991) but the remaining 150 ha area has been a nature reserve since 2000; b - Virginia depot (20 ha) that were off limit between 1945-2003 (therefor harbours rare plants and animals) and then transformed into a city biotope; c - Munich Botanical garden (20 ha). The results showed;

a. a decrease of 60 % (80/135) in present bees and an increase of 30 % (244/189) of absent bees,
b. an increase of 37,5 % (44/32) and a decrease of 3 % (280/292) respectively;
c. an increase of 35, 5 % (105/78) and a decrease of 11 % (219/246) respectively.

Moreover; they were referring to one of the authors own study (Hofmann & Renner 2018) [79] performed in Munich Botanical Garden where the outcome of "German Bee Diversity" showed no phylogenetic signal in the prediction of any vulnerability detected, and therefore used simple logistic regression. To apply and use results of phylogenetically informed models performed in a botanical garden that showed that phylogeny (oligolecty included) played no role, and use them without adding the information of where that study has taken place, could be questionable. In the study it can be read; "*We therefore here use simple logistic regression with two models applied to the 324 species recorded for Munich since 1795*" (Hofmann & Renner 2020) [51]. The two models were flight duration and seasonality. If the results used in a simple logistic regression analysis are incorrect, the outcome can lead to uncertain or erroneous conclusions. Incorrect results used as input for a statistical analysis can result in biased or misleading outcomes, which, in turn, can affect the interpretation of the results and any decisions based on them. The study could very well be in order, but due to the fact that it aroused questions, it some way failed to be clear and convincing.

In one study on green roofs, the biodiversity on nine green roofs, in sub-urbans in Vienna, was investigated (Kratschmer et al. 2018) [81]. All together 2462 individuals were found, 1470 *Apis mellifera* and 992 individuals of wild bees where the total amount of oligolectic species found were 34. In the conclusion it could be read that occurrence of oligolectic wild bee species was low, but that they were "*strongly positively affected*" by floral diversity increases. When looking at the appendix of the found species found at these roofs the distribution was as shown in table 2.

Table 2: Data extracted from the appendix of findings on respectively roof at the investigation performed in Vienna.

	Roof 1	Roof 2	Roof 3	Roof 4	Roof 5	Roof 6	Roof 7	Roof 8	Roof 9
Number of oligolectic bees	5	0	0	0	18	0	1	3	7
Number of plant species	32	23	36	38	136	11	53	15	77

Using the community weighted means (CWM) and R packages to examine characteristic traits on green roofs is a valid approach for ecological analysis. However, the key issue, in the former mentioned statement, is that of only show data where there were oligolectic bees, to show a strong positive result (Figure 5). By showing only the data where there were oligoleges, selection bias is introduced into the analysis. This means that by only considering situations where oligoleges were present, it can lead to an overestimation of the positive relationship between the examined traits and bee occurrence.

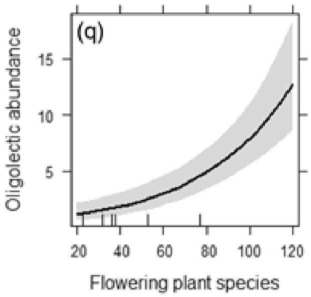

Figure 5: Figure in the study by Kratschmer et al. 2018, presenting the results of the community weighted means (CWM) and R packages presented in the study.

Moreover; excluding data where there was no oligoleges neglects important information. It's essential to consider both presence and absence data to get a comprehensive understanding of the ecological relationships. The absence of oligolectic bees might also be informative and could indicate factors that are unfavourable for oligolectic bee presence. The strong positive result observed in the data might not hold when considering a broader context. It is important to assess the relationship across a more extensive dataset to determine its generalizability. Selecting data only when oligoleges are present can lead to statistical biases and an overestimation of the significance of the relationship. This can result in misleading or inaccurate conclusions. Describing bee occurrence as "low" suggests a low frequency or abundance of bees, which is typically associated with negative or neutral impacts. Saying it's "strongly positively affected" contradicts this by implying that the presence of more flowers has a very positive effect on oligolectic bee occurrence, especially when the presence of these bees does not consistently increase with an increased number of flowers. The few data points emphasize the need for a more thorough and comprehensive analysis, including statistical methods, to understand the complex ecological dynamics that affect the relationship between oligolectic bees and flowers. A larger and more diverse dataset is necessary to draw more reliable and meaningful conclusions about the relationship between oligolectic bee occurrence and the number of flowers on green roofs.

In the review on Bee species from green roofs, conducted by Hofmann and Renner in 2017 [80], an introduced bias was notably present. Specifically, it was observed that *"11% of the species found on green roofs in Vienna were oligolectic" (Kratschmer 2015)*. However, in the work by Kratschmer et al. in 2018, the statement is articulated as *"we observed only 11% oligolectic species"*. In the preceding text, Kratschmer's study accurately presents the following figures: a total of 992 wild bee individuals were recorded, of which 34 individuals were oligolectic, representing 3.4% of the total. It is worth noting that there is no reference to Kratschmer (2015) in the citation list. Indeed, it should be noted that Kratschmer's initially published article (according to Web of Science, November 7, 2023) was released on December 12, 2017.

Are oligolectic bees particularly vulnerable?

In the majority of studies where they seriously has been investigating both oligolectic and polylectic bees the results clearly shows a greater decline of oligoleges compared to polyleges (Beismeijer et al. 2006; Bogusch et al. 2020) [40]. As a minority group within Apiformes, they are often overlooked or deemed less attractive to research funders and, consequently, researchers. The absence of taxonomic data poses challenges, as a comprehensive taxonomic description is essential for evaluating whether a species is endangered and for devising effective conservation measures. Without this information, oligolectic bees may be neglected in assessments of threat status and conservation needs. It should be emphasized that anything that poses a threat to a wild bee undoubtedly poses an even greater threat to an oligolectic bee.

This is because oligolectic bees rely on a limited number of plants, and any factor affecting the host plant also impacts the oligolectic bee (see Figure 7), it is simple math. While some studies suggest that certain larvae can develop on non-host pollen, these studies do not track the larvae throughout their entire life cycle. This could potentially result in reduced fitness in adult bees, diminished reproductive success, or a shift in the male/female ratio, all of which can contribute to a decline in abundance.

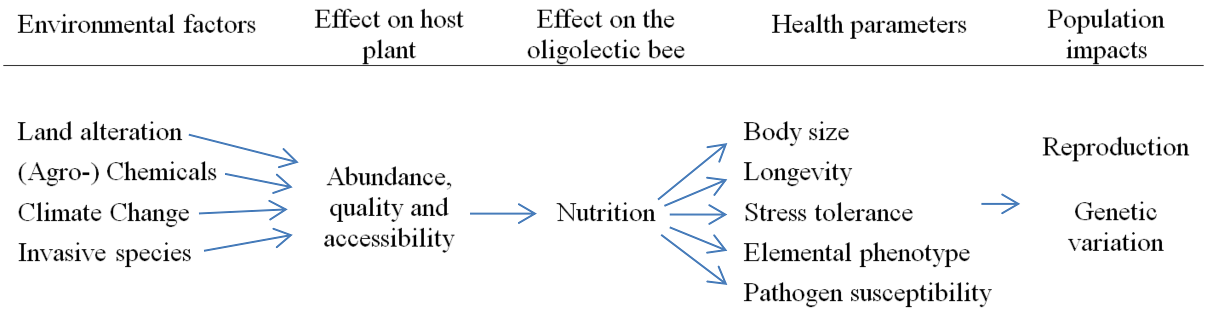

Figure 7: Global Change multiple threats to oligolectic bee health. Fig. 1 modified from Perreno et al. (2021)

Results shown in the two studies of genetic variation in oligolectic bees indicate that oligolectic bees, compared to polylectic bees, have lower levels of genetic variation. Add to that, the fact that specialist bees, in contrast to generalist bees, are forced to exist in smaller and more isolated population due to habitat loss and fragmentation. All together it point at a higher risk of endangerment or extinction for genetic and demographic reasons, due to a probably lesser capability to adapt to changing environmental conditions. Complete mismatch with floral hosts would likely cause severe fitness consequences in short-season oligolectic bees, but there are few documentations of this (Ogilvie & Forrest 2017) [91]. In temperate climates most species are triggered by the temperature, signalling the time of their seasonal activity. Those solitary bees that emerge in early spring, has spent the winter as full-fledged adults in their broad cells. Therefore could a shorter period of warmth in spring initiate quick responses in these bees, possibly result in temporal mismatches with their host plant. Consequences for plants have been well studied but research studies lack focusing on the fitness consequences for bees. Temperate (oligolectic) species occurring very early in spring or in late autumn are assumed to experience higher negative impacts of desynchronization. The higher threat is due to the risk of emerging in the absence of their preferred interaction partners, and as the plant biodiversity is lower during the season´s early and late periods, bees cannot easily switch to another potential interaction partner (Schenk et al. 2016) [88].

Then there are pesticides. There are a huge number of studies concerning sublethal and lethal effects of pesticide exposure, all done on social bees, mostly honey bees, but there some that studied bumble bees, which both have a social way of living. However, in general these studies show that the most common sublethal effects cause learning disabilities, poor memory, and aberrant foraging behavior. Such sublethal effects would impact a solitary bee much harder as they play a more important role as individual. Add to this the fact that oligolectic bees have less flexibility in their foraging, thus would face greater consequences of the sublethal effects mentioned above.

Why so few studies?

Knowledge gaps are often pointed out in studies, but no explanations to the limited number of research studies on global change impacts and oligolectic bees are to be found. To explain it as a consequence of limited awareness about the ecological significance of oligolectic bees and the need to study them in the context of global change would be to simplify the answer. Raising awareness of possible factors explaining the limited number of studies could potentially lead to increased research in the field. The most obvious factor to this limitation is; 1) limited data availability; taxonomic bias in ecological research with more studies focused on economically significant or well-known species, lack of long-term monitoring programs or extensive datasets focusing on oligolectic bees resulting in limited comprehensive data to research upon. But there are also; 2) challenges and complexity in studying oligolectic species; understanding their responses to global changes requires a nuanced approach that considers not only the bees but also the dynamics of their interactions with particular plants, the potential impacts on both the bees and their host plants, adding complexity to study designs. This pollen specialization can make them less tractable for study. Attention are not to be forgotten, affecting 3) funding priorities; researchers may prioritize research with focus on broader topics, like overall pollinator declines or the effects of global changes on more generalist species since it may receive more attention than specific subsets such as oligolectic bees. Funding priorities often influence research focus, and could therefor make a major difference by prioritize research on global change impacts and oligolectic bees.

How can this be changed?

As interest in pollinator conservation and the understanding of ecosystem dynamics grows, it is possible that more studies will emerge in the intersection of global changes and oligolectic bees. Collaborative efforts among researchers, increased funding for targeted studies, and the recognition of the ecological importance of these pollen specialized bees may contribute to a more comprehensive understanding of their responses to global changes. There are researches having competence to perform studies in this field, at least in one or another aspect. It is the prerequisites that has to change; importance of oligolectic bees has to be highlighted; funders need to understand the challenges a researcher will have in such a complex field; not only commercial important bees has to be included in studies; in situ sites, suitable for studies, has to be investigated, ways to perform in vitro studies on these bees has to be investigated.

Some researchers are already on their way:

A study that stands out among others is Beyond generalists: "The Brassicaceae pollen specialist *Osmia brevicornis* as a prospective model organism when exploring pesticide risk to bees" by Hellström and colleagues (2023) [9] where their conclusion is that the oligolectic *O. brevicornis* is a feasible model for to assess the risk of pesticides in the laboratory and in the field. In two other studies *Heriades truncurum* and *Osmia ribifloris* are suggested as oligolectic models. Studies like that might encourage other researches to find model species, in some of the other five families of bees.

And perhaps botanical gardens could be suitable places to individually study the impact that climate change has on bee biodiversity? That is suggested by Hofmann and her colleagues in their article (2018) where they analysed the bee fauna in the Munich Botanical Garden. Since the flora of the botanic garden has not changed and the protected flora of the surrounding environment has not changed for 20 years, habitat loss or loss of host plants of oligolectic species should not be reasons behind the disappearance of oligolectic species. In addition, there has been hardly any use of pesticides. The factor that remains is climate change, as the average temperature during the growing season in Munich has increased by 0.5 ºC and that winters have become almost four weeks shorter.

Conclusions

Oligolecty

That mono-/oligo-/polylecty rather is a matter of a continuum than of different categories, as Bogusch and colleagues (2020) wrote in their study, do acknowledge the potential for change and adaptation, but the key difference is in the nature of the change. A continuum represents a smooth, continuous progression without distinct categories, which might be correct in an evolutionary point of view. When it comes to spatial changes or mismatch induced changes, a continuum would not really describe the phenomena correctly. If anything it is more as a dynamic categorization; not fixed and immutable but can change over time or under different circumstances. Mono-/oligo-/polylecty are not classified within a single static category; instead, these classdifications adapts and reclassifies as needed or when new relevant information becomes available. It is important to use appropriate terms and concepts to describe the process where something can change or adapt depending on various factors, to help clarify that there is no rigid and static categorization but rather flexibility and adaptation within the system.

Oligolectic bees

While oligolectic bees are vital components in pollination ecology, their specific inclusion can vary depending on the research focus and objectives of different studies within broader fields. The overall conclusion of this study consists with what many other researches already have pointed out; there are huge knowledge gaps, especially for oligolectic bees. These knowledge gaps stretches from basic data, such as taxonomic, distribution and abundancy to researches done in the field of global change impacts on bees.

Generalizations

Using broad language in the abstract that implies a study's findings are representative of an entire group, when the study actually focused on a subset, can lead to potential misunderstandings or misinterpretations among readers who may not delve into the full study. Readers who only skim the abstract might get the impression that the study's conclusions apply universally to all oligolectic bees, which may not be the case.

While the full study may provide the necessary details and context, the abstract is often the first section a reader encounter. Misleading language in the abstract can also affect the overall scientific accuracy and integrity of the research. This can lead to misunderstandings about the generalizability of the findings and if others in the scientific community or beyond might use your study's abstract as a reference without delving into the specifics. If the abstract suggests broad conclusions about all oligolectic bees, it could be cited inaccurately in other works. It is not accurate or appropriate to claim in the abstract that the study has investigated oligolectic bees in general and then draw conclusions about all oligolectic bees if the study only focused on a few species from one of the six families of bees. The abstract should accurately reflect the scope and findings of the study.

Vulnerability of oligolectic bees

Oligolectic bees are significantly more threatened by global change than polylectic bees; a fact that is underlined by their overrepresentation in red lists. Of the anthropogenic effects described in the text above, almost every one of them involve some form of possible extra vulnerability for oligolectic bees. The overall conclusion of the reviews is that oligolectic bees are threatened by multiple factors, as many of the wild bees are. But due to their dependence on specific hostplant, they are in general, more vulnerable and less capable to adapt to global changes.

Further research

More basic research is needed on oligolectic bee foraging ranges, flight seasons, and floral-host associations. Additionally, studies examining bee behavioural and reproductive responses to fluctuations in resource availability are essential. Understanding how bee foraging and floral phenology has co-evolved, considering phylogenetic relatedness is crucial. Identification and protection of floral reserves near roost sites along the "nectar corridors" of threatened migratory pollinators is a crucial conservation strategy. Maintaining these corridors, which enable migratory pollinators to move between patches of plants, is essential for preserving their populations. Given the alterations in floral resource phenology due to anthropogenic environmental change, a better understanding of bee responses to global changes is necessary to anticipate their future population and community trajectories. Comparative analyses of the pollen preferences of oligolectic bee populations in different environmental contexts, along with experimental tests of behavior in settings with scarce floral hosts, are needed to predict specialist bee responses to changes in floral availability. Evaluating the relative effects of different environmental gradients on bee community composition is also crucial. There are knowledge gaps in understanding what oligolectic bees do under a lack of resources, such as whether they halt nesting or search elsewhere for their host. Closing these gaps is essential for comprehensive insights into the ecology and behavior of oligolectic bees.

Words of thanks

I would like to thank Björn Cederberg for all the entomological taxonomy he has contributed with during his life, and for helping me clarify concepts and classifications. To my supervisor Julia Osterman, I would like to say; thank you for your amazing patience! And thank her for the advice and tips she gave me which really improved this study. I would like to thank the Entomological Association in Stockholm for the scholarship I received, for the purchase of Stephen Falk's book on wild bees. Course leader Charlotta Kvarnemo and examiner Åslög Dahl, I thank you for being available for all of my questions.

References

Artsdatabanken, the Norwegian Biodiversity Information Center, https://www.artsdatabanken.no [Visited 2023-10-18]

Biesmeijer, J.C., Roberts, S.P.M., Reemer, M. et al., (2006), *Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands.* Science 313: 351–354

Burkle, L.A., Marlin, J.C., Knight. T.M., (2013), *Plant-Pollinator Interactions over 120 Years: Loss of Species, Co-Occurrence, and Function.* Science 2013, 339: 1611-1615, https://doi.org/10.1126/science.1232728

Cane, J.H., Sipes, S. (2006) *Floral specialization by bees: analytical methods and a revised lexicon for oligolecty*, In: Waser, N.M. & Ollerton, J. (eds.), Plant-Pollinator Interactions, pp. 99–122. Univ. Chicago Press, Illinois

Cane, J.H., (2011), *Specialist Osmia bees forage indiscriminately among hybridizing Balsamorhiza floral hosts,* Oecologia 2011, Springer-Verlag (outside the USA), https://doi.org/10.1007/s00442-011-1977-1

Cederberg, B., Swedish entomologist and part of the Swedish expert committee of Hymenoptera, continuous personal communication between 2023-09-01 until 2023-11-01

Collins (2003), Collins paperback English dictionary, HarperCollins Publishers, Glasgow, 2003, ISBN 1-85-605841-7

Crone, M.K., Boyle, N.K., Bresnahan, S.T., Biddinger, D.J., Richardson, R.T., Grozinger, C.M., (2023), *More than mesolectic: Characterizing the nutritional niche of Osmia cornifrons,* Ecology and Evolution. 2023;13:e10640. https://doi.org/10.1002/ece3.10640

Falk, S. & Lewington, R. (2015). *Field Guide to the Bees of Great Britain and Ireland* (Bloomsbury Wildlife Guides (formerly British Wildlife Field Guides)). Bloomsbury Publishing. ISBN: 978-1-9103-8902-7.

Finland's Species Data Center, https://laji.fi [Visited 2023-10-28]

GBIF, the Global Biodiversity Information Facility. https://www.gbif.org [Visited 2023-10-24]

González-Varo, J.P., Biesmeijer J.C., Bommarco, R., G. Potts, S.G., Schweiger, O., Smith, G.H., Steffan-Dewenter, I., Szentgyörgyi, H., Woyciechowski; M., Vilà, M., (2013) *Combined effects of global change pressures on animal-mediated pollination*, Trends in Ecology & Evolution, 2013, 28, 9: 524-530, https://doi.org/10.1016/j.tree.2013.05.008

Hanson T. (2018) *Buzz – the nature and necessity of bees*. Hachette Book Group, Inc.; New York; USA. Svenska utgåvan. *Binas hemliga liv.* 2019 Natur & kultur Sthlm. ISBN 978-91-16206-8

LeBuhn G. and Luna J.V. (2021) *Pollinator decline: what do we know about the drivers of solitary bee declines?* Current Opinion in Insect Science 2021, 46:106–111. https://doi.org/10.1016/j.cois.2021.05.004

Linkowski W.I., Cederberg B. & Nilsson L.A. (2004) *Vildbin och fragmentering.* Svenska Vildbiprojektet vid ArtDatabanken, SLU & Avdelningen för Växtekologi, Uppsala Universitet, 2004.

Madsen, H.B. Bier. In: Moeslund J.E., Nygaard B., Erjnæs R., Bell N, Bruun L.D., Bygebjerg R., et al., editors., (2019), Den danske Rødliste 2019. Aarhus: Aarhus Universitet, DCE–Nationalt Center for Miljø og Energi; 2019.
https://ecos.au.dk/forskningraadgivning/temasider/redlistframe/artsgrupperne/oevrige-leddyr/bier [Visited 2023-10-27]

Meeus, I., Pisman, M., Smagghe, G., Piot, N., (2018), *Interaction effects of different drivers of wild bee decline and their influence on host–pathogen dynamics.* Current Opinion in Insect Science 2018, 26:136–141, https://doi.org/10.1016/j.cois.2018.02.007

Michener, C.D. (2007) *The Bees of the World*, second edition, Johns Hopkins University Press, Baltimore

Naturbasen - Danmarks nationale Artsportal 2001-2023. https://www.naturbasen.dk

Nieto, A., Roberts, S.P.M., Kemp, J., Rasmont, P., Kuhlmann, M., García Criado, M., Biesmeijer, J.C., Bogusch, P., Dathe, H.H., De la Rúa, P., De Meulemeester, T., Dehon, M., Dewulf, A., Ortiz-Sánchez, F.J., Lhomme, P., Pauly, A., Potts, S.G., Praz, C., Quaranta, M., Radchenko, V.G., Scheuchl, E., Smit, J., Straka, J., Terzo, M., Tomozii, B., Window, J. and Michez, D. (2014). *European Red List of bees*. Luxembourg: Publication Office of the European Union. https://www.iucnredlist.org/ [Visited 2023-11-05]

Parreño M.A., Alaux C., Brunet J.-L., Buydens L., Filipiak M., Henry M., Keller A., Klein A-M., Kuhlmann M., Leroy C., Meeus I., Palmer-Young E., Piot N., Requier F., Ruedenauer F., Smagghe G., Stevenson P.C. and Leonhardt S.D., (2022), *Critical links between biodiversity and health in wild bee conservation*, Trends in Ecology & Evolution, 2022, 37, 4, https://doi.org/10.1016/j.tree.2021.11.013

Pettersson, M.W., Cederberg, B. & Nilsson, L.A., (2004), *Grödor och vildbin i Sverige*, Svenska Vildbiprojektet vid ArtDatabanken, SLU, & Avdelningen för Växtekologi, Uppsala Universitet, 2004.

Praz, C.J., Müller, A., Dorn, S., (2008), *Specialized bees fail to develop on non-host pollen: Do plants chemically protect their pollen?*, Ecology, 2008, 89(3): 795–804

Raine N.E.and Rundlöf M., (2023) *Pesticide Exposure and Effects on Non-Apis Bees*. Annu. Rev. Entomol. 2024. 69:551–76, https://doi.org/10.1146/annurev-ento-040323-020625

Rasmussen, C., Michael S. Engel M.S., Vereecken N.J. (2020) *A primer of host-plant specialization in bees*. Emerging Topics in Life Sciences, 2020; 4(1): 7-17 https://doi.org/10.1042/ETLS20190118

Rasmussen C, Dupont Y.L., Madsen H.B., Bogusch P, Goulson D, Herbertsson L, et al. (2021) *Evaluating competition for forage plants between honey bees and wild bees in Denmark.* PLoS ONE 2021, 16(4): e0250056. https://doi.org/10.1371/journal.

Rasmussen, C.; Sydenham, M.A.K.; Schmidt, H.T.; Madsen, H.B. (2022) *The Native Bees of Lolland (Denmark) Revisited after 100 Years: The Demise of the Specialists.* Insects, 2022; 13: 153 https://doi.org/10.3390/

Robertson C. (1925) *Heterotropic Bees*. Ecology, 1925; 6; 4: 412-436. https://www.jstor.org/stable/1929107

Sponsler D.B., Grozinger G.M., Hitaj C., Rundlöf M., Botías C., Code A., Lonsdorf E.V., Melathopoulos A.P., Smith D.J., Suryanarayanan S., Thogmartin W.E., Williams N.M., Zhang M., (2019), *Pesticides and pollinators: A socioecological synthesis*, Science of the Total Environment, 2019, 662: 1012–1027, https://doi.org/10.1016/j.scitotenv.2019.01.016

Straub L., Strobl V., Ya˜nez O., Albrecht M., Brown M.J.F., Neumann P. (2022) *Do pesticide and pathogen interactions drive wild bee declines?* International Journal for Parasitology: Parasites and Wildlife, 2022; 18: 232–243

Stuligross, C., Melonem G.G., Wang, L., Williams, N.M., (2023), *Sublethal behavioral impacts of resource limitation and insecticide exposure reinforce negative fitness outcomes for a solitary bee*, Science of the Total Environment, 2023, 867: 161392, http://dx.doi.org/10.1016/j.scitotenv.2023.161392

Thain M. & Hickman M. (2004) *The penguin dictionary of biology*. 11th edition, 2004. Clays Ltd, St Ives plc, England. ISBN 0-141-01396-6.

Tome´ HVV, Martins GF, Lima MAP, Campos LAO, Guedes RNC (2012) *Imidacloprid-Induced Impairment of Mushroom Bodies and Behavior of the Native Stingless Bee Melipona quadrifasciata anthidioides.* PLoS ONE, 2012; 7(6): e38406. https://doi:10.1371/journal.pone.0038406

Vázquez, D.P., Vitale, N., Dorado, J., Amico, G., Stevani, E.L., (2023), *Phenological mismatches and the demography of solitary bees.* Proc. R. Soc. B. 2023, 290: 20221847. https://doi.org/10.1098/rspb.2022.184 7

Appendixes

Appendix 1: Hit result list (references)

Database: Web of Science **Date of search and export: 2023-10-10**

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
2	Boff, S; Ayasse, M	Exposure to sublethal concentration of flupyradifurone alters sexual behavior and cuticular hydrocarbon profile in Heriades truncorum, an oligolectic solitary bee	Insect Sci.	2023				Pesticides	
3	Dominique, Z; Sabine, S; Herbert, Z; Christa, HR; Sophie, K	Changes in the wild bee community (Hymenoptera: Apoidea) over 100 years in relation to land use: a case study in a protected steppe habitat in Eastern Austria	J. Insect Conserv.	2023	27	4	625-641	Land alteration; Biodiversity, steppe	
4	Smith, C; Joly, S; Antoine, C; Hyjazie, B; Forrest, JRK	Regional plant abundance explains patterns of host use by pollen-specialist bees in eastern North America	Ecology	2023	104	8	e4122		
5	de Sousa, P; Henriques, A; Silva, SE; Carvalheiro, LG; Smagghe, G; Michez, D; Wood, TJ; Paulo, OS	Genomic Patterns of Iberian Wild Bees Reveal Levels of Diversity, Differentiation and Population Structure, Supporting the Refugia within Refugia Hypothesis	Diversity-Basel	2023	15	6	746		
6	Glasser, SK; de Santiago-Hernández, MH; Delgado-Carrillo, O; Espino, LAV; Pérez, AC; González-Rodríguez, A; Lira-Saade, R; Quesada, M	Influence of plant domestication on plant-pollinator interactions: Floral attributes and floral visitor communities in wild and cultivated squash plants	Am. J. Bot.	2023	110	5			
7	Venn, S; Teerikangas, J; Paukkunen, J	Bees and pollination in grassland habitats in Helsinki (Finland) are diverse but dominated by polylectic species	Basic Appl. Ecol.	2023	69		1-12	Land alteration; Urbanization; grassland	*Andrena wilkella; Chelostoma rapunculi, C.campanularum Eucera longicornis; Panurgus calcaratus*
8	Zaninotto, V; Fauviau, A; Dajoz, I	Diversity of greenspace design and management impacts pollinator communities in a densely urbanized landscape: the city of Paris, France	Urban Ecosyst.	2023	26	2	503-515	Land alteration; Urbanization	

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
9	Hellstrom, S; Strobl, V; Straub, L; Osterman, WHA; Paxton, RJ; Osterman, J	Beyond generalists: The Brassicaceae pollen specialist Osmia brevicornis as a prospective model organism when exploring pesticide risk to bees	Environ. Sustain. Indic.	2023	18		100239	Pesticides	*Osmia brevicornis*
10	Felderhoff, J; Gathof, AK; Buchholz, S; Egerer, M	Vegetation complexity and nesting resource availability predict bee diversity and functional traits in community gardens	Ecol. Appl.	2023	33	2		Land alteration; Urbanization	List of found bees showed not what species they considered as oligolectic
11	Ganuza, C; Ayasse, M; Boff, S	Chemical and Mechanical Signals Trigger Courtship in the Wild Large-Headed Resin Bee Heriades truncorum	J. Insect Behav.	2022	35	6/5	160-170		
12	Pelletier, D; Forrest, JRK	Pollen specialisation is associated with later phenology in Osmia bees (Hymenoptera: Megachilidae)	Ecol. Entomol.	2023	48	2	164-173		
13	Kuppler, J; Neumüller, U; Mayr, AV; Hopfenmüller, S; Weiss, K; Prosi, R; Schanowski, A; Schwenninger, HR; Ayasse, M; Burger, H	Favourite plants of wild bees	Agric. Ecosyst. Environ.	2023	342		108266	Land alteration; Flower strips	
14	Fernandes, K; Prendergast, K; Bateman, PW; Saunders, BJ; Gibberd, M; Bunce, M; Nevill, P	DNA metabarcoding identifies urban foraging patterns of oligolectic and polylectic cavity-nesting bees	Oecologia	2022	200	4/3	323-337	Land alteration; Urbanization	Oligolectic species: *Megachile canifrons, M. fabricator; Rozenapis ignita*
15	Ferrari, A; Polidori, C	How city traits affect taxonomic and functional diversity of urban wild bee communities: insights from a worldwide analysis	Apidologie	2022	53	4	46	Land alteration; Urbanization	5 narrowly oligolectic. spp. wrongly considered polylectic.
16	Stoner, KA; Nurse, A; Koethe, RW; Hatala, MS; Lehmann, DM	Where Does Honey Bee (Apis mellifera L.) Pollen Come from? A Study of Pollen Collected from Colonies at Ornamental Plant Nurseries	Insects	2022	13	8	744		
17	Kettermann, M; Poniatowski, D; Fartmann, T	Active management fosters species richness of wild bees in limestone quarries	Ecol. Eng.	2022	182		106733	Land alteration; Biodiversity	
18	Dharampal, PS; Danforth, BN; Steffan, SA	Exosymbiotic microbes within fermented pollen provisions are as important for the development of solitary bees as the pollen itself	Ecol. Evol.	2022	12	4	e8788		
19	Su, TJ; He, B; Zhao, F; Jiang, K; Lin, GH; Huang, ZH	Population genomics and phylogeography of Colletes gigas, a wild bee specialized on winter flowering plants	Ecol. Evol.	2022	12	4	e8863	Genetics	*Colletes gigas*

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
20	Müller, A; Westrich, P	Morphological specialisation for primary nectar robbing in a pollen specialist mining bee (Hymenoptera, Andrenidae)	J. Hymenopt. Res.	2022	95		215		
21	Penado, A; Rebelo, H; Goulson, D; Wood, TJ; Porto, M; Rotheray, EL; Beja, P	From pastures to forests: Changes in Mediterranean wild bee communities after rural land abandonment	Insect. Conserv. Divers.	2022	15	3	325	Land alteration; Biodiversity	
22	Török, E; Gallé, R; Batáry, P	Fragmentation of forest-steppe predicts functional community composition of wild bee and wasp communities	Glob. Ecol. Conserv.	2022	33		e01988	Land alteration; Fragmentation	
23	DeNittis, AM; Meyer, SE	Reproductive Success of an Endangered Plant after Invasive Bees Supplant Native Pollinator Services	Diversity-Basel	2022	14	1	1		
24	Araújo, PDS; de Araujo, FF; Mota, T; Schlindwein, C	The advantages of being cre-puscular for bees: major pollen gain under low competition during the brief twilight period	Biol. J. Linnean Soc.	2022	135	2	251-264		
25	Martins, HOJ; Amorim, GP; Sabino, WO; Ferreira, VS	Nesting Biology of the Solitary Ground-Nesting Bee Diadasina riparia (Apidae: Emphorini)	Sociobiology	2021	68	4	e7123		
26	Casanelles-Abella, J; Muller, S; Keller, A; Aleixo, C; Orti, MA; Chiron, F; Deguines, N; Hallikma, T; Laanisto, L; Pinho, P; Samson, R; Tryjanowski, P; Van Mensel, A; Pellissier, L; Moretti, M	How wild bees find a way in European cities: Pollen metabarcoding unravels multiple feeding strategies and their effects on distribution patterns in four wild bee species	J. Appl. Ecol.	2022	59	2	457-470	Land alteration; Urbanization	
27	Lane, IG; Portman, ZM; Herron-Sweet, CH; Pardee, GL; Cariveau, DP	Differences in bee community composition between restored and remnant prairies are more strongly linked to forb community differences than landscape differences	J. Appl. Ecol.	2022	59	1	129-140	Land alteration; Biodiversity	Cannot open S1
28	Dorchin, A; Shafir, A; Neumann, FH; Langgut, D; Vereecken, NJ; Mayrose, I	Bee flowers drive macroevolutionary diversification in long-horned bees	Proc. R. Soc. B-Biol. Sci.	2021	288	1959	533		
29	Sculfort, O; Gérard, M; Gekière, A; Nonclercq, D; Gerbaux, P; Duez, P; Vanderplanck, M	Specialized Metabolites in Floral Resources: Effects and Detection in Buff-Tailed Bumblebees	Front. Ecol. Evol.	2021	9		669352		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
30	Hostinská, L; Kunes, P; Hadrava, J; Bosch, J; Scaramozzino, PL; Bogusch, P	Comparative biology of four Rhodanthidium species (Hymenoptera, Megachilidae) that nest in snail shells	J. Hymenopt. Res.	2021	85		11-28		
31	von Konigslow, V; Mupepele, AC; Klein, AM	Overlooked jewels: Existing habitat patches complement sown flower strips to conserve pollinators	Biol. Conserv.	2021	261		109263	Land alteration; Flower strips	
32	Torretta, JP; Basilio, AM; Marrero, HJ	Nesting biology of two sympatric species of Megachile (Chrysosarus) (Megachilidae) in Argentina	J. Apic. Res.	2021					
33	Minckley, RL; Radke, WR	Extreme species density of bees (Apiformes, Hymenoptera) in the warm deserts of North America	J. Hymenopt. Res.	2021	82		317-345	Climate Change	
34	Twerd, L; Banaszak-Cibicka, W; Sobieraj-Betlinska, A; Waldon-Rudzionek, B; Hoffmann, R	Contributions of phenological groups of wild bees as an indicator of food availability in urban wastelands	Ecol. Indic.	2021	126		107616	Land alteration; Urbanization	6 narrowly oligolectic species wrongly considered polylectic.
35	Simon, SJ; Keefover-Ring, K; Park, YL; Wimp, G; Grady, J; DiFazio, SP	Characterization of Salix nigra floral insect community and activity of three native Andrena bees	Ecol. Evol.	2021	11	9	4688-4700		
36	Thapa-Magar, KB; Davis, TS; Kondratieff, B	Livestock grazing is associated with seasonal reduction in pollinator biodiversity and functional dispersion but cheatgrass invasion is not: Variation in bee assemblages in a multi-use shortgrass prairie	PLoS One	2020	15	12	e0237484	Land alteration; Biodiversity	Apidae - *Diadasia enavata (1) and 7* Long horn bees, Megachilidae - *Lithurgopsis apicalis (1)*
37	Bhatta, VR; Kumar, AN	Native bee diversity and abundance in an urban green space in Bengaluru, India	J.Environ.Biol.	2020	41	6	1536-1541	Land alteration; Urbanization	*2 Colletidae spp., 1 Megachillidae, 1 Andrenidae, 1 Apidae*
38	Bossert, S; Copeland, RS; Sless, TJL; Branstetter, MG; Gillung, JP; Brady, SG; Danforth, BN; Policarová, J; Straka, J	Phylogenomic and Morphological Reevaluation of the Bee Tribes Biastini, Neolarrini, and Townsendiellini (Hymenoptera: Apidae) With Description of Three New Species of Schwarzia	Insect Syst. Divers.	2020	4	6	1		
39	McAulay, MK; Killingsworth, SZ; Forrest, JRK	Understanding pollen specialization in mason bees: a case study of six species	Oecologia	2021	195	3	559-574		
40	Bogusch, P; Bláhová, E; Horák, J	Pollen specialists are more endangered than non-specialised bees even though they collect pollen on flowers of non-endangered plants	Arthropod-Plant Interact.	2020	14	6	759-763	Oligolectic bees	

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
41	Rothman, JA; Cox-Foster, DL; Andrikopoulos, C; McFrederick, QS	Diet Breadth Affects Bacterial Identity but Not Diversity in the Pollen Provisions of Closely Related Polylectic and Oligolectic Bees	Insects	2020	11	9	645		
42	Hennessy, G; Goulson, D; Ratnieks, FLW	Population assessment and foraging ecology of nest aggregations of the rare solitary bee,Eucera longicornisat Gatwick Airport, and implications for their management	J. Insect Conserv.	2020	24	6	947-960	Land alteration; Airport	*Eucera longicornis*
43	Dharampal, PS; Hetherington, MC; Steffan, SA	Microbes make the meal: oligolectic bees require microbes within their host pollen to thrive	Ecol. Entomol.	2020	45	6	1418-1427		
44	Dutra, AL; Schlindwein, C; Oliveira, R	Females of a solitary bee reject males to collect food for offspring	Behav. Ecol.	2020	31	4	884-891		
45	Polidori, C; Jorge, A; Ornosa, C	Antennal morphology and sensillar equipment vary with pollen diet specialization in Andrena bees	Arthropod Struct. Dev.	2020	57		100950		
46	Scott-Brown, A; Koch, H	New directions in pollinator research: diversity, conflict and response to global change	Emerg. Top. Life Sci.	2020	4	1	1-6	Plant-pollinator interactions	
47	Hofmann, MM; Fleischmann, A; Renner, SS	Foraging distances in six species of solitary bees with body lengths of 6 to 15 mm, inferred from individual tagging, suggest 150 m-rule-of-thumb for flower strip distances	J. Hymenopt. Res.	2020	77		105-117	Land alteration; Forage distances	Megachilidae: genera: *Chelostoma, Heriades, Hoplitis*
48	Kelly, TT; Elle, E	Investigating bee dietary preferences along a gradient of floral resources: how does resource use align with resource availability?	Insect Sci.	2021	28	2	555-565		
49	Ellner, SP; Ng, WH; Myers, CR	Individual Specialization and Multihost Epidemics: Disease Spread in Plant-Pollinator Networks	Am. Nat.	2020	195	5	118-131		
50	Bogusch, P; Hlavácková, L; Petr, L; Bosch, J	Nest structure, pollen utilization and parasites associated with two west-Mediterranean bees Hymenoptera, Apiformes, Megachilidae) nesting in empty snail shells	J. Hymenopt. Res.	2020	76		113-125		
51	Hofmann, MM; Renner, SS	Bee species decrease and increase between the 1990s and 2018 in large urban protected sites	J. Insect Conserv.	2020	24	4	637-642	Land alteration; Urbanization	
52	Davis, HK; Miller, DL; Thetford, M	Habitat suitability of an at-risk, monolectic, ground-nesting bee Hesperapis oraria and its floral host Balduina angustifolia at two spatial scales along the Northern Gulf of Mexico	J. Insect Conserv.	2020	24	3	561-573		
53	Maubecin, CC; Boero, L; Sérsic, AN	Specialisation in pollen collection, pollination interactions and phenotypic variation of the oil-collecting bee Chalepogenus cocuccii	Apidologie	2020	51	5	710-723		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
54	Konzmann, S; Kluth, M; Karadana, D; Lunau, K	Pollinator effectiveness of a specialist bee exploiting a generalist plant-tracking pollen transfer by Heriades truncorum with quantum dots	Apidologie	2020	51	2	201-211		
55	Heneberg, P; Bogusch, P	Identification of a previously overlooked anthropogenic habitat that attracts diverse assemblages of threatened bees and wasps	Ecol. Eng.	2020	147		105759	Land alteration; Urbanization	
56	De Araujo, FF; Oliveira, R; Mota, T; Stehmann, JR; Schlindwein, C	Solitary bee pollinators adjust pollen foraging to the unpredictable flower opening of a species of Petunia (Solanaceae)	Biol. J. Linnean Soc.	2020	129	2	273-287		
57	Erickson, E; Adam, S; Russo, L; Wojcik, V; Patch, HM; Grozinger, CM	More Than Meets the Eye? The Role of Annual Ornamental Flowers in Supporting Pollinators	Environ. Entomol.	2020	49	1	178-188	Land alteration; Urbanization	*Lasioglossum trigeminum* *4 Melissodes spp.* *Peponapis pruinosa*
58	dos Santos, AA; Parizotto, D; Schlindwein, C; Martins, CF	Nesting biology and flower preferences of Megachile (Sayapis) zaptlana	J. Apic. Res.	2020	59	4	609-625		
59	Siriani-Oliveira, S; Cerceau, I; Schlindwein, C	Specialised protagonists in a plant-pollinator interaction: the pollination of Blumenbachia insignis (Loasaceae)	Plant Biol.	2020	22	2	167-176		
60	Page, ML; Ison, JL; Bewley, AL; Holsinger, KM; Kaul, AD; Koch, KE; Kolis, KM; Wagenius, S	Pollinator effectiveness in a composite: a specialist bee pollinates more florets but does not move pollen farther than other visitors	Am. J. Bot.	2019	106	11	1487-1498		
61	Ramos, KD; Siriani-Oliveira, S; Schlindwein, C	A new oligolectic bee species of the genus Rhophitulus Ducke (Hymenoptera, Andrenidae) from South Brazil	Rev. Bras. Entomol.	2019	63	4	349-355		
62	Cerceau, I; Siriani-Oliveira, S; Dutra, AL; Oliveira, R; Schlindwein, C	The cost of fidelity: foraging oligolectic bees gather huge amounts of pollen in a highly specialized cactus-pollinator association	Biol. J. Linnean Soc.	2019	128	1	30-43	Plant-pollinator phenological mismatch	*Arhysosage cactorum*
63	Portman, ZM; Orr, MC; Griswold, T	A review and updated classification of pollen gathering behavior in bees (Hymenoptera, Apoidea)	J. Hymenopt. Res.	2019	71		171-208		
64	Smith, C; Weinman, L; Gibbs, J; Winfree, R	Specialist foragers in forest bee communities are small, social or emerge early	J. Anim. Ecol.	2019	88	8	1158-1167	Oligolectic bee; forest	*Andrena ziziae A. cornelli, A. distans, A. erigeniae, A. erythronii, A. integra, Osmia georgica*

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
65	López-Uribe, MM; Jha, S; Soro, A	A trait-based approach to predict population genetic structure in bees	Mol. Ecol.	2019	28	8	1919-1929	Genetics	
66	Hofmann, MM; Zohner, CM; Renner, SS	Narrow habitat breadth and late-summer emergence increases extinction vulnerability in Central European bees	Proc. R. Soc. B-Biol. Sci.	2019	286	1898	316	Land alteration; Climate Change	
67	Riojas-López, ME; Díaz-Herrera, IA; Fierros-López, HE; Mellink, E	The effect of adjacent habitat on native bee assemblages in a perennial low-input agroecosystem in a semiarid anthropized landscape	Agric. Ecosyst. Environ.	2019	272		199-205		
68	Love, BG; Cane, JH	Mortality and Flowering of Great Basin Perennial Forbs After Experimental Burning: Implications for Wild Bees	Rangel. Ecol. Manag.	2019	72	2	310-317		
69	Main, AR; Webb, EB; Goyne, KW; Mengel, D	Field-level characteristics influence wild bee functional guilds on public lands managed for conservation	Glob. Ecol. Conserv.	2019	17		e00598	Land alteration	
70	Polidori, C; Federici, M	Differential distribution of resources for females on a dioecious plant affects the small-scale distribution of male of an oligolectic bee	Anim. Biodivers. Conserv.	2019	42	2	267-277		
71	Westerfelt, P; Weslien, J; Widenfalk, O	Population patterns in relation to food and nesting resource for two cavity-nesting bee species in young boreal forest stands	For. Ecol. Manage.	2018	430		629-638		
72	Buhk, C; Oppermann, R; Schanowski, A; Bleil, R; Lüdemann, J; Maus, C	Flower strip networks offer promising long term effects on pollinator species richness in intensively cultivated agricultural areas	BMC Ecol.	2018	18		55	Land alteration; Flower strips	Many species but list lack info of which species considered oligolectic
73	Cross, I; Wood, TJ	New data on the Iberian endemic bee genus Flavipanurgus Warncke (Hymenoptera: Apoidea: Andrenidae): Ecological and genomic data reveal a hidden species	Zootaxa	2018	4521	4	563-572		
74	Cane, JH	Co-dependency between a specialist Andrena bee and its death camas host, Toxicoscordion paniculatum	Arthropod-Plant Interact.	2018	12	5	657-662		
75	Rasran, L; Diener, A; Pachinger, B; Bernhardt, KG	Diversity of Flower Visiting Insects in Dry Grasslands and Vineyards Close to the City of Vienna with Special Focus on Wild Bees	Sociobiology	2018	65	4	603-611	Land alteration; Flower strips	
76	Amy, C; Noël, G; Hatt, S; Uyttenbroeck, R; Van de Meutter, F; Genoud, D; Francis, F	Flower Strips in Wheat Intercropping System: Effect on Pollinator Abundance and Diversity in Belgium	Insects	2018	9	3	114	Land alteration; Flower strips	

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
77	de Melo, BT; Mota, T; Schlindwein, C; Antonini, Y; Oliveira, R	Floral colour change in Byrsonima variabilis (Malpighiaceae) as a visual cue for pollen but not oil foraging by oil-collecting bees	Sci. Nat.	2018	105	8/7	46		
78	Dharampal, PS; Carlson, CM; Diaz-Garcia, L; Steffan, SA	In Vitro Rearing of Solitary Bees: A Tool for Assessing Larval Risk Factors	J. Vis. Exp.	2018		137	e57876	Pesticides	*Osmia ribifloris*
79	Hofmann, MM; Fleischmann, A; Renner, SS	Changes in the bee fauna of a German botanical garden between 1997 and 2017, attributable to climate warming, not other parameters	Oecologia	2018	187	3	701-706	Climate Change	
80	Hofmann, MM; Renner, SS	Bee species recorded between 1992 and 2017 from green roofs in Asia, Europe, and North America, with key characteristics and open research questions	Apidologie	2018	49	3	307-313	Land alteration; Urbanization, green roofs	
81	Kratschmer, S; Kriechbaum, M; Pachinger, B	Buzzing on top: Linking wild bee diversity, abundance and traits with green roof qualities	Urban Ecosyst.	2018	21	3	429-446	Land alteration; Urbanization, green roofs	Made conclusion from too few data
82	Sheffield, CS; Heron, J	A new western Canadian record of Epeoloides pilosulus (Cresson), with discussion of ecological associations, distribution and conservation status in Canada	Biodiver. Data J.	2018	6		e22837		
83	da Rocha, LC; Ferreira-Caliman, MJ; Garófalo, CA; Augusto, SC	A specialist in an urban area: are cities suitable to harbour populations of the oligolectic bee Centris (Melacentris) collaris (Apidae : Centridini)?	Ann. Zool. Fenn.	2018	55	3/1	135-149	Land alteration; Urbanization	*Centris collaris*
84	El-Sayed, AM; Sporle, A; Colhoun, K; Furlong, J; White, R; Suckling, DM	Scents in orchards: floral volatiles of four stone fruit crops and their attractiveness to pollinators	Chemoecology	2018	28	2	39-49		
85	Portman, ZM; Tepedino, VJ; Tripodi, AD; Szalanski, AL; Durham, SL	Local extinction of a rare plant pollinator in Southern Utah (USA) associated with invasion by Africanized honey bees	Biol. Invasions	2018	20	3	593-606	Competition; Invasive species	
86	Parker, AJ; Williams, NM; Thomson, JD	Geographic patterns and pollination ecotypes in Claytonia virginica	Evolution	2018	72	1	202-210		
87	Russell, AL; Mauerman, KB; Golden, RE; Papaj, DR	Linking components of complex signals to morphological part: the role of anther and corolla in the complex floral display	Anim. Behav.	2018	135		223-236		
88	Schenk, M; Krauss, J; Holzschuh, A	Desynchronizations in bee-plant interactions cause severe fitness losses in solitary bees	J. Anim. Ecol.	2018	87	1	139-149	Plant-pollinator phenological mismatch	*Osmia brevicornis*
89	Moron, D; Skórka, P; Lenda, M; Celary, W; Tryjanowski, P	Railway lines affect spatial turnover of pollinator communities in an agricultural landscape	Divers. Distrib.	2017	23	9	1090-1097	Land alteration; Railway	

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
90	Cane, JH	Specialist bees collect Asteraceae pollen by distinctive abdominal drumming (Osmia) or tapping (Melissodes, Svastra)	Arthropod-Plant Interact.	2017	11	3	257-261		
91	Ogilvie, JE; Forrest, JRK	Interactions between bee foraging and floral resource phenology shape bee populations and communities	Curr. Opin. Insect Sci.	2017	21		75-82	Plant-pollinator interaction	
92	Vanderplanck, M; Vereecken, NJ; Grumiau, L; Esposito, F; Lognay, G; Wattiez, R; Michez, D	The importance of pollen chemistry in evolutionary host shifts of bees	Sci Rep	2017	7				
93	Forrest, JRK; Chisholm, SPM	Direct benefits and indirect costs of warm temperatures for high-elevation populations of a solitary bee	Ecology	2017	98	2	359-369	Climate Change	*Osmia iridis*
94	Brandt, K; Dötterl, S; Francke, W; Ayasse, M; Milet-Pinheiro, P	Flower Visitors of Campanula: Are Oligoleges More Sensitive to Host-Specific Floral Scents Than Polyleges?	J. Chem. Ecol.	2017	43	1	4-12		
95	Cane, JH; Love, B	Floral Guilds of Bees in Sagebrush Steppe: Comparing Bee Usage of Wildflowers Available for Postfire Restoration	Nat. Areas J.	2016	36	4	377-391		
96	Lerman, SB; Milam, J	Bee Fauna and Floral Abundance Within Lawn-Dominated Suburban Yards in Springfield, MA	Ann. Entomol. Soc. Am.	2016	109	5	713-723	Land alteration; Urbanization; Lawns	No table of which oligolectic species they found, referred to oligolectic as a "specialists on a single plant"
97	Ritchie, AD; Ruppel, R; Jha, S	Generalist Behavior Describes Pollen Foraging for Perceived Oligolectic and Polylectic Bees	Environ. Entomol.	2016	45	4	909-919		
98	Meurgey, F	Bee species and their associated flowers in the French West Indies (Guadeloupe, Les Saintes, La Desirade, Marie Galante, St Barthelemy and Martinique) (Hymenoptera: Anthophila: Apoidea)	Ann. Soc. Entomol. Fr.	2016	52	4	209-232	Competition & Invasive species	
99	López-Uribe, MM; Cane, JH; Minckley, RL; Danforth, BN	Crop domestication facilitated rapid geographical expansion of a specialist pollinator, the squash bee Peponapis pruinosa	Proc. R. Soc. B-Biol. Sci.	2016	283	1833	443		
100	Fowler, J	Specialist Bees of the Northeast: Host Plants and Habitat Conservation	Northeast. Nat	2016	23	2	305-320	Plant-pollinator interaction	
101	Leite, AV; Nadia, T; Machado, IC	Pollination of Aosa rupestris (Hook.) Weigend (Loasaceae): are stamen movements induced by pollinators?	Braz. J. Bot.	2016	39	2	559-567		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
102	Spear, DM; Silverman, S; Forrest, JRK	Asteraceae Pollen Provisions Protect Osmia Mason Bees (Hymenoptera: Megachilidae) from Brood Parasitism	Am. Nat.	2016	187	6	797-803		
103	Milet-Pinheiro, P; Herz, K; Dötterl, S; Ayasse, M	Host choice in a bivoltine bee: how sensory constraints shape innate foraging behaviors	BMC Ecol.	2016	16		20		
104	Wappler, T; Labandeira, CC; Engel, MS; Zetter, R; Grímsson, F	Specialized and Generalized Pollen-Collection Strategies in an Ancient Bee Lineage	Curr. Biol.	2015	25	23	3092-3098		
105	Goldstein, PZ; Scott, VL	Taxonomic and behavioral components of faunal comparisons over time: The bees (Hymenoptera: Antophila) of Boulder County, Colorado; Past and Present	Proc. Entomol. Soc. Wash.	2015	117	3	290-346		
106	Milet-Pinheiro, P; Ayasse, M; Dötterl, S	Visual and Olfactory Floral Cues of Campanula (Campanulaceae) and Their Significance for Host Recognition by an Oligolectic Bee Pollinator	PLoS One	2015	10	6	e0128577		
107	Schiestl, FP	Ecology and evolution of floral volatile-mediated information transfer in plants	New Phytol.	2015	206	2	571-577		
108	Müller, A	Palaearctic Chelostoma bees of the subgenus Gyrodromella (Megachilidae, Osmiini): biology, taxonomy and key to species	Zootaxa	2015	3936	3	408-420		
109	Dellicour, S; Michez, D; Rasplus, JY; Mardulyn, P	Impact of past climatic changes and resource availability on the population demography of three food-specialist bees	Mol. Ecol.	2015	24	5	1074-1090	Climate Change	3 *Melitta* spp.
110	Sydenham, MAK; Moe, SR; Totland, O; Eldegard, K	Does multi-level environmental filtering determine the functional and phylogenetic composition of wild bee species assemblages?	Ecography	2015	38	2	140-153		
111	Gonçalves, RB; Sydney, NV; Oliveira, PS; Artmann, NO	Bee and wasp responses to a fragmented landscape in southern Brazil	J. Insect Conserv.	2014	18	6	1193-1201	Land alteration; Fragmentation	List of found species did not show which species considered oligolectic
112	Straka, J; Cerná, K; Macháčková, L; Zemenová, M; Keil, P	Life span in the wild: the role of activity and climate in natural populations of bees	Funct. Ecol.	2014	28	5	1235-1244	Climate Change	*Andrena vaga*
113	MacIvor, JS; Cabral, JM; Packer, L	Pollen specialization by solitary bees in an urban landscape	Urban Ecosyst.	2014	17	1	139-147		
114	Silva, DP; Gonzalez, VH; Melo, GAR; Lucia, M; Alvarez, LJ; De Marco, P	Seeking the flowers for the bees: Integrating biotic interactions into niche models to assess the distribution of the exotic bee species Lithurgus huberi in South America	Ecol. Model.	2014	273		200-209		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
115	Vanderplanck, M; Moerman, R; Rasmont, P; Lognay, G; Wathelet, B; Wattiez, R; Michez, D	How Does Pollen Chemistry Impact Development and Feeding Behaviour of Polylectic Bees?	PLoS One	2014	9	1	e86209		
116	Dellicour, S; Mardulyn, P; Hardy, OJ; Hardy, C; Roberts, SPM; Vereecken, NJ	Inferring the mode of colonization of the rapid range expansion of a solitary bee from multilocus DNA sequence variation	J. Evol. Biol.	2014	27	1	116-132		
117	Milet-Pinheiro, P; Ayasse, M; Dobson, HEM; Schlindwein, C; Francke, W; Dötterl, S	The Chemical Basis of Host-Plant Recognition in a Specialized Bee Pollinator	J. Chem. Ecol.	2013	39	12/11	1347-1360		
118	Gosselin, M; Michez, D; Vanderplanck, M; Roelants, D; Glauser, G; Rasmont, P	Does Aconitum septentrionale chemically protect floral rewards to the advantage of specialist bumblebees?	Ecol. Entomol.	2013	38	4	400-407		
119	Martins, AC; Gonçalves, RB; Melo, GAR	Changes in wild bee fauna of a grassland in Brazil reveal negative effects associated with growing urbanization during the last 40 years	Zoologia	2013	30	2	157-176	Land alteration; Urbanization; grassland	
120	Danforth, BN; Cardinal, S; Praz, C; Almeida, EAB; Michez, D	The Impact of Molecular Data on Our Understanding of Bee Phylogeny and Evolution	Annu. Rev. Entomol.	2013	58		57		
121	Rozen, JG; Hall, HG	Nesting biology and immatures of the oligolectic bee Trachusa larreae (Apoidea: Megachilidae: Anthidiini)	Am. Mus. Novit.	2012		3765	1-24		
122	Oliveira, R; Carvalho, AT; Schlindwein, C	Territorial or wandering: how males of Protodiscelis palpalis (Colletidae, Paracolletinae) behave in searching for mates	Apidologie	2012	43	6	674-684		
123	Hagbery, J; Nieh, JC	Individual lifetime pollen and nectar foraging preferences in bumble bees	Naturwissenschaften	2012	99	10	821-832		
124	Bried, JT; Dillon, AM	Bee diversity in scrub oak patches 2 years after mow and herbicide treatment	Insect. Conserv. Divers.	2012	5	3	237-243	Land alteration; Biodiversity, scrub oak	
125	Milet-Pinheiro, P; Ayasse, M; Schlindwein, C; Dobson, HEM; Dötterl, S	Host location by visual and olfactory floral cues in an oligolectic bee: innate and learned behavior	Behav. Ecol.	2012	23	3	531-538		
126	Gonçalves, L; da Silva, CI; Buschini, MLT	Collection of Pollen Grains by Centris (Hemisiella) tarsata Smith (Apidae: Centridini): Is C. tarsata an Oligolectic or Polylectic Species?	Zool. Stud.	2012	51	2	195-203		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
127	Filella, I; Bosch, J; Llusià, J; Peñuelas, A; Peñuelas, J	Chemical cues involved in the attraction of the oligolectic bee Hoplitis adunca to its host plant Echium vulgare	Biochem. Syst. Ecol.	2011	39	6/4	498-508		
128	Pick, RA; Schlindwein, C	Pollen partitioning of three species of Convolvulaceae among oligolectic bees in the Caatinga of Brazil	Plant Syst. Evol.	2011	293	4/1	147-159	Competition	
129	Carvalho, AT; Schlindwein, C	Obligate association of an oligolectic bee and a seasonal aquatic herb in semi-arid north-eastern Brazil	Biol. J. Linnean Soc.	2011	102	2	355-368		
130	Burger, H; Dötterl, S; Ayasse, M	Host-plant finding and recognition by visual and olfactory floral cues in an oligolectic bee	Funct. Ecol.	2010	24	6	1234-1240		
131	Artz, DR; Villagra, CA; Raguso, RA	Spatiotemperal variation in the reproductive ecology of two parapatric subspecies of Oenothera cespitosa (Onagraceae)	Am. J. Bot.	2010	97	9	1498-1510		
132	Grundel, R; Jean, RP; Frohnapple, KJ; Glowacki, GA; Scott, PE; Pavlovic, NB	Floral and nesting resources, habitat structure, and fire influence bee distribution across an open-forest gradient	Ecol. Appl.	2010	20	6	1678-1692	Land alteration	No list of which bees they consider as oligolectic
133	Oliveira, R; Schlindwein, C	Experimental demonstration of alternative mating tactics of male Ptilothrix fructifera (Hymenoptera, Apidae)	Anim. Behav.	2010	80	2	241-247		
134	Dötterl, S; Vereecken, NJ	The chemical ecology and evolution of bee-flower interactions: a review and perspectives	Can. J. Zool.	2010	88	7	668-697		
135	Milet-Pinheiro, P; Schlindwein, C	Mutual reproductive dependence of distylic Cordia leucocephala (Cordiaceae) and oligolectic Ceblurgus longipalpis (Halictidae, Rophitinae) in the Caatinga	Ann. Bot.	2010	106	1	17-27		
136	Zurbuchen, A; Bachofen, C; Müller, A; Hein, S; Dorn, S	Are landscape structures insurmountable barriers for foraging bees? A mark-recapture study with two solitary pollen specialist species	Apidologie	2010	41	4	497-508	Land alteration; Forage distances	*Chelostoma florisomne*
137	Zurbuchen, A; Cheesman, S; Klaiber, J; Müller, A; Hein, S; Dorn, S	Long foraging distances impose high costs on offspring production in solitary bees	J. Anim. Ecol.	2010	79	3	674-681	Land alteration; Forage distances	*Hoplitis adunca, Chelostoma rapunculi*
138	Silveira, FA	A synopsis of Actenosigynes Moure, Graf & Urban, 1999 (Hymenoptera: Colletidae)-new species, possible oligolecty and biogeographic comments	Zootaxa	2009		2292	15-24		
139	Slagle, MW; Hendrix, SD	Reproduction of Amorpha canescens (Fabaceae) and diversity of its bee community in a fragmented landscape	Oecologia	2009	161	4	813-823	Land alteration; Fragmentation	*Andrena quintilis*

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
140	Michez, D; Patiny, S; Danforth, B	Phylogeny of the bee family Melittidae (Hymenoptera: Anthophila) based on combined molecular and morphological data	Syst. Entomol.	2009	34	3	574-597		
141	Batley, M; Hogendoorn, K	Diversity and conservation status of native Australian bees	Apidologie	2009	40	3	347-354	Climate Change	
142	Franzén, M; Larsson, M; Nilsson, S	Small local population sizes and high habitat patch fidelity in a specialised solitary bee	J. Insect Conserv.	2009	13	1	89-95	Land alteration; Forage distances	*Andrena hattorfiana*
143	Moron, D; Szentgyörgyi, H; Wantuch, M; Celary, W; Westphal, C; Settele, J; Woyciechowski, M	DIVERSITY OF WILD BEES IN WET MEADOWS: IMPLICATIONS FOR CONSERVATION	Wetlands	2008	28	4	975-983	Land alteration; Biodiversity; wet meadows	
144	Michez, D; Patiny, S; Rasmont, P; Timmermann, K; Vereecken, NJ	Phylogeny and host-plant evolution in Melittidae s.l. (Hymenoptera: Apoidea)	Apidologie	2008	39	1	146-162		
145	Minckley, R	Faunal composition and species richness differences of bees (Hymenoptera: Apiformes) from two north American regions	Apidologie	2008	39	1	176-U134	Land alteration; Biodiversity	
146	Franzén, M; Larsson, M	Pollen harvesting and reproductive rates in specialized solitary bees	Ann. Zool. Fenn.	2007	44	6	405-414	Oligolectic bees	*Andrena humilis*
147	Zayed, A; Packer, L	The population genetics of a solitary oligolectic sweat bee, Lasioglossum (Sphecodogastra) oenotherae (Hymenoptera: Halictidae)	Heredity	2007	99	4	397-405	Genetics	*Lasioglossum oenotherae*
148	Larsson, M; Franzén, M	Critical resource levels of pollen for the declining bee Andrena hattorfiana (Hymenoptera, Andrenidae)	Biol. Conserv.	2007	134	3	405-414	Plant-pollinator interaction	*Andrena hattorfiana*
149	Pascarella, JB	Foraging patterns of the southeastern blueberry bee Habropoda laboriosa (Apidae, Hymenoptera):: Implications for understanding oligolecty	J. Apic. Res.	2007	46	1	19-27		
150	Hisamatsu, M; Yamane, S	Faunal makeup of wild bees and their flower utilization in a semi-urbanized area in central Japan	Entomol. Sci.	2006	9	2	137-145	Land alteration; Urbanization	
151	Cane, JH; Minckley, RL; Kervin, LJ; Roulston, TH; Williams, NM	Complex responses within a desert bee guild (Hymenoptera: Apiformes) to urban habitat fragmentation	Ecol. Appl.	2006	16	2	632-644	Land alteration; Fragmentation	
152	Sipes, SD; Tepedino, VJ	Pollen-host specificity and evolutionary patterns of host switching in a clade of specialist bees (Apoidea:Diadasia)	Biol. J. Linnean Soc.	2005	86	4	487-505		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
153	Moeller, DA; Geber, MA	Ecological context of the evolution of self-pollination in Clarkia xantiana:: Population size, plant communities, and reproductive assurance	Evolution	2005	59	4	786-799		
154	Packer, L; Zayed, A; Grixti, JC; Ruz, L; Owen, RE; Vivallo, F; Toro, H	Conservation genetics of potentially endangered mutualisms: Reduced levels of genetic variation in specialist versus generalist bees	Conserv. Biol.	2005	19	1	195-202	Genetics	
155	Moeller, DA	Pollinator community structure and sources of spatial variation in plant-pollinator interactions in Clarkia xantiana ssp xantiana	Oecologia	2005	142	1	28-37		
156	Antonini, Y; Martins, RP; Rosa, CA	Inverse density-dependent and density-independent parasitism in a solitary ground-nesting bee in Southeast Brazil	Trop. Zool.	2003	16	1	83-92		
157	Minckley, RL; Cane, JH; Kervin, L; Yanega, D	Biological impediments to measures of competition among introduced honey bees and desert bees (Hymenoptera: Apiformes)	J. Kans. Entomol. Soc.	2003	76	2	306-319	Competition & Invasive species	
158	Norden, BB; Krombein, KV; Deyrup, MA; Edirisinghe, JP	Biology and behavior of a seasonally aquatic bee, Perdita (Alloperdita) floridensis Timberlake (Hymenoptera: Andrenidae: Panurginae)	J. Kans. Entomol. Soc.	2003	76	2	236-249		
159	Sipes, SD; Wolf, PG	Phylogenetic relationships within Diadasia, a group of specialist bees	Mol. Phylogenet. Evol.	2001	19	1	144-156		
160	Minckley, RL; Cane, JH; Kervin, L	Origins and ecological consequences of pollen specialization among desert bees	Proc. R. Soc. B-Biol. Sci.	2000	267	1440	265-271		
161	Dobson, HEM; Bergström, G	The ecology and evolution of pollen odors	Plant Syst. Evol.	2000	222	4/1	63-87		
162	Schlindwein, C; Martins, CF	Competition between the oligolectic bee Ptilothrix plumata (Anthophoridae) and the flower closing beetle Pristimerus calcaratus (Curculionidae) for floral resources of Pavonia cancellata (Malvaceae)	Plant Syst. Evol.	2000	224	4/3	183-194		
163	Minckley, RL; Cane, JH; Kervin, L; Roulston, TH	Spatial predictability and resource specialization of bees (Hymenoptera: Apoidea) at a superabundant, widespread resource	Biol. J. Linnean Soc.	1999	67	1	119-147		
164	Hingston, AB	Affinities between southern Tasmanian plants in native bee visitor profiles	Aust. J. Zool.	1999	47	4	361-384		
165	Schlindwein, C; Wittmann, D	Micro-foraging routes of Bicolletes pampeana (Colletidae) and bee-induced pollen presentation in Cajophora arechavaletae (Loasaceae)	Bot. Acta	1997	110	2	177-183		

[No.]	Authors	Article Title	J. Abbrev.	Publ. Year	Vol.	Issue	Pg. or Art. No.	Study field	Notes
166	Pekkarinen, A	Oligolectic bee species in Northern Europe (Hymenoptera, Apoidea)	Entomol. Fenn.	1997	8	4	205-214	Oligolectic bees	
167	Wcislo, WT; Cane, JH	Floral resource utilization by solitary bees (Hymenoptera: Apoidea) and exploitation of their stored foods by natural enemies	Annu. Rev. Entomol.	1996	41		257-286		
168	Martins RP; Antonini, Y	The biology of Diadasina distincta (Holmberg, 1903) (Hymenoptera, Anthophoridae)	Proc. Entomol. Soc. Wash.	1994	96	3	553-560		
169	Minckley, RL; Wcislo, WT; Yanega, D; Buchmann, SL	Behavior and phenology of a specialist bee (Dieunomia) and sunflower (Helianthus) pollen availability	Ecology	1994	75	5	1406-1419		

Appendix 2: A revised list of oligolectic bees in Sweden 2023

Species regionally extinct in Sweden is printed in grey.

Species	Hostplant	Informal qualifier
Andrena afzeliella (albofasciata)	Fabaceae	Moderate
Andrena apicata	Salicaceae: *Salix*	Narrow
Andrena batava	Salicaceae: *Salix*	Narrow
Andrena clarkella	Salicaceae: *Salix*	Narrow
Andrena curvungula	Campanulaceae: *Campanula*	Narrow
Andrena denticulata	Asteraceae	Broad
Andrena fulvago	Asteraceae	Moderate
Andrena fuscipes	Ericaceae: *Calluna*	Broad
Andrena gelriae	Fabaceae	Moderate
Andrena hattorfiana	Dipsacaceae: *Knautia*	Narrow
Andrena humilis	Asteraceae	Moderate
Andrena intermedia	Fabaceae	Broad
Andrena labialis	Fabaceae	Moderate
Andrena lapponica	Ericaceae: *Vaccinium*	Narrow
Andrena lathyri	Fabaceae: *Lathyrus*	Narrow
Andrena marginata	Dipsacaceae: *Succisa*	Moderate
Andrena morawitzi	Salicaceae: *Salix*	Narrow
Andrena nanula	Apiaceae	Moderate
Andrena niveata	Brassicaceae	Moderate
Andrena nycthemera	Salicaceae: *Salix*	Narrow
Andrena praecox	Salicaceae: *Salix*	Narrow
Andrena ruficrus	Salicaceae: *Salix*	Narrow
Andrena russula (similis)	Fabaceae	Moderate
Andrena tarsata	Rosaceae: *Potentilla*	Narrow
Andrena vaga	Salicaceae: *Salix*	Narrow
Andrena wilkella	Fabaceae	Broad
Anthophora furcata	Lamiaceae	Moderate
Bombus consobrinus	Ranunculaceae: *Aconitum*	Narrow
Chelostoma campanularum	Campanulaceae: *Campanula*	Narrow
Chelostoma florisomne	Ranunculaceae: *Ranunculus*	Narrow
Chelostoma rapunculi	Campanulaceae: *Campanula*	Narrow
Colletes cunicularius	Salicaceae: *Salix*	Narrow
Colletes daviesanus	Asteraceae	Moderate
Colletes fodiens	Asteraceae	Moderate
Colletes marginatus	Fabaceae	Moderate
Colletes similis	Asteraceae	Moderate
Colletes succinctus	Ericaceae: *Calluna*	Narrow

Species	Hostplant	Informal qualifier
Dasypoda argentata	Dipsacaceae	Moderate
Dasypoda hirtipes	Asteraceae	Broad
Dasypoda suripes	Dipsacaceae – Väddväxter	Moderate
Dufourea dentiventris	Campanulaceae: *Campanula*	Narrow
Dufourea halictula	Campanulaceae: *Jasione*	Narrow
Dufourea inermis	Campanulaceae: *Campanula*	Narrow
Dufourea minuta	Asteraceae	Moderate
Eucera longicornis	Fabaceae	Broad
Heriades truncorum	Asteraceae	Broad
Hoplitis adunca	Boraginaceae: *Echium*	Narrow
Hoplitis anthocopoides	Boraginacae: *Echium vulgare*	Narrow
Hoplitis mitis	Campanulaceae: *Campanula*	Narrow
Hoplosmia spinulosa (Osmia spinulosa)	Asteraceae	Broad
Hylaeus signatus	Resedaceae: *Reseda*	Narrow
Macropis europaea	Primulaceae: *Lysimachia*	Narrow
Megachile circumcincta	Fabaceae	Broad
Megachile lagopoda	Asteraceae	Broad
Megachile lapponica	Onagraceae: *Epilobium*	Narrow
Megachile ligniseca	Asteraceae	Broad
Megachile nigriventris	Fabaceae	Moderate
Melitta haemorrhoidalis	Campanulaceae	Narrow
Melitta leporina	Fabaceae	Broad
Melitta melanura (wankowiczi)	Campanulaceae: *Campanula*	Narrow
Melitta tricincta	Scrophulariaceae: *Odontites*	Narrow
Osmia leaiana	Asteraceae	Moderate
Osmia maritima	Fabaceae	Moderate
Panurginus romani	Rosaceae: *Rubus idaeus*	Narrow
Panurgus banksianus	Asteraceae	Moderate
Panurgus calcaratus	Asteraceae	Moderate
Rophites quinquespinosus	Lamiaceae	Moderate
Trachusa byssina	Fabaceae	Broad

Sources: Pettersson et al (2004), Linkowski et al. (2004), Swedish Observation Species Center (Artportalen, Artfakta), Bees Wasps & Ants Recording Society (BWARS), Steven Falk's book; Field Guide to the Bees of Great Britain and Ireland (2015), the Norwegian Biodiversity Information Center (Artsdatabanken), Finnish Biodiversity Info Facility (Artdatacenter), Global Biodiversity Information Facility (GBIF), Denmark's national Artportal. The list is fact-checked and corrected by the Swedish entomologist Björn Cederberg (part of the Swedish expert committee of Hymenoptera). The data was collected between 2023-06-01 and 2023-10-31.

Appendix 3: Current prevailing red list status of oligolectic bees

LC = Least concern
NT = Near Threatened
VU = Vulnerable
EN = Endangered
CR = Critical endangered
RE = Regionally extinct
DD = Data deficiency
NE = Not assessed
NA = Not appliable

Current prevailing red list status of bees considered to be oligolectic in Sweden. It should be emphasized that some species could be considered polylectic in other countries. Species regionally extinct in Sweden are printed in grey.

Country Year of red list classification	Sweden 2020	Denmark 2019	Norway 2021	Finland 2019	IUCN 2012-14	IUCN 2012-2014
*Andrena afzeliella (albofasciata)**	NA	VU		RE	NT	RE in Finland
Andrena apicata	LC	LC	EN		DD	RE in Czechia
Andrena batava	VU				DD	
Andrena clarkella	LC	LC	LC	LC	DD	RE in Switzerland
Andrena curvungula	NT	NA			DD	RE in Netherlands
Andrena denticulata	LC	LC	LC	LC	DD	
Andrena fulvago	LC	VU	VU	VU	DD	
Andrena fuscipes	LC	LC	LC	LC	DD	RE in Czechia
Andrena gelriae	EN	RE		EN	DD	
Andrena hattorfiana	LC	LC	CR	LC	NT	
Andrena humilis	VU	NT	RE	CR	DD	RE in Norway
Andrena intermedia	LC	NA	LC	LC	LC	
Andrena labialis	NT	LC		RE	DD	
Andrena lapponica	LC	LC	LC	LC	LC	
Andrena lathyri	LC	VU	LC	EN	DD	
Andrena marginata	NT	EN	VU	CR	DD	RE in Netherlands
Andrena morawitzi	CR	EN*			DD	RE in Czechia
Andrena nanula	VU	NA	VU		DD	Possibly RE in Great Britain
Andrena niveata	EN	RE			DD	
Andrena nycthemera	VU	NA			DD	RE in Switzerland
Andrena praecox	LC	LC	LC	LC	LC	
Andrena ruficrus	LC	LC	LC	LC	LC	

Country Year of red list classification	Sweden 2020	Denmark 2019	Norway 2021	Finland 2019	IUCN 2012-14	IUCN 2012-2014
Andrena russula (similis)	EN		EN	EN	DD	
Andrena tarsata	LC	NT	LC	LC	DD	RE in Hungary
Andrena vaga	LC	LC	LC	LC	LC	
Andrena wilkella	LC	LC	LC	LC	DD	
Anthophora furcata	LC	LC	LC	LC	LC	
Bombus consobrinus	LC		LC	EN	LC	
Chelostoma campanularum	LC	LC	LC	LC	LC	
Chelostoma florisomne	LC	LC	LC	LC	LC	
Chelostoma rapunculi	LC	LC		LC	LC	
Colletes cunicularius	LC	LC	LC	LC	LC	
Colletes daviesanus	LC	LC	LC	LC	LC	
Colletes fodiens	NT	LC			VU	
Colletes marginatus	NT	NT	VU	EN	LC	
Colletes similis	LC	LC	LC	LC	LC	
Colletes succinctus	LC	LC	LC	LC	NT	
Dasypoda argentata	RE				NT	Extant in Sweden 2013
Dasypoda hirtipes	LC		VU	LC	LC	
Dasypoda suripes	RE	CR			EN	RE in Czechia; Denmark; Germany; Sweden
Dufourea dentiventris	LC	EN	NT	LC	NT	
Dufourea halictula	VU	EN			NT	
Dufourea inermis	EN	EN		EN	NT	
Dufourea minuta	CR	RE	RE	VU	NT	RE in Netherlands; Sweden
Eucera longicornis	LC	LC	LC	LC	LC	
Heriades truncorum	LC	NT	LC	LC	LC	
Hoplitis adunca	NA	NA			LC	
Hoplitis anthocopoides	NA	VU			LC	
Hoplitis mitis	NT				LC	

Country Year of red list classification	Sweden 2020	Denmark 2019	Norway 2021	Finland 2019	IUCN 2012-14	IUCN 2012-2014
Hoplosmia spinulosa	LC	VU	LC		LC	*(Osmia spinulosa)*
Hylaeus signatus	NT	DD			LC	
Macropis europaea	LC	LC	LC	LC	LC	
Megachile circumcincta	LC	LC	LC	LC	LC	
Megachile lagopoda	NT	LC	CR	NT	LC	
Megachile lapponica	LC	LC	NT	LC	DD	RE in Great Britain
Megachile ligniseca	LC		RE	LC	DD	RE in Norway
Megachile nigriventris	LC	NA	LC	LC	DD	
Melitta haemorrhoidalis	LC	LC	LC	LC	LC	
Melitta leporina	LC	LC	NT	NT	LC	
Melitta melanura (wankowiczi)	CR				EN	RE in Germany
Melitta tricincta	NT	VU			NT	
Osmia leaiana	LC	LC	LC	VU	LC	
Osmia maritima	EN	NT	EN		EN	RE in Poland
Panurginus romani	LC		LC	LC	DD	
Panurgus banksianus	VU	LC	VU		LC	Presence Uncertain in Norway; Romania
Panurgus calcaratus	LC	LC	LC		LC	
Rophites quinquespinosus	RE	RE			NT	RE in Netherlands; Sweden
Trachusa byssina	LC	NA		LC	LC	

Sources of oligolectic current prevailing red list status are the Biodiversity Information Centers of; Sweden (Artportalen); Norway (Artsdatabanken); Finland (Finnish Biodiversity Info Facility), Madsen`s “Den danske Rødliste 2019” and IUCN Red list:
https://www.artportalen.se/Occurrence/TaxonOccurrence/16/2002991 (Visited 2023-10-10)
https://artsdatabanken.no/lister/rodlisteforarter/2021 (Visited 2023-10-18)
https://ecos.au.dk/forskningraadgivning/temasider/redlistframe/soeg-en-art (Visited 2023-10-27)
https://punainenkirja.laji.fi/sv/results?type=species&year=2019&redListGroup= (Visited 2023-10-28)
https://www.iucnredlist.org/ (Visited 2023-11-05)

Appendix 4: Combination of search words

Oligolecty

Combination of search words	Date	No. hits
“bee*" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*")	2023-10-20	704
"bee*" AND ("oligol*" OR "pollen speciali*")	2023-10-20	492
"bee*" AND ("food speciali*" OR " diet speciali*" OR "plant speciali*") NOT ("oligol*" OR "pollen speciali*")	2023-10-20	212
“bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*")	2023-10-20	610
"bee" AND ("oligol*" OR "pollen speciali*")	2023-10-20	287
"bee" AND ("food speciali*" OR " diet speciali*" OR "plant speciali*") NOT ("oligol*" OR "pollen speciali*")	2023-10-20	21

Global Change – “the full search”

Combination of search words	Date	No. hits
"Bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Land use" OR "Urban*" OR "Fragment*" OR "Habitat loss" OR "Monoculture*")	2023-10-10	49
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Weed control" OR "Pesticide*" OR "Pest management*" OR "Pest control" OR "Insecticide *" OR "Herbicide*" OR "Fungicide*" OR "Fertilizer" OR "Biocide*" OR "Agrochemical*" OR "Pollution*" OR "Combustion*" OR "Heavy metal*")	2023-10-10	14
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pathogen*" OR "Parasite*" OR "Disease*" OR "Virus*" OR "Invasive species" OR "Non-native species" OR "Exotic species")	2023-10-10	18
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("competition")	2023-10-10	19
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Climate change" OR “Desiccation" OR "Dehydrat*" OR "Drought" OR "Wildfire*" OR "Heat tolerance" OR "Thermal tolerance" OR "Landslide*" OR "Extreme weather" OR "Heavy rain*" OR "Extreme rain*" OR "Global warming" OR "Flood*")	2023-10-10	20
“bee” AND (“oligol*” OR “pollen speciali*”OR “food speciali*” OR “diet speciali*”) AND (“Mismatch”)	2023-10-10	1
“bee” AND (“oligol*” OR “pollen speciali*” OR “food speciali*” OR “diet speciali*”) AND (“Nutri* defici*” OR “Malnutrition” OR “Floral resorce*” OR “poor flower “ OR “nectar quality*” OR “poor nutrition”)	2023-10-10	1
“bee” AND (“oligol*” OR “pollen speciali*”OR “food speciali*” OR “diet speciali*”) AND (“synergis*” OR “interact*” OR “multiple” OR “Additiv*” OR “combin*”)	2023-10-10	89
“bee” AND (“oligol*” OR “pollen speciali*”OR “food speciali*” OR “diet speciali*”) AND (“threat*” OR “risk” OR “decline” OR “stress*” OR “drive*” OR “harm*” OR “impact*” OR “impaired” OR “damage*”)	2023-10-10	74
Total number of hit results		268

Land alteration

Combination of search words	Date	No. hits
"Bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Land use")	2023-10-20	14
"Bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Urban*")	2023-10-20	28
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Fragment*")	2023-10-20	19
"Bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Habitat loss")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Monoculture*")	2023-10-20	1
"Bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Land use" OR "Urban*" OR "Fragment*" OR "Habitat loss" OR "Monoculture*")	2023-10-10	49

(Agro-) Chemicals & Pollution

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Weed control")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pesticide*")	2023-10-20	10
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pest management")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pest control")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Insecticide *")	2023-10-20	2
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Herbicide*")	2023-10-20	3
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Fungicide*")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Fertilizer")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Biocide*")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Agrochemical*")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pollution*")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Combustion*")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Heavy metal*")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Weed control" OR "Pesticide*" OR "Pest management*" OR "Pest control" OR "Insecticide *" OR "Herbicide*" OR "Fungicide*" OR "Fertilizer" OR "Biocide*" OR "Agrochemical*" OR "Pollution*" OR "Combustion*" OR "Heavy metal*")	2023-10-20	14

Invasive species & Pathogens

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pathogen*")	2023-10-20	4
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Parasite*")	2023-10-20	10
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Disease*")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Virus*")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Invasive species")	2023-10-20	2
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Non-native species")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Exotic species")	2023-10-20	4
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Pathogen*" OR "Parasite*" OR "Disease*" OR "Virus*" OR "Invasive species" OR "Non-native species" OR "Exotic species")	2023-10-20	18

Competition

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*") AND ("Competition")	2023-10-10	19
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Competition")	2023-10-10	19

Climate changes & Mismatch

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Climate change")	2023-10-20	15
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Desiccation")		1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Dehydrat*")		1
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Drought")		0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Wildfire*")		2
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Heat tolerance")		0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Thermal tolerance")		0
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Landslide")		0
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Extreme weather")		0
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Heavy rain*")		0
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Extreme rain*")		0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Global warming")		1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Flood*")		0
"bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Climate change" OR "Desiccation" OR "Dehydrat*" OR "Drought" OR "Wildfire*" OR "Heat tolerance" OR "Thermal tolerance" OR "Landslide*" OR "Extreme weather" OR "Heavy rain*" OR "Extreme rain*" OR "Global warming" OR "Flood*")		20

Mismatch

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Mismatch")	2023-10-10	2

Nutrient deficiency

Combination of search words	Date	No. hits
“bee" AND ("oligol*" OR "pollen speciali*" OR "food speciali*" OR "diet speciali*") AND ("Nutri* defici*" OR "Malnutrition" OR "Floral resorce*" OR "poor flower " OR "nectar qualit*" OR "poor nutrition")	2023-10-10	1

Synergism

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Synergis*")	2023-10-20	0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Interact*")		56
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Multiple")		0
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Additiv*")		1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("Combin*")		34
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("synergis*" OR "interact*" OR "multiple" OR "Additiv*" OR "combin*")	2023-10-10	89

Threat

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("threat")	2023-10-20	1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("risk")	2023-10-21	8
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("decline")	2023-10-20	21
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("drive*")	2023-10-21	19
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("harm*")		4
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("impact*")		34
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("impaired")		1
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("damage*")		2
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("threat" OR "risk" OR "decline" OR "stress*" OR "drive*" OR "harm*" OR "impact*" OR "impaired" OR "damage*")	2023-10-10	74

Impossible search combination

Combination of search words	Date	No. hits
"bee" AND ("oligol*" OR "pollen speciali*"OR "food speciali*" OR "diet speciali*") AND ("threat" OR "risk" OR "decline" OR "stress*" OR "drive*" OR "harm*" OR "impact*" OR "impaired" OR "damage*") OR ("Nutrition defici*" OR "Malnutrition" OR "Floral resorce*" OR "poor flower " OR "nectar qualit*" OR "poor nutrition") OR ("Climate change" OR "Mis match" OR "Desiccation" OR "Dehydrat*" OR "Drought" OR "Wildfire*" OR "Heat tolerance" OR "Thermal tolerance" OR "Landslide*" OR "Extreme weather" OR "Heavy rain*" OR "Extreme rain*" OR "Climate change*" OR "Global warming" OR "Flood*")	2021-10-10	**928,030**