

**Appendices to J Poll Ecol 35(12), Greenop et al.**

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| **Table S1.** Traits commonly used to predict pollination ecosystem services, their general availability across species and evidence for a link with pollination. It is worth highlighting that most of the traits have been investigated within the context of bees.In brackets we have categorised each trait using Moretti *et al.*, 2016 as a guide. *Morphological traits* are those relating to the structure of the organism that could impact on pollination, for example, hairiness determining how much pollen an individual carries (Stavert *et al.*, 2016). *Behavioural traits* are largely related to foraging characteristics, although following Moretti *et al.*, 2016 also include sociality. *Phenological traits* are those describing diurnal or seasonal changes in foraging and tend to be linked to temporal changes in abundance often linked to changes in resource availability (e.g., pollen and nectar). *Ecological traits* are those describing general ecological characteristics of a species, such as nesting requirements, and are more often viewed as response traits (Williams *et al.*, 2010). Finally, some of the traits are a product of both behaviour and morphology, for example single-visit pollen deposition, where the morphology of a species could dictate how much pollen a species transfers, carries, or deposits, but this is also affected by foraging behaviour determining the chance that pollen would be transferred. These traits have been labelled as *behavioural/morphological*. |
| **Trait** | **Metrics** | **Overview** |
| **Body size** (morphological) | **Body dimensions** (including intertegular distance, length or width of the whole body, thorax or abdomen) | ***Trait availability:*** Body size is a relatively widely available trait, particularly for bees. Values are often available in the literature (Bommarco *et al.*, 2010; Bartomeus *et al.*, 2013), online repositories/databases (Borges *et al.*, 2020; Speight *et al.*, 2020) and field guides (Falk & Lewington, 2016). **Evidence for link to pollination:** Body size has been shown to be linked with pollination in number of studies (Garibaldi *et al.*, 2015; Jauker *et al.*, 2016; Földesi *et al.*, 2020). Larger pollinators deposit more pollen on plant stigmas (Földesi *et al.*, 2020), and when matched with floral structure, body size predicts crop yields as it can determine access to nectar resources (Garibaldi *et al.*, 2015). Intraspecific variation may be important, with larger individuals of *Osmia rufa* increasing yields of oilseed rape compared to smaller individuals (Jauker *et al.*, 2016). However, some studies suggest body size does not consistently predict pollination efficiency and yield (Bartomeus *et al.*, 2018; Woodcock *et al.*, 2019).  |
| **Mass**: Weight, most often dry. | ***Trait availability:*** Mass is often overlooked in favour of other measures of body size. Direct measurements are uncommon. **Evidence for link to pollination:** Mass is correlated with intertegular distance (Cane, 1987), thus evidence regarding its importance in predicting pollination is likely to be similar to other measures of body size. Dry body mass can predict the pollen requirements of brood cells (Müller *et al.*, 2006). It may be expected that species with greater pollen requirements on an individual-by-individual basis may make greater functional contributions; however, further research is needed to ascertain this. |
| **Wing length**: Length of wings (usually this is measured as the length of the forewing in bees).  | ***Trait availability:*** Sometimes included in field guides (e.g., Falk & Lewington, 2016). It also may not be directly measured but inferred due to its correlation with body size (Harder, 1985). **Evidence for link to pollination:** Wing length may affect overall efficiency of a pollinator as it is correlated with both flight times (Harder, 1985) and the amount of pollen an individual can carry (Johnson & Carter, 2014; Vance & Roberts, 2014). However, there is limited evidence directly linking wing length to pollination efficacy in a species.  |
| **Tongue length:** Length in mm or categorical family based trait (e.g. short or long).  | ***Trait availability:*** Tongue length is readily available for bee species as a family-based categorical trait (Michener, 2007). Actual measurements of tongue length are rarer, but it can be estimated from body length (see Cariveau *et al.*, 2016). **Evidence for link to pollination:** Tongue length influences the availability of nectar resources to a species (Garibaldi *et al.*, 2015) and may determine pollinator effectiveness for specific crops where flower morphology limits access to nectar and pollen. For example, short-tongued species nectar robbing legumes by biting a hole at the base of flowers (Kendall & Smith, 1975). For this reason, tongue length may only be an important trait in some plants with its importance not consistently found in a number of crop systems (Bartomeus *et al.*, 2018; Woodcock *et al.*, 2019). |
| Hairiness (morphological) | A number of methods have been used:***Shannon entropy*** index based on images of the species face (Stavert *et al.*, 2016; Goulnik *et al.*, 2020); ***Density and length of hair*** on an individual (Roquer‐Beni *et al.*, 2020); ***Percentage of the body***, or particular body part, that is covered with hair (Phillips *et al.*, 2018; Woodcock *et al.*, 2019). | ***Trait availability:*** While the use of hairiness is increasing, at present it has mostly been derived for common European bee species (Stavert *et al.*, 2016; Phillips *et al.*, 2018; Woodcock *et al.*, 2019; Goulnik *et al.*, 2020; Roquer‐Beni *et al.*, 2020). **Evidence for link to pollination (FD):** Hairiness is likely a key effects trait as it plays a strong role in determining the amount of pollen that is carried on an individual’s body and is correlated with single-visit pollen deposition (Stavert *et al.*, 2016; Goulnik *et al.*, 2020). Overall hairiness is likely to be a useful trait and possible proxy for single-visit pollen deposition (Stavert *et al.*, 2016). |
| Height of flower/foraging area preference (behavioural) | Species preference for particular flower heights based on the distance from the ground. | ***Trait availability:*** Height of flower has currently received relatively limited use in trait studies and as such is not a widely available trait. **Evidence for link to pollination:** It has been used to place pollinators into functional groups that were correlated with pumpkin seed set (Hoehn *et al.*, 2008) and honeybees and wild bees have been found to forage preferentially at different heights of almond trees impacting on spatial complementarity (Brittain *et al.*, 2013).  |
| Diet breadth (behavioural) | Describes the diet breadth of a species. Usually a categorical description. For example, oligolectic species collect pollen from a single family of plants or polylectic collect pollen from multiple plant families. | ***Trait availability:*** Diet breadth is a generally widely known trait for bees and values are often available in the literature (Bommarco *et al.*, 2010; Bartomeus *et al.*, 2013) and online repositories/databases (Borge*s et al*. 2020). **Evidence for link to pollination:** Diet breadth may affect pollinator efficacy where more generalist species forage on a wider range of plants, which could decrease the likelihood of conspecific pollen transfer to a focal plant species (Brosi & Briggs, 2013; Brosi, 2016). However, due to plasticity in floral use between communities diet breadth may not accurately capture the likelihood of conspecific pollen transfer (Brosi & Briggs, 2013; Brosi, 2016). Diet breadth has also not been found to be a predictor of pe- visit pollination efficiency (Bartomeus et al., 2018). There is currently limited evidence to suggest diet breadth is an important trait in predicting pollination services. |
| **Activity period** (phenological) | **Daily**: The time of day of peak abundance, or hour of peak observations. Alternatively, activity period is used to derive preferential foraging conditions i.e., temperature preferences (Fründ *et al.*, 2013; Kühsel & Blüthgen, 2015). | ***Trait availability:*** Daily activity period is reasonably easy to measure, as it is derived from visitation rates/abundance at different times of the day (Hoehn *et al.*, 2008; Coux *et al.*, 2016). **Evidence for link to pollination:** Due to complementarity between species showing different daily activity periods it has been shown to maximise seed set across a number of plant species (Fründ *et al.*, 2013). Further, functional group richness based on daily activity period (amongst other traits) was correlated with seed set in pumpkin (Hoehn *et al.*, 2008). Activity period is likely to be a useful trait and capture temporal resource use. |
| **Seasonal**: Month of peak abundance, month of emergence or general description of flight period.  | ***Trait availability:*** Seasonal activity period is widely available for a number insect species from field guides and trait databases (e.g. in the UK Falk & Lewington, 2016 and Speight, Castella, & Sarthou, 2020). This trait may show strong regional variation as well as undergo shifts due to climate change (Memmott *et al.*, 2007; Bartomeus *et al.*, 2011; Stemkovski *et al.*, 2020). **Evidence for link to pollination:** As for daily activity this trait may be important in terms of temporal complementarity. It has been used with other traits to model abundance and pollination services in coffee, watermelon and sunflower (Lonsdorf *et al.*, 2009). However, when included with other traits in a measure of functional diversity it was no more predictive of crop yields than species richness (Garibaldi *et al.*, 2015). Therefore the importance of seasonal activity period is likely to be study-dependent.  |
| Time on flower (behavioural)  | Time spent handling or foraging on a flower.  | ***Trait availability:*** Time on a flower has been used in a limited number of studies (Woodcock *et al.*, 2013a; Russo *et al.*, 2017). Any measurement is likely to be highly dependent on site-specific characteristics, as flower handling behaviours are affected by a number of external factors, such as resource quality (Goulson, 1999). **Evidence for link to pollination (FD):** Time on flower may affect pollination as the longer an individual spends on a flower increases the chance they could make contact with the plant stigma (Woodcock *et al.*, 2013a). However, evidence suggests longer visits do not increase pollen deposition (Thomson & Goodell, 2002). Currently, there is limited evidence for the importance of this trait. |
| Resource acquisition (behavioural) | Ratio, percentage of visits or categorical description of the behaviour for pollen and nectar collection  | ***Trait availability:*** Measured mainly for bee species on a limited number of crop plants (Woodcock *et al.*, 2013a; Martins *et al.*, 2015; Russo *et al.*, 2017; Marzinzig *et al.*, 2018). It may be strongly affected by site-specific characteristics as resource acquisition is affected by external factors, including weather (Peat & Goulson, 2005). **Evidence for link to pollination (FD):** Resource acquisition is likely to affect pollinator effectiveness as pollen foraging may increase the chance an individual will make contact with the plant stigma instead of bypassing reproductive parts of a plant for nectar (Woodcock *et al.*, 2013a; Russo *et al.*, 2017; Marzinzig *et al.*, 2018). Overall, more evidence is needed to determine the importance of this trait.  |
| Robbing behaviour (behavioural) | Where an insect avoids the reproductive parts of a flower to access nectar. Classed as the proportion of visits where this behaviour is displayed or binary assessment of behaviour. | ***Trait availability:*** Nectar robbing behaviour has been widely recorded for a number of insect and bird species (Irwin *et al.*, 2010). In bees this characteristic is often driven by tongue length (Kendall & Smith, 1975; Marzinzig et al., 2018). **Evidence for link to pollination:** Whether or not a species nectar robs can strongly impact pollinator effectiveness for some crop species, including legumes (Kendall & Smith, 1975; Marzinzig et al., 2018). |
| Foraging range (behavioural) | A number of methods have been used; ***Derived from body size*** (Greenleaf *et al.*, 2007); estimated directly using ***fluorescent powder*** (Sardiñas *et al.*, 2016); or ***radio frequency identification*** (RFID) tags are used to track species (Minahan & Brunet, 2018) .  | ***Trait availability:*** Foraging range is often derived from body size (Greenleaf *et al.*, 2007), although this may only weakly capture actual foraging ranges (Sardiñas *et al.*, 2016). **Evidence for link to pollination:** Unlikely to impact pollinator effectiveness at the floral level, but can determine spatial resource use important for crop pollination (Kremen *et al.*, 2007; Garibaldi *et al.*, 2011; Sardiñas *et al.*, 2016; Cunningham‐Minnick *et al.*, 2020). For example, some species may be more likely to forage at the edge of fields rather than the centre (Sardiñas *et al.*, 2016).  |
| Buzz pollination (behavioural) | The ability to vibrate at high frequencies to dislodge pollen, which is known as buzz pollination (De Luca & Vallejo-Marín, 2013).  | ***Trait availability:*** Often associated with *Bombus*, but has been recorded across 7 bee families and one hoverfly species (De Luca & Vallejo-Marín, 2013). **Evidence for link to pollination:** Many plants are dependent on buzz-pollination, therefore to specific species it is likely to impact yield/seed set (De Luca & Vallejo-Marín, 2013). |
| Pollen-carrying location including corbicula (pollen basket) and crop (morphological) | Categorical description of where pollen is carried by a bee species (Michener, 1999). | ***Trait availability:*** Pollen-carrying structures are predominantly a family based trait in bees, therefore are available for most bee species (Michener, 1999). **Evidence for link to pollination (FD):** Corbicula location and presence/absence of a crop are likely to influence the distribution of pollen on an individual’s body that is available for pollination (Michener, 1999; Woodcock *et al.*, 2019; Cunningham‐Minnick *et al.*, 2020). Pollen packed into the corbicula can limit its viability for fertilisation (Parker *et al.*, 2015). Overall, this trait is likely to be important, but further research is needed to ascertain this. |
| Moistening pollen (behavioural) | Categorical description of whether a species carries pollen dry or moist | ***Trait availability:*** Available at a family / generic level for bees, e.g., *Apis* and *Bombus* spp. **Evidence for link to pollination:** Where pollen is moistened during carrying it is less available for fertilisation which could affect pollinator efficacy (Martins *et al.*, 2015; Parker *et al.*, 2015). Currently, further research is needed to ascertain the importance of this trait. |
| Stigmal contact (behavioural/morphological) | Percentage/proportion of visits that end in stigmal contact | ***Trait availability:*** Stigmal contact has largely been derived for bees and in reference to a limited number of plant species (Artz & Nault, 2011; Woodcock *et al.*, 2013b; Martins *et al.*, 2015; Campbell *et al.*, 2017). **Evidence for link to pollination (FD):** Where plants depend on insect pollination, contact with the plant stigma is likely a pre-requisite for pollination success. For example, wild bees were found to make stigmal contact more often than honeybees, and a greater abundance of wild bees was found to increase apple yields (Russo *et al.*, 2017). Similarly, bumblebees were found to touch plant stigmas more than honeybees, and bumblebee pollination also led to higher pumpkin yields (Artz & Nault, 2011). Overall, stigma contact is likely to be important in conjunction with dry pollen on the body. |
| Dry pollen on the body or pollen load (behavioural/morphological) | Probability that there is dry pollen on the body. Or quantification of the number of pollen grains on the body of an individual. | ***Trait availability:*** At present dry pollen on the body has mainly been observed for bees and flies in reference to a limited number of crop species (Howlett *et al.*, 2011; Marzinzig *et al.*, 2018; Woodcock *et al.*, 2019). **Evidence for link to pollination (FD):** Dry pollen on the body is a pre-requisite for successful pollination in most systems (Woodcock *et al.*, 2013a), and the amount of pollen on an individual has been correlated with single-visit pollen deposition (Howlett *et al.*, 2011). Overall, this trait is likely to be important in conjunction with stigmal contact.  |
| Single-visit pollen deposition (SVD) or pollen transfer (behavioural/morphological) | The amount of pollen deposited on a plant stigma in a single visit. | ***Trait availability:*** Single-visit pollen deposition has been assessed for bees and flies for predominantly crop plants, although measurements for some wild plants do exist (Rader *et al.*, 2009; Artz & Nault, 2011; Kearns et al 1994; King *et al.*, 2013; Phillips *et al.*, 2018). **Evidence for link to pollination:** More pollen deposited on a plant stigma is likely to increase the chance of successful fertilisation (Rader *et al.*, 2009). Bumblebees were found to deposit more pollen on plant stigmas than honeybees, and bumblebee pollination also led to higher pumpkin yields (Artz & Nault, 2011). Brittain et al., 2013 found that the amount of pollen deposited on a plant stigma affected pollen tube growth and subsequent fruit set in apple. This may be one of the most important effects traits as it captures the efficacy of a pollinator at the point of delivery. However, it may show large variability among crops for the same pollinator species, as well as within pollinator species for the same crop (Rader *et al.*, 2009). |
| Pollen load purity (behavioural) | The proportion of the pollen load made up of the target plant species. Alternatively, the identity of plant species carried in the pollen.  | ***Trait availability:*** Pollen load is likely to show high specificity to the study in which it is assessed as a number of factors can affect diet the diet breadth of a species and the plants they forage on (Brosi & Briggs, 2013). Currently it has been mainly derived for bees in reference to a limited number of plant species, although some measurements do exist for wild plants (Brosi & Briggs, 2013; Russo *et al.*, 2017; Marzinzig *et al.*, 2018). **Evidence for link to pollination:** Conspecific pollen is essential for fertilisation, therefore this trait does capture a key aspect of pollinator effectiveness and is likely to be useful alongside single-visit pollen deposition.  |
| Sociality (behavioural) | Categorical definition of sociality (e.g., eusocial or solitary). Could also include whether a species is parasitic.  | ***Trait availability:*** Generally widely available for bee species in the literature (Bommarco *et al.*, 2010; Bartomeus *et al.*, 2013), online repositories/databases (Borges *et al.*, 2020; Speight *et al.*, 2020) and field guides (Falk & Lewington, 2016) **Evidence for link to pollination:** Sociality is unlikely to affect directly the efficacy of individual pollinators. Where used to place species into different functional groups it may capture complementarity in pollination services (Blitzer *et al.*, 2016). However, sociality was not correlated with visitation or pollination effectiveness in a number of crop systems (Bartomeus *et al.*, 2018), thus it is difficult to determine the importance of this trait.  |
| Nesting place and substrate (ecological) | Categorical definition (e.g. wood or ground) | ***Trait availability:*** Widely available for many bee species and hoverflies in online databases (Bartomeus *et al.*, 2013; Borges *et al.*, 2020; Speight *et al.*, 2020) and field guides (Falk & Lewington, 2016). **Evidence for link to pollination (FD):** Nesting requirements are unlikely to affect directly the efficacy of individual pollinators. Where used to place species into different functional groups it may capture complementarity in pollination services (Blitzer *et al.*, 2016). However, nesting was not correlated with visitation or pollination effectiveness in a number of crop systems (Bartomeus *et al.*, 2018), and is unlikely to be linked to pollinator efficacy. However, nesting sites may be a limiting factor for bees in some agroecosystems, for example those characterised by a high degree of soil disturbance (Forest *et al.*, 2015). |

`Where [FD] is indicated this means that this trait has not been shown to be important predictor of crop yields above that attributable to local pollinator abundance alone, although has been shown to predict yields as part of an overall measure of functional diversity in combination with other traits (see Woodcoc*k et al.* 2019).

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