

Supplementary Material: Predicting bee community  
responses to land-use changes: Effects of geographic and  
taxonomic biases

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## **Supplementary Data S1. Relationship between sampled abundance and sampling effort**

Generalized additive mixed models (Wood & Scheipl, 2014) were used to assess whether total abundance at a site was non-linearly related to sampling effort, for 18 studies where sampling effort varied among sites. Random effects included Source, Study and Block (see main text for details). A non-linear term for sampling effort was not supported although total abundance did significantly increase with sampling effort as expected (edf = 1, ref.df = 1,  $F = 7.111$ ,  $p < 0.01$ ).

Supplementary Table S1: Land-use class and intensity definitions as used in Hudson *et al.* (2014)

| Level 1 Land Use                                   | Predominant Land Use              | Low Intensity   | Medium Intensity   | High Intensity   |
|--|-----------------------------------|---|--|--|
| No evidence of prior destruction of the vegetation | Primary forest                    | Any disturbances identified are very minor (e.g., a trail or path) or very limited in the scope of their effect (e.g., hunting of a particular species of limited ecological importance). | One or more disturbances of moderate intensity (e.g., selective logging) or breadth of impact (e.g., bushmeat extraction), which are not severe enough to markedly change the nature of the ecosystem. | One or more disturbances that is severe enough to markedly change the nature of the ecosystem; this includes clear-felling of part of the site too recently for much recovery to have occurred. Primary sites in fully urban settings should be classed as high intensity. |
|  | Primary Non-Forest                | As above  | As above   | As above   |
| Recovering after destruction of the vegetation     | Mature Secondary Vegetation       | As for Primary Vegetation-low intensity   | As for Primary Vegetation-medium intensity   | As for Primary Vegetation-high intensity   |
|  | Intermediate Secondary Vegetation | As for Primary Vegetation-low intensity   | As for Primary Vegetation-medium intensity   | As for Primary Vegetation-high intensity   |
|  | Young Secondary Vegetation        | As for Primary Vegetation-low intensity   | As for Primary Vegetation-medium intensity   | As for Primary Vegetation-high intensity   |
|  | Secondary Vegetation              | As for Primary Vegetation-low intensity   | As for Primary Vegetation-medium intensity   | As for Primary Vegetation-high intensity   |
|  | Indeterminate age                 | As for Primary Vegetation-low intensity   | As for Primary Vegetation-medium intensity   | As for Primary Vegetation-high intensity   |
|  | Primary Non-Forest                | As above  | As above   | As above   |
|  | Mature Secondary Vegetation       | As for Primary Vegetation-low intensity   | As for Primary Vegetation-medium intensity   | As for Primary Vegetation-high intensity   |

| Human use<br>(agricultural) | Plantation forest | Extensively managed or mixed<br>timber, fruit/coffee, oil-palm or<br>rubber plantations in which native<br>understorey and/or other native<br>tree species are tolerated, which are<br>not treated with pesticide or<br>fertiliser, and which have not been<br>recently (< 20 years) clear-felled. | Monoculture fruit/coffee/rubber<br>plantations with limited pesticide<br>input, or mixed species plantations<br>with significant inputs. Monoculture<br>timber plantations of mixed age<br>with no recent (< 20 years)<br>clear-felling. Monoculture oil-palm<br>plantations with no recent (< 20<br>years) clear-felling.   | Monoculture fruit/coffee/rubber<br>plantations with significant<br>pesticide input. Monoculture timber<br>plantations with similarly aged trees<br>or timber/oil-palm plantations with<br>extensive recent (< 20 years)<br>clear-felling.     |
|-----------------------------|-------------------|--|--|---|
|                             | <b>Cropland</b>   | Low-intensity farms, typically with<br>small fields, mixed crops, crop<br>rotation, little or no inorganic<br>fertiliser use, little or no pesticide<br>use, little or no ploughing, little or<br>no irrigation, little or no<br>mechanisation.  | Medium intensity farming, typically<br>showing some but not many of the<br>following: large fields, annual<br>ploughing, inorganic fertiliser<br>application, pesticide application,<br>irrigation, no crop rotation,<br>mechanisation, monoculture crop.<br>Organic farms in developed<br>countries often fall within this<br>category, as may high-intensity<br>farming in developing countries. | High-intensity monoculture farming,<br>typically showing many of the<br>following features: large fields,<br>annual ploughing, inorganic<br>fertiliser application, pesticide<br>application, irrigation,<br>mechanisation, no crop rotation. |
|                             | <b>Pasture</b>    | Pasture with minimal input of<br>fertiliser and pesticide, and with low<br>stock density ( <i>not</i> high enough to<br>cause significant disturbance or to<br>stop regeneration of vegetation).   | Pasture either with significant input<br>of fertiliser or pesticide, or with<br>high stock density (high enough to<br>cause significant disturbance or to<br>stop regeneration of vegetation).   | Pasture with significant input of<br>fertiliser or pesticide, <i>and</i> with high<br>stock density (high enough to cause<br>significant disturbance or to stop<br>regeneration of vegetation).   |
| <b>Human use (urban)</b>    | <b>Urban</b>      | Extensive managed green spaces;<br>villages.   | Suburban (e.g. gardens), or small<br>managed or unmanaged green<br>spaces in cities.   | Fully urban with no significant<br>green spaces.  |

**Supplementary Data S2. List of species (with known binomial name)  
included in the dataset**

|                                 |                             |
|---------------------------------|-----------------------------|
| <i>Agapostemon melliventris</i> | <i>Andrena bicolor</i>      |
| <i>Agapostemon radiatus</i>     | <i>Andrena brevipalpis</i>  |
| <i>Agapostemon semimelleus</i>  | <i>Andrena bucephala</i>    |
| <i>Agapostemon texanus</i>      | <i>Andrena carantonica</i>  |
| <i>Agapostemon virescens</i>    | <i>Andrena carlini</i>      |
| <i>Agapostemonoides hurdi</i>   | <i>Andrena chrysopus</i>    |
| <i>Aglaoapis tridentata</i>     | <i>Andrena chrysoseles</i>  |
| <i>Allodape interrupta</i>      | <i>Andrena cineraria</i>    |
| <i>Allodape mea</i>             | <i>Andrena cinerea</i>      |
| <i>Allodapula variegata</i>     | <i>Andrena clarkella</i>    |
| <i>Amegilla albigena</i>        | <i>Andrena coitana</i>      |
| <i>Amegilla asserta</i>         | <i>Andrena combinata</i>    |
| <i>Amegilla chlorocyanea</i>    | <i>Andrena commoda</i>      |
| <i>Amegilla pulchra</i>         | <i>Andrena congruens</i>    |
| <i>Amegilla quadrifasciata</i>  | <i>Andrena cressonii</i>    |
| <i>Amphylaeus nubilosellus</i>  | <i>Andrena curvungula</i>   |
| <i>Ancyloscelis apiformis</i>   | <i>Andrena decipiens</i>    |
| <i>Andrena afrensis</i>         | <i>Andrena denticulata</i>  |
| <i>Andrena agilissima</i>       | <i>Andrena distinguenda</i> |
| <i>Andrena albofasciata</i>     | <i>Andrena dorsata</i>      |
| <i>Andrena alfkenella</i>       | <i>Andrena dunningi</i>     |
| <i>Andrena angustior</i>        | <i>Andrena enslinella</i>   |
| <i>Andrena anthrisci</i>        | <i>Andrena erigeniae</i>    |
| <i>Andrena arabis</i>           | <i>Andrena erythronii</i>   |
| <i>Andrena barbareae</i>        | <i>Andrena falsifica</i>    |
| <i>Andrena barbilabris</i>      | <i>Andrena flavipes</i>     |
|                                 | <i>Andrena florea</i>       |
|                                 | <i>Andrena floricola</i>    |

*Andrena florivaga*  
*Andrena forbesii*  
*Andrena fucata*  
*Andrena fulva*  
*Andrena fulvago*  
*Andrena fulvata*  
*Andrena fulvida*  
*Andrena fuscipes*  
*Andrena gravida*  
*Andrena haemorrhoea*  
*Andrena hattorfiana*  
*Andrena helianthiformis*  
*Andrena helvola*  
*Andrena hippotes*  
*Andrena humilis*  
*Andrena illinoiensis*  
*Andrena intermedia*  
*Andrena labialis*  
*Andrena labiata*  
*Andrena lagopus*  
*Andrena lapponica*  
*Andrena lathyri*  
*Andrena mandibularis*  
*Andrena minutula*  
*Andrena minutuloides*  
*Andrena miserabilis*  
*Andrena mitis*  
*Andrena nasonii*  
*Andrena nasuta*  
*Andrena nigrihirta*  
*Andrena nigroaenea*  
*Andrena nigroolivacea*  
*Andrena nitida*  
*Andrena nitidiuscula*  
*Andrena niveata*  
*Andrena ocreata*  
*Andrena ovatula*  
*Andrena pandellei*  
*Andrena pilipes*  
*Andrena polita*  
*Andrena praecox*  
*Andrena probata*  
*Andrena propinqua*  
*Andrena proxima*  
*Andrena quintilis*  
*Andrena ranunculorum*  
*Andrena rosae*  
*Andrena rudbeckiae*  
*Andrena rufa*  
*Andrena ruficrus*  
*Andrena rufizona*  
*Andrena sabulosa*  
*Andrena saundersella*  
*Andrena semilaevis*  
*Andrena similis*  
*Andrena spinigera*  
*Andrena strohmeella*  
*Andrena subopaca*

|                                 |                                   |
|---------------------------------|-----------------------------------|
| <i>Andrena synadelpha</i>       | <i>Anthophora atroalba</i>        |
| <i>Andrena tarsata</i>          | <i>Anthophora balneorum</i>       |
| <i>Andrena thaspiae</i>         | <i>Anthophora crassipes</i>       |
| <i>Andrena thoracica</i>        | <i>Anthophora dispar</i>          |
| <i>Andrena tibialis</i>         | <i>Anthophora furcata</i>         |
| <i>Andrena ungeri</i>           | <i>Anthophora plumipes</i>        |
| <i>Andrena vaga</i>             | <i>Anthophora quadrimaculata</i>  |
| <i>Andrena varians</i>          | <i>Anthophora retusa</i>          |
| <i>Andrena ventralis</i>        | <i>Anthophora terminalis</i>      |
| <i>Andrena viridescens</i>      | <i>Anthophora walshii</i>         |
| <i>Andrena vulpecula</i>        | <i>Apis mellifera</i>             |
| <i>Andrena wheeleri</i>         | <i>Augochlora cordicefloris</i>   |
| <i>Andrena wilkella</i>         | <i>Augochlora nigrocyanea</i>     |
| <i>Anthidiellum notatum</i>     | <i>Augochlora nominata</i>        |
| <i>Anthidiellum strigatum</i>   | <i>Augochlora pura</i>            |
| <i>Anthidium byssinum</i>       | <i>Augochlora repandirostris</i>  |
| <i>Anthidium caturigense</i>    | <i>Augochlora sidaefaline</i>     |
| <i>Anthidium laterale</i>       | <i>Augochlorella aurata</i>       |
| <i>Anthidium manicatum</i>      | <i>Augochlorella edentata</i>     |
| <i>Anthidium montanum</i>       | <i>Augochlorella striata</i>      |
| <i>Anthidium oblongatum</i>     | <i>Augochloropsis auriventris</i> |
| <i>Anthidium punctatum</i>      | <i>Augochloropsis callichroa</i>  |
| <i>Anthidium scapulare</i>      | <i>Augochloropsis metallica</i>   |
| <i>Anthidium septemdentatum</i> | <i>Augochloropsis vesta</i>       |
| <i>Anthidium strigatum</i>      | <i>Bombus argillaceus</i>         |
| <i>Anthodioctes calcaratum</i>  | <i>Bombus atratus</i>             |
| <i>Anthodioctes mapirensis</i>  | <i>Bombus auricomus</i>           |
| <i>Anthophora aestivalis</i>    | <i>Bombus barbutellus</i>         |
|                                 | <i>Bombus bimaculatus</i>         |
|                                 | <i>Bombus bohemicus</i>           |



*Bombus campestris*

*Bombus citrinus*

*Bombus cryptarum*

*Bombus dahlbomii*

*Bombus distinguendus*

*Bombus fervidus*

*Bombus gerstaeckeri*

*Bombus griseocollis*

*Bombus hortorum*

*Bombus humilis*

*Bombus hypnorum*

*Bombus impatiens*

*Bombus jonellus*

*Bombus lapidarius*

*Bombus lucorum*

*Bombus magnus*

*Bombus mesomelas*

*Bombus monticola*

*Bombus muscorum*

*Bombus norvegicus*

*Bombus pascuorum*

*Bombus pensylvanicus*

*Bombus pomorum*

*Bombus pratensis*

*Bombus pratorum*

*Bombus quadricolor*

*Bombus rapunculi*

*Bombus ruderarius*

*Bombus ruderatus*

*Bombus rufocinctus*

*Bombus rupestris*

*Bombus schrencki*

*Bombus semenoviellus*

*Bombus sichelii*

*Bombus soroensis*

*Bombus subterraneus*

*Bombus sylvarum*

*Bombus sylvestris*

*Bombus ternarius*

*Bombus terrestris*

*Bombus vagans*

*Bombus vestalis*

*Bombus veteranus*

*Bombus wurflenii*

*Braunsapis calidula*

*Braunsapis diminuta*

*Braunsapis facialis*

*Braunsapis luapulana*

*Braunsapis simillima*

*Cadeguala albopilosa*

*Caenaugochlora perpectinata*

*Calliopsis andreniformis*

*Callohesma calliopsisiformis*

*Callohesma ornatula*

*Callohesma pedalis*

*Camptopoeum frontale*

*Centris ferruginea*

*Centris flavifrons*

|                                 |                              |
|---------------------------------|------------------------------|
| <i>Centris lubrosa</i>          | <i>Coelioxys afra</i>        |
| <i>Centris obscurior</i>        | <i>Coelioxys banksi</i>      |
| <i>Centris varia</i>            | <i>Coelioxys conoidea</i>    |
| <i>Cephalotrigona zexmeniae</i> | <i>Coelioxys inermis</i>     |
| <i>Ceratina australensis</i>    | <i>Coelioxys octodentata</i> |
| <i>Ceratina calcarata</i>       | <i>Coelioxys rufescens</i>   |
| <i>Ceratina chalybea</i>        | <i>Coelioxys rufitarsis</i>  |
| <i>Ceratina chloris</i>         | <i>Coelioxys simillima</i>   |
| <i>Ceratina cucurbitina</i>     | <i>Colletes americanus</i>   |
| <i>Ceratina cyanea</i>          | <i>Colletes compactus</i>    |
| <i>Ceratina dupla</i>           | <i>Colletes cunicularius</i> |
| <i>Ceratina eximia</i>          | <i>Colletes daviesanus</i>   |
| <i>Ceratina nigrolabiata</i>    | <i>Colletes floralis</i>     |
| <i>Ceratina placida</i>         | <i>Colletes fodiens</i>      |
| <i>Ceratina regalis</i>         | <i>Colletes howardi</i>      |
| <i>Ceratina strenua</i>         | <i>Colletes hyalinus</i>     |
| <i>Ceratina viridicincta</i>    | <i>Colletes inflatus</i>     |
| <i>Ceratina viridis</i>         | <i>Colletes latitarsis</i>   |
| <i>Ceratina zeteki</i>          | <i>Colletes marginatus</i>   |
| <i>Ceylalicthus perditellus</i> | <i>Colletes nigricans</i>    |
| <i>Chalepogenus caeruleus</i>   | <i>Colletes robertsonii</i>  |
| <i>Chalicodoma florisomne</i>   | <i>Colletes seminitidus</i>  |
| <i>Chelostoma campanularum</i>  | <i>Colletes sierrensis</i>   |
| <i>Chelostoma distinctum</i>    | <i>Colletes simulans</i>     |
| <i>Chelostoma florisomne</i>    | <i>Colletes succinctus</i>   |
| <i>Chelostoma grande</i>        | <i>Colletes susannae</i>     |
| <i>Chelostoma rapunculi</i>     | <i>Corynura prothysteres</i> |
| <i>Chlerogella elongaticeps</i> | <i>Dasypoda altercator</i>   |
|                                 | <i>Dasypoda argentata</i>    |
|                                 | <i>Dasypoda plumipes</i>     |

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|--------------------------------|--------------------------------|
| <i>Diphaglossa gayi</i>        | <i>Euglossa championi</i>      |
| <i>Dufourea dentiventris</i>   | <i>Euglossa cognata</i>        |
| <i>Dufourea inermis</i>        | <i>Euglossa cordata</i>        |
| <i>Dufourea minuta</i>         | <i>Euglossa crassipunctata</i> |
| <i>Dufourea monardae</i>       | <i>Euglossa cyanura</i>        |
| <i>Epicharis albofasciata</i>  | <i>Euglossa cybelia</i>        |
| <i>Epicharis maculata</i>      | <i>Euglossa deceptrix</i>      |
| <i>Epicharis monozona</i>      | <i>Euglossa dressleri</i>      |
| <i>Epicharis rustica</i>       | <i>Euglossa fimbriata</i>      |
| <i>Eucera clypeata</i>         | <i>Euglossa flammea</i>        |
| <i>Eucera eucnemidea</i>       | <i>Euglossa hansonii</i>       |
| <i>Eucera hamata</i>           | <i>Euglossa hemichlora</i>     |
| <i>Eucera interrupta</i>       | <i>Euglossa heterosticta</i>   |
| <i>Eucera longicornis</i>      | <i>Euglossa ignita</i>         |
| <i>Eucera nigrescens</i>       | <i>Euglossa imperialis</i>     |
| <i>Eufriesea brasilianorum</i> | <i>Euglossa intersecta</i>     |
| <i>Eufriesea concava</i>       | <i>Euglossa magnipes</i>       |
| <i>Eufriesea lucifera</i>      | <i>Euglossa mixta</i>          |
| <i>Eufriesea macroglossa</i>   | <i>Euglossa modestior</i>      |
| <i>Eufriesea mussitans</i>     | <i>Euglossa nigropilosa</i>    |
| <i>Eufriesea ornata</i>        | <i>Euglossa orellana</i>       |
| <i>Eufriesea pulchra</i>       | <i>Euglossa parvula</i>        |
| <i>Eufriesea purpurata</i>     | <i>Euglossa pleosticta</i>     |
| <i>Eufriesea surinamensis</i>  | <i>Euglossa sapphirina</i>     |
| <i>Euglossa allagticta</i>     | <i>Euglossa securigera</i>     |
| <i>Euglossa analis</i>         | <i>Euglossa singularis</i>     |
| <i>Euglossa bursigera</i>      | <i>Euglossa towasendi</i>      |
| <i>Euglossa chalybeata</i>     | <i>Euglossa townsendi</i>      |
|                                | <i>Euglossa tridentata</i>     |
|                                | <i>Euglossa truncata</i>       |

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|------------------------------|-------------------------------|
| <i>Euglossa variabilis</i>   | <i>Halictus kessleri</i>      |
| <i>Euglossa viridis</i>      | <i>Halictus langobardicus</i> |
| <i>Euglossa viridissima</i>  | <i>Halictus leucaheneus</i>   |
| <i>Euhesma neglectula</i>    | <i>Halictus leucopus</i>      |
| <i>Eulaema bombiformis</i>   | <i>Halictus ligatus</i>       |
| <i>Eulaema cingulata</i>     | <i>Halictus maculatus</i>     |
| <i>Eulaema meriana</i>       | <i>Halictus parallelus</i>    |
| <i>Eulaema nigrifacies</i>   | <i>Halictus patellatus</i>    |
| <i>Eulaema nigrita</i>       | <i>Halictus pollinosus</i>    |
| <i>Eulaema polychroma</i>    | <i>Halictus quadricinctus</i> |
| <i>Eulaema seabrai</i>       | <i>Halictus rubicundus</i>    |
| <i>Eulaema speciosa</i>      | <i>Halictus scabiosae</i>     |
| <i>Euryglossa adelaidae</i>  | <i>Halictus seladonius</i>    |
| <i>Euryglossa depressa</i>   | <i>Halictus semitectus</i>    |
| <i>Euryglossa edwardsii</i>  | <i>Halictus sexcinctus</i>    |
| <i>Evylaeus calceatus</i>    | <i>Halictus simplex</i>       |
| <i>Evylaeus leucopus</i>     | <i>Halictus smaragdulus</i>   |
| <i>Evylaeus morio</i>        | <i>Halictus subauratus</i>    |
| <i>Evylaeus rufitarsis</i>   | <i>Halictus tumulorum</i>     |
| <i>Exaerete frontalis</i>    | <i>Heriades carinatus</i>     |
| <i>Exaerete smaragdina</i>   | <i>Heriades crenulatus</i>    |
| <i>Exomalopsis artifex</i>   | <i>Heriades leavitti</i>      |
| <i>Exoneurella setosa</i>    | <i>Heriades truncorum</i>     |
| <i>Frieseomelitta nigra</i>  | <i>Heriades variolosa</i>     |
| <i>Habralictus xanthinus</i> | <i>Heriades variolosus</i>    |
| <i>Halictus compressus</i>   | <i>Honey bees</i>             |
| <i>Halictus confusus</i>     | <i>Hoplitis claviventris</i>  |
| <i>Halictus gemmeus</i>      | <i>Hoplitis lepeletieri</i>   |
|                              | <i>Hoplitis leucomelana</i>   |
|                              | <i>Hoplitis pilosifrons</i>   |

|                              |                                  |
|------------------------------|----------------------------------|
| <i>Hoplitis producta</i>     | <i>Hylaeus nigrinus</i>          |
| <i>Hoplitis spoliata</i>     | <i>Hylaeus nubilosus</i>         |
| <i>Hyanth 0</i>              | <i>Hylaeus paulus</i>            |
| <i>Hylaeus affinis</i>       | <i>Hylaeus punctatus</i>         |
| <i>Hylaeus albocuneatus</i>  | <i>Hylaeus punctulatissimus</i>  |
| <i>Hylaeus albonitens</i>    | <i>Hylaeus relegatus</i>         |
| <i>Hylaeus amiculinus</i>    | <i>Hylaeus rinki</i>             |
| <i>Hylaeus angustatus</i>    | <i>Hylaeus signatus</i>          |
| <i>Hylaeus annularis</i>     | <i>Hylaeus sinuatus</i>          |
| <i>Hylaeus annulatus</i>     | <i>Hylaeus stevensi</i>          |
| <i>Hylaeus asperithorax</i>  | <i>Hylaeus styriacus</i>         |
| <i>Hylaeus brevicornis</i>   | <i>Hylaeus variegatus</i>        |
| <i>Hylaeus chlorosomus</i>   | <i>Isepeolus viperinus</i>       |
| <i>Hylaeus clypearis</i>     | <i>Lasioglossum admirandum</i>   |
| <i>Hylaeus communis</i>      | <i>Lasioglossum aeratum</i>      |
| <i>Hylaeus confusus</i>      | <i>Lasioglossum albipenne</i>    |
| <i>Hylaeus cressoni</i>      | <i>Lasioglossum albipes</i>      |
| <i>Hylaeus cyanurus</i>      | <i>Lasioglossum albocinctum</i>  |
| <i>Hylaeus difformis</i>     | <i>Lasioglossum anomalum</i>     |
| <i>Hylaeus gibbus</i>        | <i>Lasioglossum aspratulum</i>   |
| <i>Hylaeus gredleri</i>      | <i>Lasioglossum asteris</i>      |
| <i>Hylaeus hyalinatus</i>    | <i>Lasioglossum atlanticum</i>   |
| <i>Hylaeus illinoisensis</i> | <i>Lasioglossum bicingulatum</i> |
| <i>Hylaeus kahri</i>         | <i>Lasioglossum bidentatum</i>   |
| <i>Hylaeus lateralis</i>     | <i>Lasioglossum brazieri</i>     |
| <i>Hylaeus leptcephalus</i>  | <i>Lasioglossum brevicorne</i>   |
| <i>Hylaeus mesillae</i>      | <i>Lasioglossum breviventre</i>  |
| <i>Hylaeus modestus</i>      | <i>Lasioglossum brisbanense</i>  |
|                              | <i>Lasioglossum calceatum</i>    |
|                              | <i>Lasioglossum callidum</i>     |

*Lasioglossum cambagei*  
*Lasioglossum cinctipes*  
*Lasioglossum clelandi*  
*Lasioglossum clypeare*  
*Lasioglossum coeruleum*  
*Lasioglossum cognatum*  
*Lasioglossum converiusculum*  
*Lasioglossum coriaceum*  
*Lasioglossum corvinum*  
*Lasioglossum costulatum*  
*Lasioglossum cressonii*  
*Lasioglossum cupromicans*  
*Lasioglossum dampieri*  
*Lasioglossum disabanci*  
*Lasioglossum discum*  
*Lasioglossum divergens*  
*Lasioglossum dreisbachi*  
*Lasioglossum ebeneum*  
*Lasioglossum euboecense*  
*Lasioglossum expansifrons*  
*Lasioglossum fattigi*  
*Lasioglossum foxii*  
*Lasioglossum fratellum*  
*Lasioglossum fulvicorne*  
*Lasioglossum glabriusculum*  
*Lasioglossum griseolum*  
*Lasioglossum gynochilum*  
*Lasioglossum helichrysi*  
*Lasioglossum hemichalceum*  
*Lasioglossum hiltacum*  
*Lasioglossum illinoense*  
*Lasioglossum imitator*  
*Lasioglossum interruptum*  
*Lasioglossum laeve*  
*Lasioglossum laevigatum*  
*Lasioglossum laevissimum*  
*Lasioglossum lanarium*  
*Lasioglossum laticeps*  
*Lasioglossum lativentre*  
*Lasioglossum leucopus*  
*Lasioglossum leucozonium*  
*Lasioglossum lineare*  
*Lasioglossum lineatum*  
*Lasioglossum lissonotum*  
*Lasioglossum lucidulum*  
*Lasioglossum majus*  
*Lasioglossum malachurum*  
*Lasioglossum marginatum*  
*Lasioglossum michiganense*  
*Lasioglossum minutissimum*  
*Lasioglossum minutulum*  
*Lasioglossum morio*  
*Lasioglossum mundulum*  
*Lasioglossum nigripes*  
*Lasioglossum nigroviride*  
*Lasioglossum nitidiusculum*  
*Lasioglossum nitidulum*  
*Lasioglossum pallens*

|                                    |                                   |
|------------------------------------|-----------------------------------|
| <i>Lasioglossum paradmirandum</i>  | <i>Lasioglossum speculatum</i>    |
| <i>Lasioglossum paraforbesii</i>   | <i>Lasioglossum sphaecodoides</i> |
| <i>Lasioglossum parvulum</i>       | <i>Lasioglossum sphaecodopsis</i> |
| <i>Lasioglossum pauperatum</i>     | <i>Lasioglossum subfasciatum</i>  |
| <i>Lasioglossum pauxillum</i>      | <i>Lasioglossum sulthicum</i>     |
| <i>Lasioglossum pectorale</i>      | <i>Lasioglossum tegulare</i>      |
| <i>Lasioglossum peraustrale</i>    | <i>Lasioglossum tricinctum</i>    |
| <i>Lasioglossum perpunctatum</i>   | <i>Lasioglossum uncinatum</i>     |
| <i>Lasioglossum pilosum</i>        | <i>Lasioglossum urbanum</i>       |
| <i>Lasioglossum politum</i>        | <i>Lasioglossum versatum</i>      |
| <i>Lasioglossum pruinatum</i>      | <i>Lasioglossum villosulum</i>    |
| <i>Lasioglossum punctatissimum</i> | <i>Lasioglossum viridatum</i>     |
| <i>Lasioglossum punctatum</i>      | <i>Lasioglossum willsi</i>        |
| <i>Lasioglossum puncticolle</i>    | <i>Lasioglossum xanthopus</i>     |
| <i>Lasioglossum pygmaeum</i>       | <i>Lasioglossum zephyrum</i>      |
| <i>Lasioglossum quadrinotatum</i>  | <i>Lasioglossum zonulum</i>       |
| <i>Lasioglossum quadrisignatum</i> | <i>Lasioglossum zophops</i>       |
| <i>Lasioglossum rohweri</i>        | <i>Leioproctus amabilis</i>       |
| <i>Lasioglossum rufitarse</i>      | <i>Leioproctus carinatus</i>      |
| <i>Lasioglossum sabulosum</i>      | <i>Leioproctus fulvescens</i>     |
| <i>Lasioglossum sagax</i>          | <i>Leioproctus pango</i>          |
| <i>Lasioglossum sculpturatum</i>   | <i>Lestrimelitta niitkib</i>      |
| <i>Lasioglossum semilucens</i>     | <i>Liotrigona bottegoi</i>        |
| <i>Lasioglossum sexnotatum</i>     | <i>Lipotriches australica</i>     |
| <i>Lasioglossum sexsetum</i>       | <i>Lipotriches excellens</i>      |
| <i>Lasioglossum sexstrigatum</i>   | <i>Lipotriches flavoviridis</i>   |
| <i>Lasioglossum smeathmanellum</i> | <i>Lipotriches halictella</i>     |
| <i>Lasioglossum sordidum</i>       | <i>Lipotriches moerens</i>        |
|                                    | <i>Lipotriches muscosa</i>        |
|                                    | <i>Lipotriches semipallida</i>    |

|                                |                                |
|--------------------------------|--------------------------------|
| <i>Lithurgus cornutus</i>      | <i>Megachile lucidiventris</i> |
| <i>Macropis europaea</i>       | <i>Megachile macularis</i>     |
| <i>Macropis fulvipes</i>       | <i>Megachile melanopyga</i>    |
| <i>Manuelia gayi</i>           | <i>Megachile mendica</i>       |
| <i>Manuelia postica</i>        | <i>Megachile montivaga</i>     |
| <i>Megachile albisecta</i>     | <i>Megachile nigriventris</i>  |
| <i>Megachile alpicola</i>      | <i>Megachile oblonga</i>       |
| <i>Megachile analis</i>        | <i>Megachile parietina</i>     |
| <i>Megachile apicalis</i>      | <i>Megachile pilidens</i>      |
| <i>Megachile apicata</i>       | <i>Megachile pugnata</i>       |
| <i>Megachile atrella</i>       | <i>Megachile pyrenaea</i>      |
| <i>Megachile brevis</i>        | <i>Megachile pyrenaica</i>     |
| <i>Megachile callura</i>       | <i>Megachile relativa</i>      |
| <i>Megachile campanulae</i>    | <i>Megachile rotundata</i>     |
| <i>Megachile canifrons</i>     | <i>Megachile semiluctuosa</i>  |
| <i>Megachile captionis</i>     | <i>Megachile sequior</i>       |
| <i>Megachile centuncularis</i> | <i>Megachile serricauda</i>    |
| <i>Megachile circumcincta</i>  | <i>Megachile texana</i>        |
| <i>Megachile clara</i>         | <i>Megachile versicolor</i>    |
| <i>Megachile crassipes</i>     | <i>Megachile willughbiella</i> |
| <i>Megachile discolor</i>      | <i>Megachile zaplana</i>       |
| <i>Megachile ericetorum</i>    | <i>Megalopta centralis</i>     |
| <i>Megachile ferox</i>         | <i>Melecta albifrons</i>       |
| <i>Megachile heriadiformis</i> | <i>Melecta luctuosa</i>        |
| <i>Megachile inermis</i>       | <i>Melipona beecheii</i>       |
| <i>Megachile latimanus</i>     | <i>Melipona compressipes</i>   |
| <i>Megachile leachella</i>     | <i>Melipona fasciata</i>       |
| <i>Megachile ligniseca</i>     | <i>Melipona fuliginosa</i>     |
|                                | <i>Meliponula lendliana</i>    |
|                                | <i>Melissodes agilis</i>       |



|                                    |                             |
|------------------------------------|-----------------------------|
| <i>Melissodes apicata</i>          | <i>Nomada emarginata</i>    |
| <i>Melissodes bimaculata</i>       | <i>Nomada erigeronis</i>    |
| <i>Melissodes comptoides</i>       | <i>Nomada fabriciana</i>    |
| <i>Melissodes denticulata</i>      | <i>Nomada facilis</i>       |
| <i>Melissodes desponsa</i>         | <i>Nomada femoralis</i>     |
| <i>Melissodes druriella</i>        | <i>Nomada ferruginata</i>   |
| <i>Melissodes subillata</i>        | <i>Nomada flava</i>         |
| <i>Melissodes trinodis</i>         | <i>Nomada flavoguttata</i>  |
| <i>Melitta dimidiata</i>           | <i>Nomada flavopicta</i>    |
| <i>Melitta haemorrhoidalis</i>     | <i>Nomada fucata</i>        |
| <i>Melitta leporina</i>            | <i>Nomada fulvicornis</i>   |
| <i>Melitta nigricans</i>           | <i>Nomada goodeniana</i>    |
| <i>Melitta tricineta</i>           | <i>Nomada guttulata</i>     |
| <i>Melitturga clavicornis</i>      | <i>Nomada hirtipes</i>      |
| <i>Meroglossa torrida</i>          | <i>Nomada integra</i>       |
| <i>Mesocheira bicolor</i>          | <i>Nomada lathburiana</i>   |
| <i>Nannotrigona mellaria</i>       | <i>Nomada leucophthalma</i> |
| <i>Nannotrigona perilampoides</i>  | <i>Nomada marshamella</i>   |
| <i>Nannotrigona testaceicornis</i> | <i>Nomada melathoracica</i> |
| <i>Nesocolletes paahaumaa</i>      | <i>Nomada miniuscula</i>    |
| <i>Nomada alboguttata</i>          | <i>Nomada obtusifrons</i>   |
| <i>Nomada armata</i>               | <i>Nomada panzeri</i>       |
| <i>Nomada articulata</i>           | <i>Nomada pygmaea</i>       |
| <i>Nomada bethunei</i>             | <i>Nomada ruficornis</i>    |
| <i>Nomada bifasciata</i>           | <i>Nomada rufipes</i>       |
| <i>Nomada castellana</i>           | <i>Nomada sexfasciata</i>   |
| <i>Nomada conjungens</i>           | <i>Nomada sheppardana</i>   |
| <i>Nomada denticulata</i>          | <i>Nomada signata</i>       |
|                                    | <i>Nomada stoeckherti</i>   |
|                                    | <i>Nomada striata</i>       |

*Nomada succincta*

*Nomada zonata*

*Nomia maneei*

*Osiris barrocoloradensis*

*Osiris mourei*

*Osiris panamensis*

*Osmia adunca*

*Osmia albiventris*

*Osmia anceyi*

*Osmia andrenooides*

*Osmia anthocopoides*

*Osmia atriventris*

*Osmia aurulenta*

*Osmia bicolor*

*Osmia brevicornis*

*Osmia caerulescens*

*Osmia campanularum*

*Osmia conjuncta*

*Osmia cornigera*

*Osmia dalmatica*

*Osmia florisonne*

*Osmia florisonnis*

*Osmia gallarum*

*Osmia labialis*

*Osmia leaiana*

*Osmia leucomelana*

*Osmia lignaria*

*Osmia loti*

*Osmia mitis*

*Osmia mustelina*

*Osmia parietina*

*Osmia praestans*

*Osmia pumila*

*Osmia rapunculi*

*Osmia rufa*

*Osmia simillima*

*Osmia spinulosa*

*Osmia submicans*

*Osmia tergestensis*

*Osmia truncorum*

*Osmia uncinata*

*Osmia villosa*

*Osmia xanthomelana*

*Oxytrigona daemoniaca*

*Oxytrigona mellicolor*

*Pachyprosopis eucalypti*

*Pachyprosopis flavicauda*

*Pachyprosopis haematostoma*

*Pachyprosopis trichopoda*

*Panurgus banksianus*

*Panurgus calcaratus*

*Panurgus dentipes*

*Paratetrapedia calcarata*

*Paratrigona isopterophila*

*Partamona bilineata*

*Partamona cupira*

*Partamona testacea*

*Pasites maculatus*

|                                     |                                 |
|-------------------------------------|---------------------------------|
| <i>Patellapis stirlingi</i>         | <i>Sphecodes ephippius</i>      |
| <i>Peponapis limitaris</i>          | <i>Sphecodes ferruginatus</i>   |
| <i>Peponapis pruinosa</i>           | <i>Sphecodes geoffrellus</i>    |
| <i>Pereirapis rhizophila</i>        | <i>Sphecodes gibbus</i>         |
| <i>Pereirapis semiaurata</i>        | <i>Sphecodes heraclei</i>       |
| <i>Plebeia franki</i>               | <i>Sphecodes hyalinatus</i>     |
| <i>Plebeia frontalis</i>            | <i>Sphecodes miniatus</i>       |
| <i>Plebeia minima</i>               | <i>Sphecodes monilicornis</i>   |
| <i>Protandrena andrenoides</i>      | <i>Sphecodes niger</i>          |
| <i>Protandrena bancrofti</i>        | <i>Sphecodes pellucidus</i>     |
| <i>Pseudapis diversipes</i>         | <i>Sphecodes profugus</i>       |
| <i>Pseudaugochlora graminea</i>     | <i>Sphecodes puncticeps</i>     |
| <i>Pseudopanurgus albitarsis</i>    | <i>Sphecodes ranunculi</i>      |
| <i>Rhinetula denticus</i>           | <i>Sphecodes reticulatus</i>    |
| <i>Rhodanthidium septemdentatum</i> | <i>Sphecodes rufiventris</i>    |
| <i>Rophites algirus</i>             | <i>Sphecodes scabricollis</i>   |
| <i>Rophites canus</i>               | <i>Sphecodes spinulosus</i>     |
| <i>Rophites quinquespinosus</i>     | <i>Sphecodes unknown</i>        |
| <i>Ruizantheda mutabilis</i>        | <i>Stelis lateralis</i>         |
| <i>Ruizantheda proxima</i>          | <i>Stelis punctulatissima</i>   |
| <i>Scaptotrigona mexicana</i>       | <i>Stelis signata</i>           |
| <i>Scaptotrigona pectoralis</i>     | <i>Svastra obliqua</i>          |
| <i>Scaptotrigona xanthotricha</i>   | <i>Svastrides melanura</i>      |
| <i>Sphecodes albilabris</i>         | <i>Synhalonia hamata</i>        |
| <i>Sphecodes alternatus</i>         | <i>Tetragonula carbonaria</i>   |
| <i>Sphecodes banksii</i>            | <i>Tetralonia macroglossa</i>   |
| <i>Sphecodes crassus</i>            | <i>Tetraloniella alticincta</i> |
| <i>Sphecodes dichrous</i>           | <i>Tetraloniella lyncea</i>     |
|                                     | <i>Tetraloniella nana</i>       |
|                                     | <i>Tetraloniella scabiosae</i>  |

*Thygater crawfordi*  
*Thyreus waroonensis*  
*Trachusa byssina*  
*Triepeolus helianthi*  
*Trigona amathea*  
*Trigona angostula*  
*Trigona corvina*  
*Trigona dorsalis*  
*Trigona fulviventris*  
*Trigona fuscipennis*  
*Trigona leucogastra*  
*Trigona muzoensis*  
*Trigona nigerrima*  
*Trigona nigra*  
*Trigona perangulata*  
*Trigona recursa*  
*Trigona subgrisea*  
*Trigonisca buyssoni*  
*Trigonisca schulthessi*  
*Xylocopa imitator*  
*Xylocopa lachnea*  
*Xylocopa muscaria*  
*Xylocopa transitoria*  
*Xylocopa valga*  
*Xylocopa violacea*  
*Xylocopa virginica*

## Supplementary Methods. Decomposition of Mean Squared Error into Bias and Variance

Following Sheiner & Beal (1981), we decompose Mean Squared Error into  $bias^2$  and  $variance$  in the following way across all cross validation sets.

Prediction errors ( $pe$ ) are defined as:

$$pe = p_i - y_i$$

where  $p$  is the prediction and  $y$  is the observation for the  $i$ th value.

Mean prediction errors ( $me$ ) are a measure of  $bias$ :

$$bias = mean(pe)$$

Finally, the variance of the prediction error can be defined as the mean squared deviation of prediction errors from their mean:

$$variance = (pe_i - me)^2$$

Supplementary Table S2: Decomposition of Mean Squared Error (MSE) into Bias<sup>2</sup> and Variance (Sheiner & Beal, 1981). The square root of MSE is also given. Note that the bees dataset refers to models where all bees were assessed; the bombus dataset refers to models where bumblebees were compared with all other bees.

| Dataset | Response Variable   | Model                   | MSE <sup>0.5</sup> ( $\pm$ standard error) | Bias <sup>2</sup> | Variance |
|---------|---------------------|-------------------------|--|-------------------|----------|
| bees    | NULL                | log(total abundance+1)  | 1.88( $\pm$ 0.0167)                        | 0.43000           | 3.100    |
| bees    | LUI                 | log(total abundance+1)  | 2.08( $\pm$ 0.02)                          | 0.80000           | 3.500    |
| bees    | Subregion           | log(total abundance+1)  | 1.78( $\pm$ 0.0199)                        | 0.22000           | 3.000    |
| bees    | LUI+Subregion       | log(total abundance+1)  | 1.93( $\pm$ 0.0232)                        | 0.47000           | 3.300    |
| bees    | LUI*Subregion       | log(total abundance+1)  | 1.74( $\pm$ 0.0292)                        | 0.30000           | 2.800    |
| bees    | NULL                | Simpson's Diversity (D) | 0.312( $\pm$ 0.0034)                       | 0.00130           | 0.096    |
| bees    | LUI                 | Simpson's Diversity (D) | 0.316( $\pm$ 0.00376)                      | 0.00250           | 0.098    |
| bees    | Subregion           | Simpson's Diversity (D) | 0.3( $\pm$ 0.00322)                        | 0.00021           | 0.090    |
| bees    | LUI+Subregion       | Simpson's Diversity (D) | 0.303( $\pm$ 0.00374)                      | 0.00030           | 0.092    |
| bees    | LUI*Subregion       | Simpson's Diversity (D) | 0.297( $\pm$ 0.00315)                      | 0.00140           | 0.087    |
| bees    | NULL                | Species Richness        | 12.6( $\pm$ 1.04)                          | 12.00000          | 160.000  |
| bees    | LUI                 | Species Richness        | 12.6( $\pm$ 1.04)                          | 12.00000          | 160.000  |
| bees    | Subregion           | Species Richness        | 12.4( $\pm$ 1.04)                          | 8.80000           | 160.000  |
| bees    | LUI+Subregion       | Species Richness        | 12.4( $\pm$ 1.04)                          | 8.30000           | 160.000  |
| bees    | LUI*Subregion       | Species Richness        | 12.2( $\pm$ 1.05)                          | 11.00000          | 150.000  |
| bombus  | LUI*Subregion       | log(total abundance+1)  | 1.84( $\pm$ 0.0296)                        | 0.77000           | 2.600    |
| bombus  | LUI*Genus           | log(total abundance+1)  | 2.13( $\pm$ 0.0288)                        | 1.60000           | 2.900    |
| bombus  | LUI*Subregion*Genus | log(total abundance+1)  | 1.74( $\pm$ 0.0291)                        | 0.77000           | 2.200    |
| bombus  | LUI*Subregion       | Simpson's Diversity (D) | 0.302( $\pm$ 0.00328)                      | 0.00180           | 0.089    |
| bombus  | LUI*Genus           | Simpson's Diversity (D) | 0.306( $\pm$ 0.00221)                      | 0.00260           | 0.091    |
| bombus  | LUI*Subregion*Genus | Simpson's Diversity (D) | 0.285( $\pm$ 0.00311)                      | 0.00260           | 0.079    |
| bombus  | LUI*Subregion       | Species Richness        | 9.44( $\pm$ 0.677)                         | 3.90000           | 89.000   |
| bombus  | LUI*Genus           | Species Richness        | 9.49( $\pm$ 0.684)                         | 1.40000           | 93.000   |
| bombus  | LUI*Subregion*Genus | Species Richness        | 7.63( $\pm$ 0.563)                         | 2.00000           | 59.000   |

Supplementary Table S3: Spatial autocorrelation in residuals for minimum adequate model, conducted on each study in turn. Note that this table only includes studies where Moran’s I returned a result; some tests failed because of too few datapoints, because the study either had no or too few neighbouring sites within 10km of one another, or because the test assumptions were not met.

| Minimum adequate model      | Number of studies | Test of equal proportions showing evidence of autocorrelation |
|-----------------------------|-------------------|---|
| Total abundance, bees       | 2                 | $\chi = 0.18, p = 0.55$                                       |
| Simpson’s diversity, bees   | 0                 | $\chi = 1.46, p = 0.89$                                       |
| Species richness, bees      | 6                 | $\chi = 0.24, p = 0.31$                                       |
| Total abundance, bombus     | 4                 | $\chi = 0.097, p = 0.38$                                      |
| Simpson’s diversity, bombus | 3                 | $\chi = 0.00, p = 0.50$                                       |
| Species richness, bombus    | 4                 | $\chi = 0.08, p = 0.39$                                       |

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