Pollinator Observatories

Citizen science to engage people with nature in cities

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Report prepared for Westgate Biodiversity: Bili Nursery & Landcare

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by

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Cover photo by Luis Mata **'Blue-banded bee flying through Westgate Park'**

All photographs by Luis Mata unless otherwise stated.

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Why are insect pollinators important and why should we strive to provide for insect pollinators in urban environments?

Pollination is a key ecological function provided largely by insects (Figures 1.1-1.7). Nearly 90% of all wild flowering plants are pollinated by insects and other animals and up to 75% of agricultural crops rely on insect pollinators for improved seed and fruit setting (Ollerton et al. 2011, IPBES 2016). While some cities show higher species richness of insect pollinators than surrounding rural areas (Baldock et al. 2015, Hall et al. 2017), many urbanisation-related processes such as habitat loss, fragmentation, the heat-island effect and pesticide-related mortality, continue to drive the decline of insect pollinators in urban environments (Harrison and Winfree 2015, New 2015, Hamblin and Youngsteadt 2018). There is a wide recognition of the need for insect conservation, particularly in cities and other urban environments, and of the importance of engaging public interest and support to achieve positive conservation outcomes (New 2018).

What is a pollinator observatory and why use them to study plant-insect pollinator interactions?

Communicating the importance of insect pollinator conservation can be challenging, as most are difficult to observe and not widely appreciated by the public (Hunter and Hunter 2008). Flowering plants are insect pollinators' primary interaction partners and can act as anchors to observe plant-insect interactions, just as trees can act as anchors to observe birds (Stagoll et al. 2012). To encourage public appreciation of insect pollinators in cities, greenspace managers require practical and contextual knowledge about plant-insect pollinator interactions. To this purpose we explore the idea of 'Pollinator Observatories' – a network of flowering plant species located within an urban greenspace, which are repeatedly surveyed for plant-insect pollinator interactions. We envisage that this interaction data may provide crucial knowledge for greenspace managers of how best to select plant palettes beneficial for insect pollinators and assist greenspace managers to increase awareness and engagement with these important but elusive ecological interactions occurring in cities and other urban environments.

What were the project's research questions?

In this project we asked the following research questions:

1. Which insect pollinators are attracted to Westgate Park's network of pollinator observatories?

2. Which are the most frequent pollinator observatory – insect pollinator interactions across Westgate Park?

3. What is the contribution of citizen scientists in documenting plant-insect pollinator interactions across the network of pollinator observatories in Westgate Park?

4. Which insect species and functional groups other than pollinators occur in Westgate Park's network of pollinator observatories?

5. Which pollinator observatories have the largest number of associated insect species across all taxonomical and functional groups?

How were the research questions developed?

The project's research questions were developed collaboratively between Westgate Biodiversity: Bili Nursery & Landcare (henceforth Westgate Biodiversity) and the Clean Air and Urban Landscapes Hub of the Australian Government's National Environmental Science Program (henceforth CAUL Hub). Westgate biodiversity – a community-based not-for-profit organisation working to improve the inner Melbourne environment and its biodiversity with locally indigenous vegetation – was represented by co-author Janet Bolitho, who consulted extensively with other Westgate Biodiversity practitioners throughout the project. The CAUL Hub – a research consortium integrating expertise in air quality, urban ecology, urban planning, urban design, public health and green infrastructure – was represented by co-authors Blythe Vogel and Luis Mata.

Has Westgate Park's insect biodiversity been documented by previous studies?

Yes Westgate Park was one amongst 15 urban greenspace sites studied as part of *The Little Things*

Figure 1.1 (Opposite page) The blue-banded bee *Amegilla chlorocyanea* on the austral storksbill pollinator observatory.

Figure 1.2 The white caper butterfly *Belenois java* on the rounded noon-flower pollinator observatory.

Figure 1.3 The grass blue butterfly *Zizina labradus* on the snowy daisy-bush pollinator observatory.

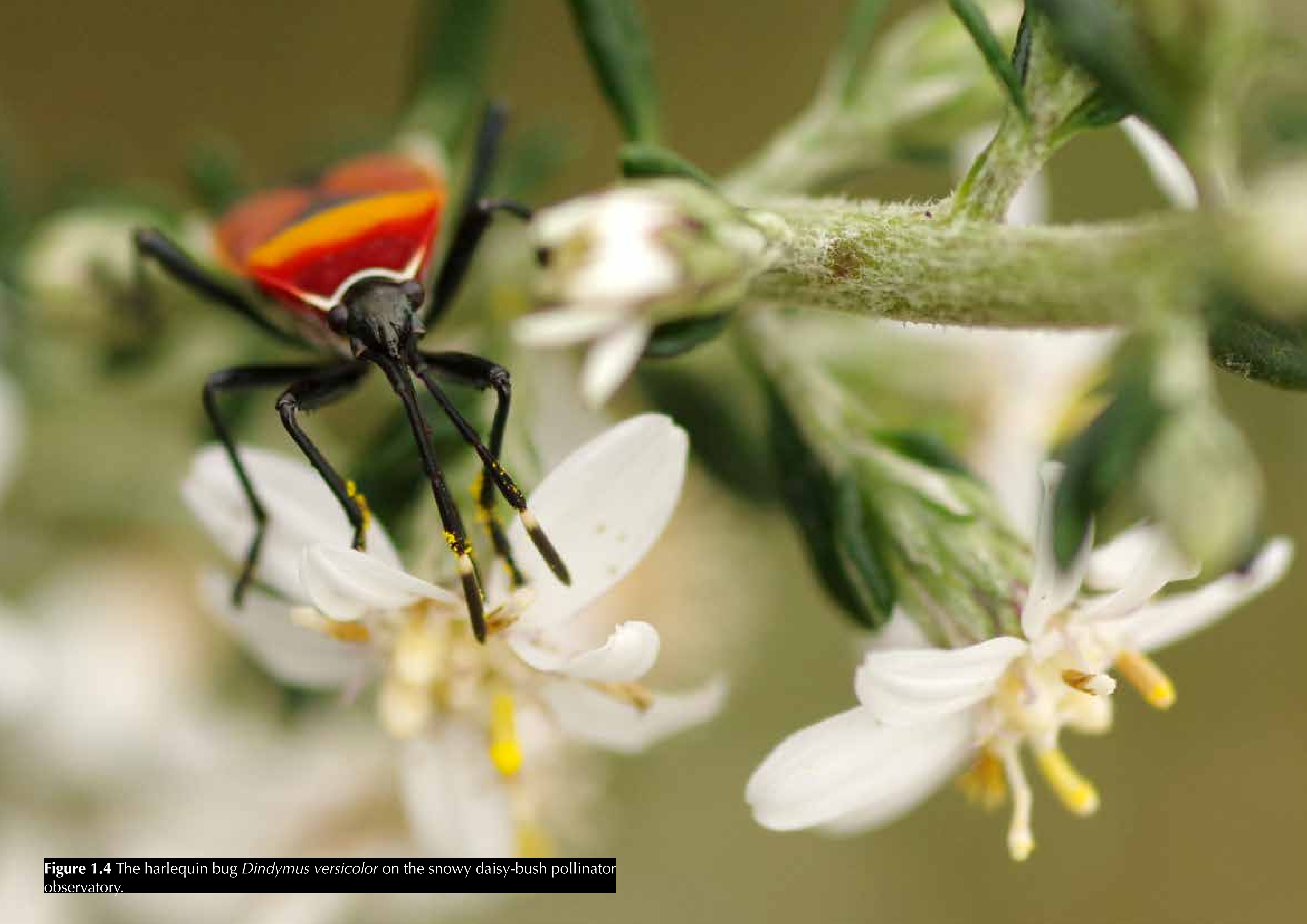

Figure 1.4 The harlequin bug *Dindymus versicolor* on the snowy daisy-bush pollinator observatory.

Figure 1.5 A sweet bee in genus *Lassioglossum* on the swamp daisy pollinator observatory.

Figure 1.6 A hoverfly [family Syrphidae] on the large river buttercup pollinator observatory.

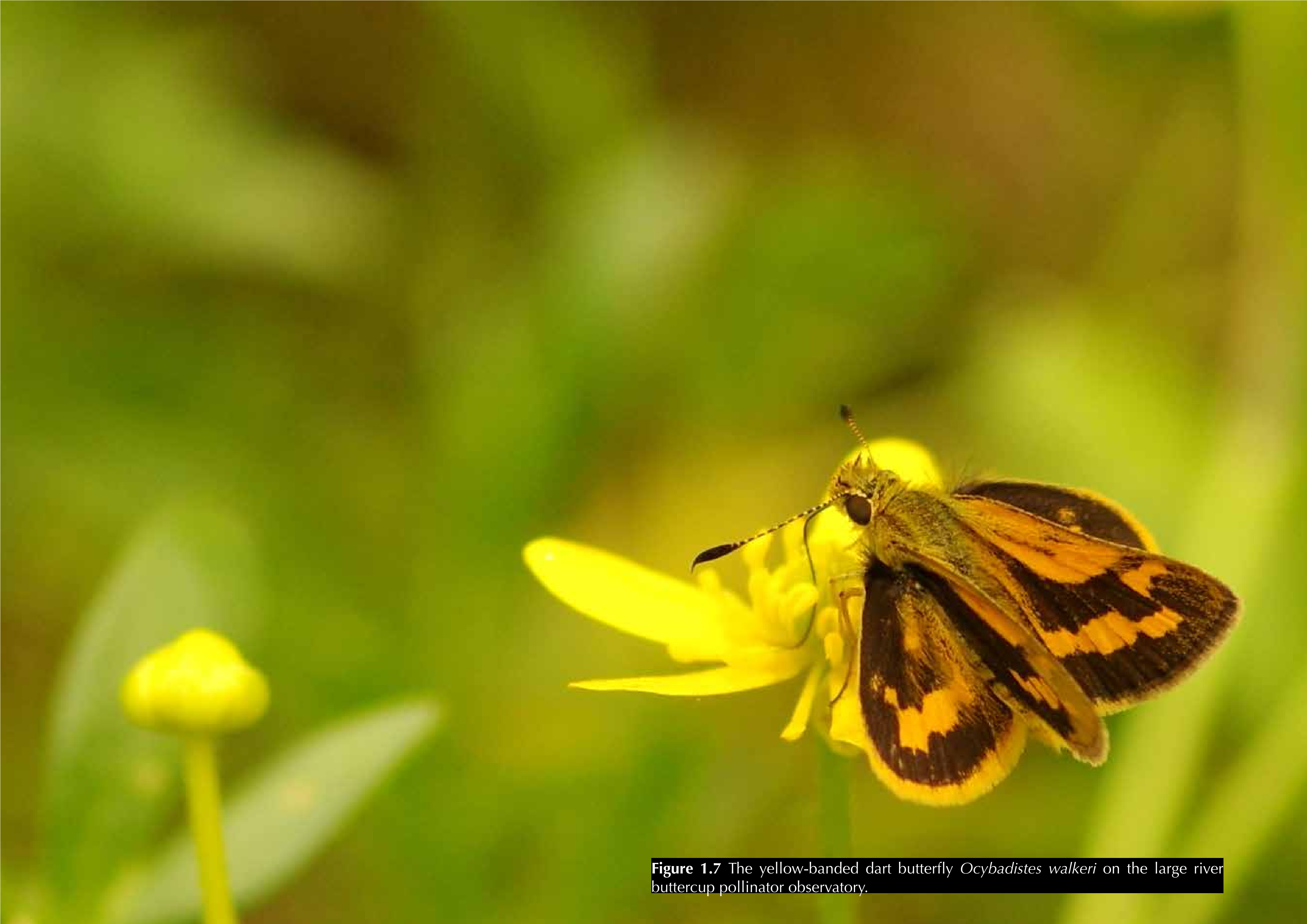

Figure 1.7 The yellow-banded dart butterfly *Ocybadistes walkeri* on the large river buttercup pollinator observatory.

that Run the City, a project that recently assessed the insect biodiversity of the City of Melbourne (Mata et al. 2015, 2016). This study reported 186 insect species occurring in the park, which were documented interacting with 18 plants species indigenous to the local bioregions (five trees, seven shrubs, three graminoids and two lilioids), two shrubs native to Australia and four lawn patches dominated by introduced graminoids and forbs (Mata et al. 2016).

The park was also included in *Our City's Little Gems*, a follow up project from *The Little Things that Run the City* focusing on butterfly diversity and flower-butterfly interaction in the City of Melbourne (Kirk et al. 2017). This study reported four adult butterfly taxa for the park, which were documented interacting with the flowers of 17 indigenous plant species (12 shrubs, four forbs and one lilioid), one shrub native to Australia and eight introduced forbs (Kirk et al. 2017). The four taxa were reported as: little blue butterfly group, cabbage white, Hesperiidae group and small grass-yellow.

Insect records for Westgate Park may also be found at the Atlas of Living Australia (https://www.ala.org.au/), iNaturalist (https://www.inaturalist.org/) and the Westgate Biodiversity website (https://westgatebiodiversity.org.au/).

Will the project's data synergistically contribute to other research projects?

Yes The project's data contributed significantly to Blythe Vogel's Master of Science Thesis (Vogel 2019). For her thesis, Blythe studied the plant – insect pollinator interactions presented in this report, alongside fluctuations in the flower density of the pollinator observatories throughout the two years of the study. Using quantitative modelling techniques, Blythe was able to predict when the insect pollinators would most likely be interacting with the pollinator observatories across their flowering seasons, depending on the flower density of the observatories at any given time of the year. Blythe would like to use these findings to help guide visitors in Westgate Park to when and where they are most likely to see insect pollinators in action. She hopes that in doing so, more urban residents will gain an appreciation of the often unknown, but fascinating, interactions between flowering plants and insect pollinators, and to help foster pollinator friendly gardening practices and conservation actions.

Is the City of Melbourne and other local governments interested in conserving insect biodiversity and engaging people with nature in cities?

The commitment of local governments to conserve the biodiversity occurring within their jurisdictional boundaries is perhaps best exemplified by the numerous targets being set by city policymakers across the world that explicitly aim to increase the abundance of species and the area of remnant and designed greenspace habitat (Nilon et al. 2017). For instance, the Nature in the City – Thriving biodiversity and healthy ecosystems strategy recently launched by the City of Melbourne (2017) aims to "create a more diverse, connected, and resilient natural environment". This strategy has the goal to achieve by 2027 a net increase in biodiversity across the municipality, for example, by increasing understorey plant cover by 20% with a suitable and diverse species palette. Most relevantly, the Nature in the City strategy specifically recognises the key role that shrub, grasses and other under- and mid-storey plants play in providing habitat for insects. Equally importantly, one of the priorities of the strategy is to "connect more people with nature to improve social resilience, health, and wellbeing", with the goal that by 2027 residents , workers and visitors will have encountered nature in the city more than they did in 2017.

How will the project's findings inform Westgate Biodiversity management guidelines and the City of Melbourne urban greenspace policy?

The project will illustrate how pollinator observatories may be used to inform which plant species are best suited to provide food and habitat resources for insect pollinators, as well as insect species across a diverse range of functional groups, in Westgate Park and other greenspaces around Melbourne. This knowledge could be then used to guide the design and maintenance of urban greenspaces across the municipality, and assist federal, state and local government decision-makers consider insects in broader biodiversity plans and strategies. The study's findings will also provide valuable baseline data that can be integrated into the council's planned research agendas, for example in future iterations of the City of Melbourne's BioBlitz and in the future development of monitoring programs.

Who funded Pollinator Observatories?

The Pollinator Observatories study was the outcome of a City of Melbourne funded project entitled 'Providing for Pollinators in Westgate Park'. The grant followed from the City of Melbourne and Westgate Biodiversity working together on the 2014 and 2016 BioBlitz events. There was a desire to ‘dig deeper’ than was possible in the BioBlitz to gain more detailed understanding of pollinator biodiversity in Westgate Park. Additional in-kind support was provided by RMIT University, the University of Melbourne and the CAUL Hub.

2 Methodology

Where did the study take place?

The study took place in Westgate Park, a 41.2ha public greenspace located in the City of Melbourne, Victoria, Australia. The park is primarily used for recreation and conservation purposes (Parks Victoria 2019). Over the last 20 years, as many as 330 plant and 164 bird species have been recorded in the park. Westgate Park is managed by Parks Victoria and Westgate Biodiversity manages a volunteer-based revegetation programme in the park.

When did the project take place?

The study took place over two years from April 2017 to March 2019.

What is a pollinator observatory?

In the simplest terms, a pollinator observatory is a single plant species of at least 5 m^2 in ground cover area that is repeatedly surveyed for its associated insect pollinators and other flower-visiting insect species during its flowering season. Three examples of pollinator observatories are given in Figures 2.1-2.3.

How many pollinator observatories were included in the study?

12 The locations of these 12 pollinator observatories within Westgate Park are shown in Figure 2.4 and detailed information for each observatory given in Table 2.1.

How were the pollinator observatories chosen?

The pollinators observatories were chosen to: (1) represent a diversity of growth forms, including erect and prostrate forbs, lilioids, prostrate and erect shrubs, and trees; (2) have overlapping flowering phenologies, with the intention that at least four observatories would be in flower during each month of the year; (3) portray a selection of indigenous plant species occurring in the two local bioregions represented in the park – Volcanic Victorian Plain and Gippsland Plain bioregions (State of Victoria 2019), with an emphasis in species that, while present in the park, are currently of conservation significance across these bioregions; and (4) be spatially arranged throughout the park to produce an efficient walking route for visitors and workshop participants.

Which pollinator observatories have the shortest and longest flowering seasons?

The pollinator observatories with the shortest flowering season are the running postman and the pale flax-lily, which during a given year flower only for one and two months, respectively (Table 2.1). In contrast, the hop goodenia and woodland swamp-daisy pollinator observatories flower all year long (Table 2.1), but it is important to keep in mind that the density of flowers present on each observatory may fluctuate considerably throughout the year.

How were plant-pollinator interactions recorded?

We used two plant-insect interaction survey methods to record insect pollinators and other flower-visiting insect species: (1) monthly research science surveys, and (2) seasonal citizen science surveys. In total, we conducted 24 research science surveys and seven seasonal citizen science surveys.

What did the monthly research science survey consist of?

The research scientist surveys consisted of two components: direct plant observation and sweep-netting of aboveground vegetation. Surveys were conducted on clear, sunny days with less than 50% cloud cover, and discontinued if rain developed or if wind speed was greater than 5m/s.

Direct Observations: This component consisted of at least two and up to four five-minute periods of actively observing the pollinator observatories' flowers and noting down the first sighting of any insect that came in touch with the flower's reproductive organs (i.e. carpels and stamens). We used a stopping rule – adapted from the one developed by Kirk and colleagues (2017) for flower-butterfly interactions – to determine the number of observation periods, whereby new flower-visiting insect(s) observed during the second period not

Figure 2.1 (Opposite page) The austral storksbill pollinator observatory at Westgate Park.

Figure 2.2 The large river buttercup pollinator observatory at Westgate Park.

Figure 2.3 The golden wattle pollinator observatory at Westgate Park.

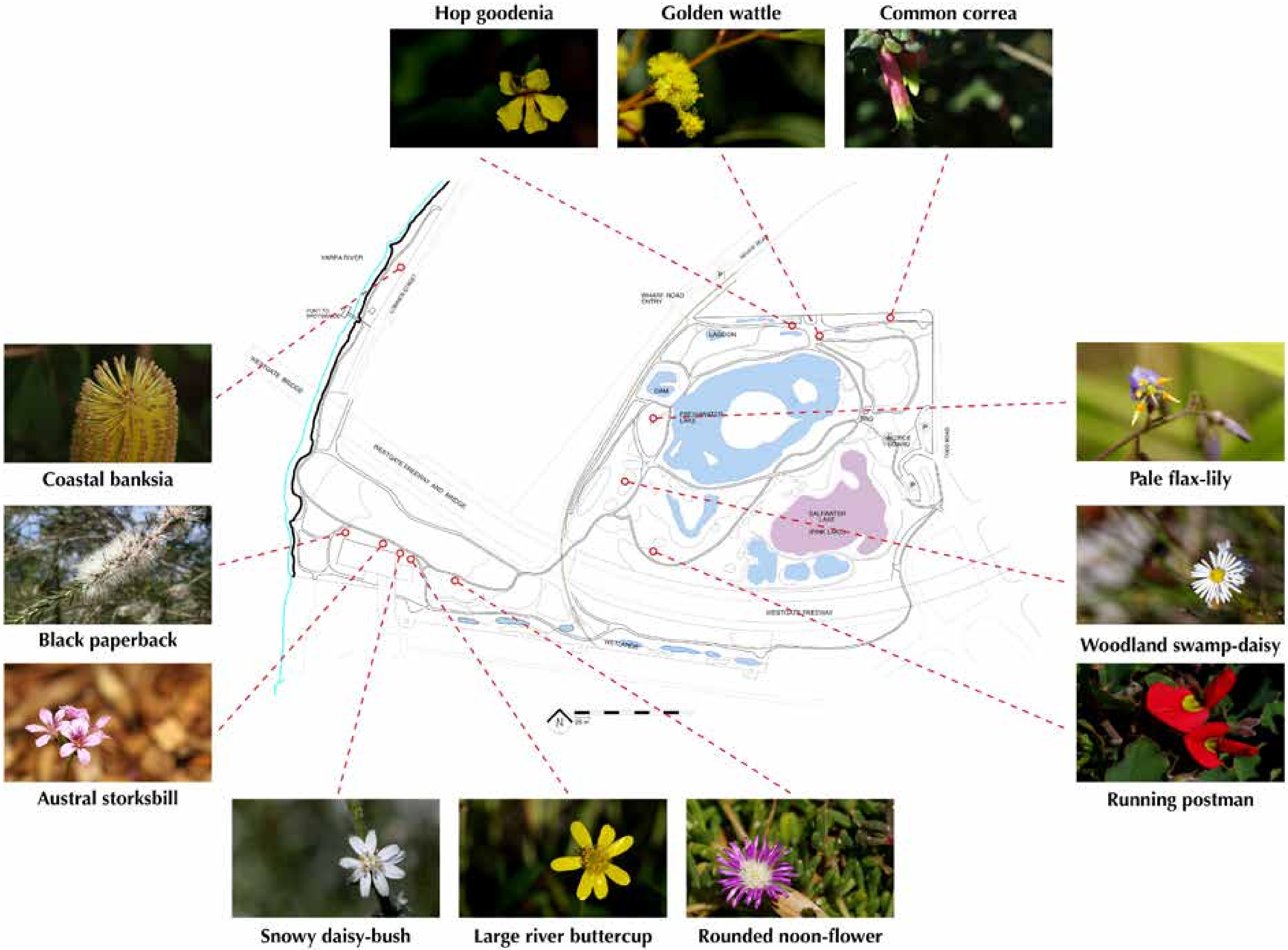

Figure 2.4 Location of the 12 pollinator observatories within Westgate Park.

observed in the first period instigated a third five minute period, and so on for a maximum of four periods. We recorded a targeted subset of 18 insect pollinator and other flower-visiting insect taxa (Figure 2.5; Table 2.2; Appendix I) in the direct observation surveys.

Sweep-netting: Just after the direct observation surveys, we sweep-netted the aboveground vegetation of each pollinator observatory using a 50cm diameter entomological net. We conducted five sweeps per cubic meter of vegetation, focusing on the flowering areas of the observatory.

Table 2.1 Names, taxonomical affiliation, growth form and flowering phenology of the 12 pollinator observatories studied in the project.

Common name	Scientific name	Family	Growth form	Flowering sesson begins	Flowering sesson ends
Austral stork's-bill	*Pelargonium australe*	Geraniaceae	Erect forb	October	May
Black paperbark	*Melaleuca lanceolata*	Myrtaceae	Erect shrub	November	May
Common correa	*Correa reflexa*	Rutaceae	Erect shrub	May	October
Coastal banksia	*Banksia integrifolia*	Protaceae	Tree	March	September
Golden wattle	*Acacia pycnantha*	Fabaceae	Tree	July	September
Hop goodenia	*Goodenia ovata*	Goodeniaceae	Erect shrub	September	August
Large river buttercup	*Ranunculus papulentus*	Ranunculaceae	Erect forb	August	February
Pale flax-lily	*Dianella longifolia*	Asphodelaceae	Liliod	October	November
Rounded noon-flower	*Disphyma crassifolium*	Aizoaceae	Prostrate shrub	October	January
Running postman	*Kennedia prostrata*	Fabaceae	Prostrate forb	September	September
Snowy daisy-bush	*Olearia lirata*	Asteraceae	Erect shrub	October	June
Woodland swamp-daisy	*Brachyscome paludicola*	Asteraceae	Erect forb	September	August

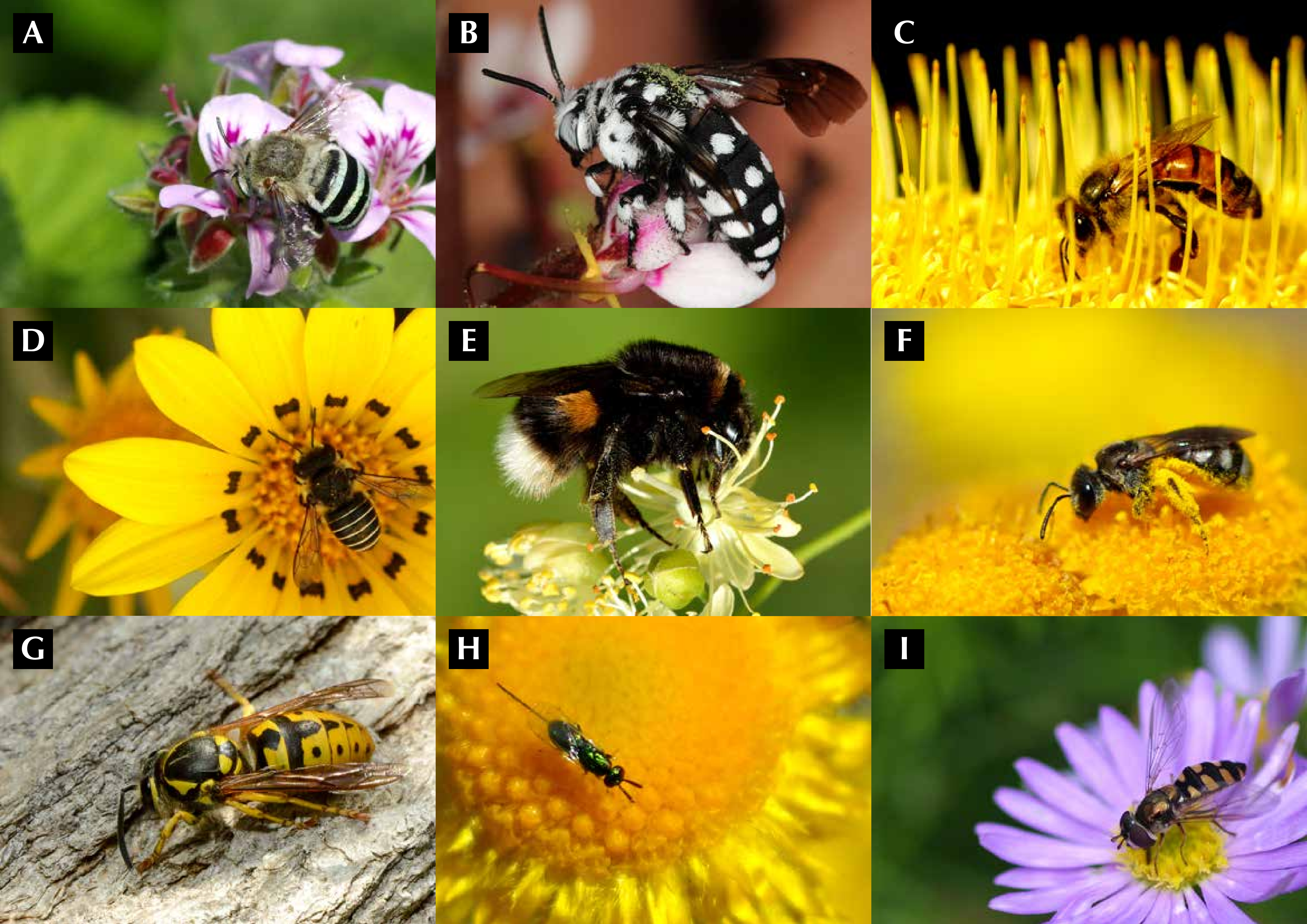
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Figure 2.5 (previous spread) The 18 targeted flower-visiting taxa that the field researchers and citizen scientists were trained to identify for the study:

A. Blue-banded bees
B. Cuckoo-bees
C. European honeybee
D. African carderbee
E. Large Earth bumblebee
F. Other native bees
G. European wasp
H. Other native wasps
I. Hoverflies
J. Other native flies
K. Dingy swallowtail
L. Panted lady
M. Yellow admiral
N. Meadow argus
O. Lesser wanderer
P. Monarch
Q. Cabbage white
R. Other native butterflies

We identified and released well-known taxa (e.g. European honeybee) in-situ, only collecting as few specimens as possible from taxa that we were unable to identify with certainty in the field. Collected specimens were post-processed into a reference collection and identified to species or morphospecies.

What did the seasonal citizen science survey consist of?

Approximately every three months, we organised a half-day workshop in which we recruited and trained a group of citizen scientists to conduct direct observation surveys of the pollinator observatories that were in flower. In total, 189 citizen scientists participated in one or more workshops across the study period – approximately 25 participants attended each workshop. In the first half of each workshop, we trained the citizen scientists to identify 18 targeted pollinator and flower-visiting insect taxa (Figure 2.5; Table 2.2.; Appendix I).

Following training, we tested the citizen scientists with a short photo-based questionnaire to assess the reliability of their identification skills. Following training and certification, each participant conducted one seven-minute direct observation survey at each pollinator observatory that was flowering. During that period, they recorded the targeted taxa in the same manner as the research surveys.

Table 2.2 Names, taxonomical affiliation and origin of the 18 insect pollinator and other flower-visiting insect taxa targeted for direct observation surveys.

Bees

Wasps

Flies

Butterflies

Common name	Order	Family/ies	Genus/era	Scientific/morphospecies name	Origin
Blue-banded bees	Hymenoptera	Apidae	Amegilla	*Amegilla sp.*	Indigenous
Cuckoo-bees	Hymenoptera	Apidae	Thyreus	*Thyreus sp.*	Indigenous
European honeybee	Hymenoptera	Apidae	Apis	*Apis mellifera*	Introduced
African carderbee	Hymenoptera	Apidae	Pseudoanthidium	*Pseudoanthidium repetitum*	Introduced
Large Earth bumblebee	Hymenoptera	Apidae	Bombus	*Bombus terrestris*	Introduced
Other native bees	Hymenoptera	Multiple	Multiple	*Anthophila 1*	Indigenous
European wasp	Hymenoptera	Vespidae	Vespula	*Vespula germanica*	Introduced
Other native wasps	Hymenoptera	Multiple	Multiple	*Hymenoptera 1*	Indigenous
Hoverflies	Diptera	Syrphidae	Multiple	*Syrphidae 1*	Indigenous
Other native flies	Diptera	Multiple	Multiple	*Diptera 1*	Indigenous
Dingy swallowtail	Lepidoptera	Papilionidae	Papilio	*Papilio anactus*	Indigenous
Panted lady	Lepidoptera	Nymphalidae	Vanesa	*Vanesa kershawi*	Indigenous
Yellow admiral	Lepidoptera	Nymphalidae	Vanesa	*Vanesa itea*	Indigenous
Meadow argus	Lepidoptera	Nymphalidae	Jumonia	*Jumonia villida*	Indigenous
Lesser wanderer	Lepidoptera	Nymphalidae	Danaus	*Danaus petilia*	Indigenous
Monarch	Lepidoptera	Nymphalidae	Danuas	*Danaus plexippus*	Introduced
Cabbage white	Lepidoptera	Pieridae	Pieris	*Pieris rapae*	Introduced
Other native butterflies	Lepidoptera	Multiple	Multiple	*Lepidoptera 1*	Indigenous

How many insect pollinator and other flower-visiting insect taxa were the field researcher and citizen scientists trained to identify?

18 These are shown in Figure 2.5 and taxonomical information about them given in Table 2.2. In Appendix I we provide the 'Pollinators Observatories' field guide, which includes a sheet for each taxon showing the visual attributes used to develop the identification skills of both research and citizen scientists.

Were the targeted insect taxa indigenous to Westgate Park?

Not all Twelve taxa may be considered native to Australia and locally indigenous to Westgate Park (Table 2.2). The remaining six taxa may be considered non-native and introduced to Australia, these are: the European honeybee (Figure 2.5C), the African carderbee (Figure 2.5D), the large Earth bumblebee (Figure 2.5E), the European wasp (Figure 2,5G), the monarch butterfly (Figure 2.5P) and the cabbage white butterfly (Figure 2.5Q).

Will the data be available to the public?

Yes Links to the data and to other sources of information regarding Pollinator Observatories will be available at the websites of Westgate Biodiversity (https://westgatebiodiversity.org.au/) and the National Environmental Science Programme – Clean Air and Urban Landscapes Hub (http://www.nespurban.edu.au).

3 Findings

How many of the targeted insect pollinator and other flower-visiting insect taxa were recorded in the research and citizen science direct observation surveys?

9 As shown in Figure 3.1, these were blue-banded bees (Figures 1.1, 2.5A & 3.2), European honeybee (Figures 2.5C & 3.3), native bees (Figures 1.5, 2.5C & 3.4), European wasp (Figures 2.5G & 3.5), native wasps (Figures 2.5H & 3.6), hoverflies (Figures 1.6 & 2.5I), native flies (Figures 2.5J & 3.7), cabbage white (Figures 2.5Q & 3.8) and native butterflies (Figures 1.2, 1.3, 1.5 & 1.7).

Which was the most frequently recorded targeted taxa?

Native flies Species belonging in this group were sighted 94 times during the research and citizen science direct observation surveys, accounting for over 20% of all records (Figure 3.1).

How many of the observed targeted taxa were indigenous to the local bioregions?

6 These were: blue-banded bees (Figures 1.1, 2.5A & 3.2), native bees (Figures 1.5, 2.5C & 3.4), native wasps (Figures 2.5H & 3.6), hoverflies (Figures 1.6 & 2.5I), native flies (Figures 2.5J & 3.7) and native butterflies (Figures 1.2, 1.3, 1.5 & 1.7).

How many of the observed targeted taxa were introduced to Australia?

3 These were: the European honeybee (Figures 2.5C & 3.3), the European wasp (Figures 2.5G & 3.5) and the cabbage white (Figures 2.5Q & 3.8).

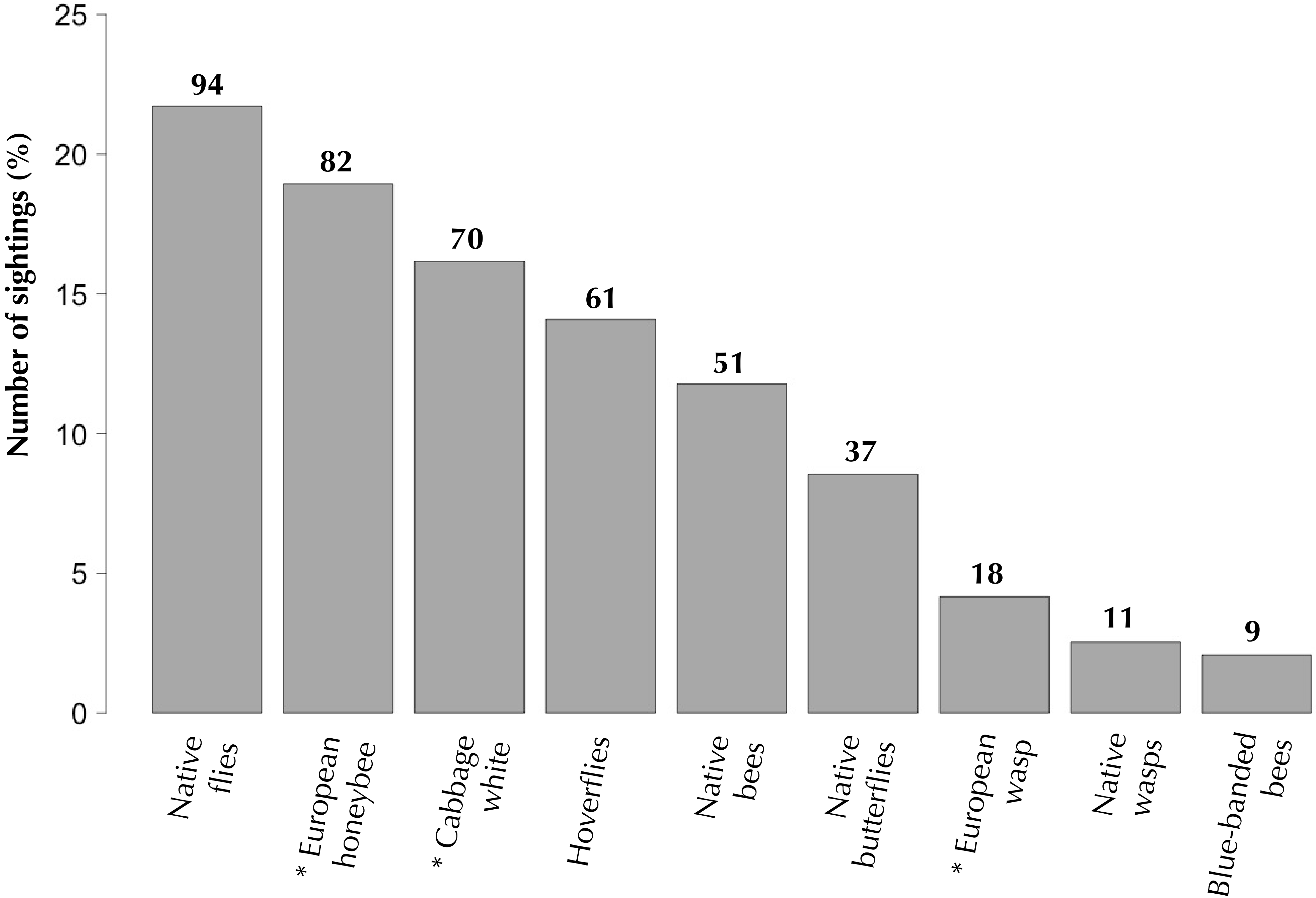


Figure 3.1 Number of sightings of each insect pollinator and other flower-visiting insect taxa as a percentage of the total number of sightings during the research and citizen science direct observation surveys. The bold numbers at the top of each bar indicate the total number of sightings of that taxa. Introduced species are indicated with an *.

Figure 3.2 The blue-banded bee *Amegilla chlorocyanea* on the pale flax-lily pollinator observatory.

Figure 3.3 The European honeybee on the austral stork's-bill pollinator observatory.

Figure 3.4 A leafcutter bee in genus *Megachile* on the hop goodenia pollinator observatory.

Figure 3.5 The European wasp on the coastal banksia pollinator observatory.

Figure 3.6 A flower wasp on the snowy daisy-bush pollinator observatory.

Figure 3.7 A native fly on the snowy daisy-bush pollinator observatory.

Figure 3.8 The cabbage white butterfly on the austral stork's-bill pollinator observatory.

Which pollinator observatories had the largest number of associated insect pollinator and other flower-visiting insect taxa as documented by the research and citizen science direct observation surveys?

Austral stork's-bill All nine of the observed targeted insect taxa were recorded at the austral stork's-bill pollinator observatory (Figures 3.9 & 3.10). The second, third and fourth pollinator observatories with the largest number of associated insect taxa were hop goodenia, black paperback and snowy daisy-bush, with eight taxa recorded at each (Figures 3.9 & 3.10).

How many plant-insect interactions were recorded during the research and citizen science direct observation surveys?

433

What percentage of the records were contributed by citizen scientists?

20% As many as one in every five records of interactions between the targeted insect taxa and the pollinator observatories were contributed by the seasonal citizen science direct observation surveys.

How many citizen scientists participated in the seasonal workshops and direct observation surveys?

189 Of these, approximately 25 attended each seasonal workshop.

In which pollinator observatory were the largest number of interactions recorded?

Hop goodenia As many as 16% of all observed interactions were recorded at the hop goodenia pollinator observatory (Table 3.1). The following observatories with the largest number of observed interactions were the austral stork's-bill (15%) and snowy daisy-bush (13%) (Table 3.1).

Which was the plant-insect interaction most frequently documented by the research and citizen science direct observation surveys?

The most frequent interaction documented between a pollinator observatory and one of the targeted insect pollinator and other flower-visiting insect taxa was that between hop goodenia and European honeybees, which was observed 19 times (Figure 3.10, Table 3.1).

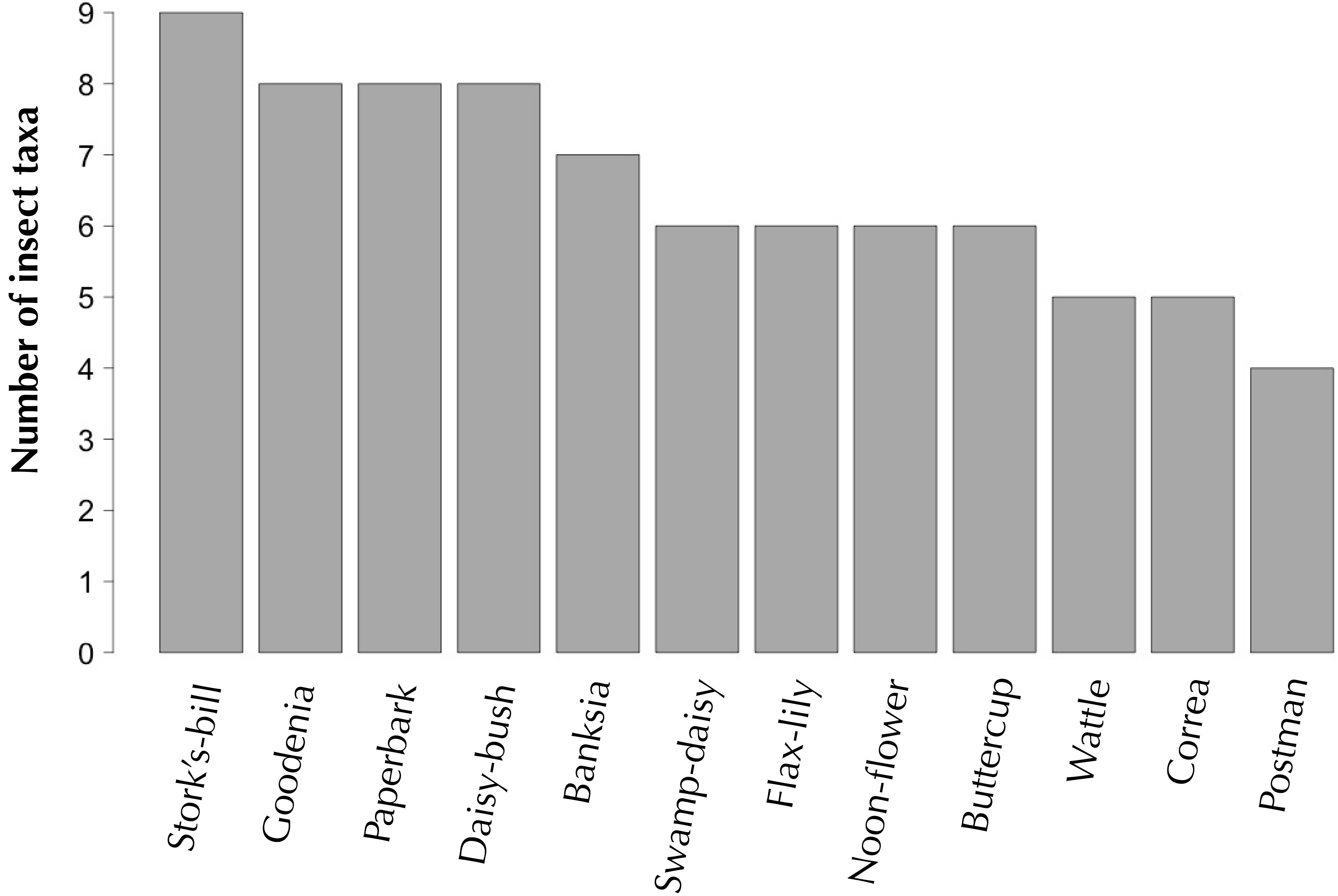


Figure 3.9 Number of targeted insect pollinator and other flower-visiting insect taxa seen in each pollinator observatory during the research and citizen science direct observation surveys.

Did each of the targeted insect taxa interact with each pollinator observatory?

No Only about 70% of all potential interactions between the targeted insects and the pollinator observatories were documented through the research and citizen science direct observation surveys (Figure 3.10, Table 3.1). The remaining 30% (zeros in Table 3.1) correspond to interactions that either do not happen in natural conditions due to ecological and biological reasons – sometimes referred to as 'Forbidden links' – or that we simply failed to observe due to inherent limitations of the direct observation survey protocol (e.g. observations only took place during the day but interaction may be realised only at night).

Which insect taxa interacted with the largest number of pollinator observatories?

As shown in Figure 3.10 and Table 3.1, native flies and hoverflies interacted with all 12 pollinator observatories. The European honeybee interacted with all but the woodland swamp-daisy observatory, and native bees with all but the common correa and running postman observatories. These four taxa may be considered 'generalists'; that is, they are capable of interacting with a wide range of plant species.

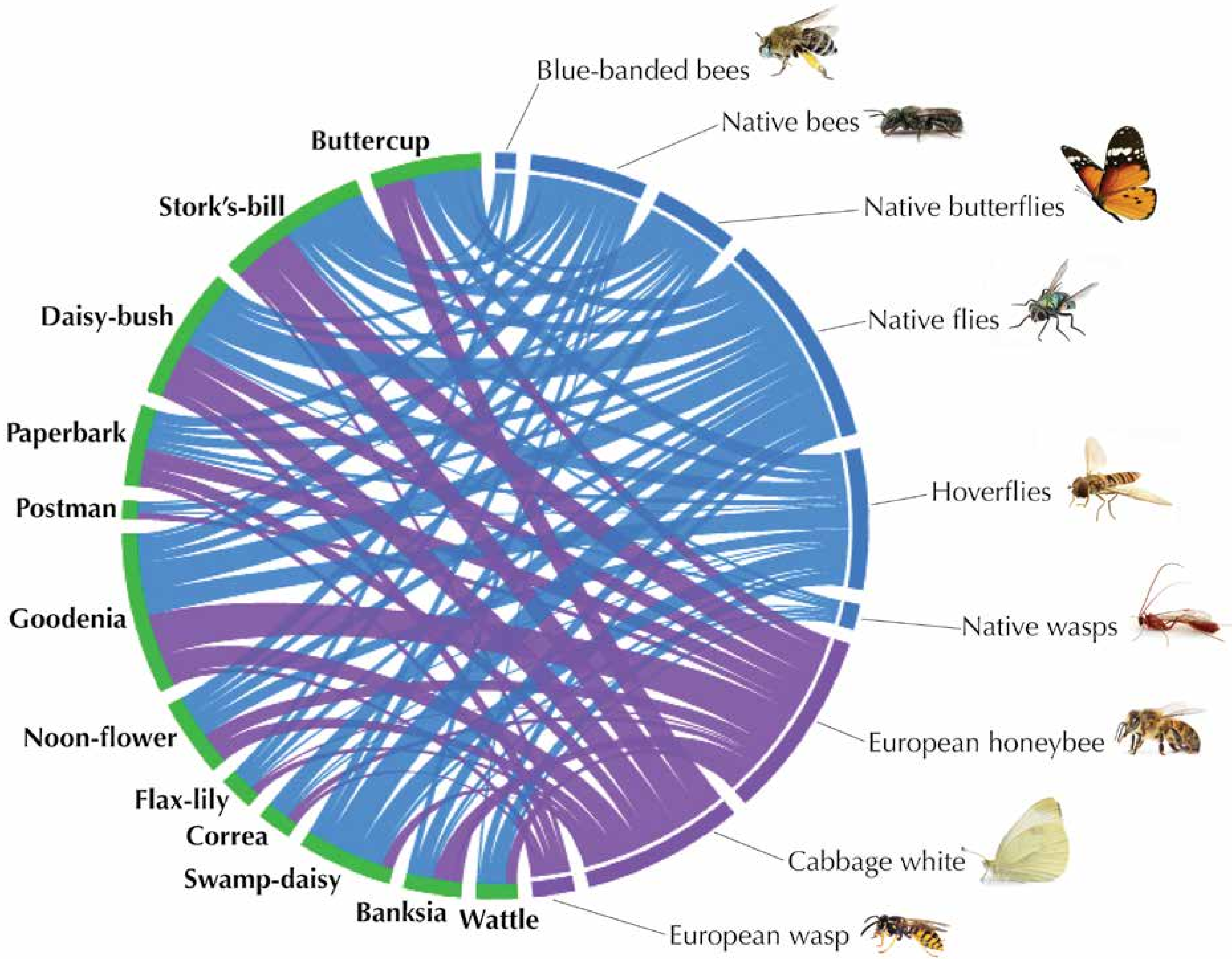
Which insect taxa interacted with the least number of pollinator observatories?

Blue-banded bees were recorded in only three pollinator observatories: hop goodenia, austral stork's-bill and pale flax-lily (Figure 3.10, Table 3.1). Blue-banded bees may be considered 'specialists'; that is, they are ecologically and/or biologically constrained to interact with a limited range of plant species. It is important to consider that some of the species comprising some of the insect taxa identified as generalist in this study (e.g. native flies and native bees) will likely also be specialists.

Were some of the documented interactions between the pollinator observatories and the targeted insect taxa only or first recorded by the citizen scientists that participated in the seasonal direct observation surveys?

Yes The interaction between the hop goodenia pollinator observatory and blue-banded bees,

Figure 3.10 (Opposite page) Network of plant-insect interactions between Westgate Park's pollinator observatories (green nodes) and native (blue nodes) and introduced (purple node) insect pollinator and other flower-visiting insect taxa as documented by the research and citizen science direct observation surveys. The width of a ribbon indicates the strength of the interaction. The chord diagram was created in the online implementation of Circos (http://mkweb.bcgsc.ca/tableviewer/).



Blue-banded bees
Native bees
Native butterflies
Native flies
Hoverflies
Native wasps
European honeybee
Cabbage white
European wasp
Buttercup
Stork's-bill
Daisy-bush
Paperbark
Postman
Goodenia
Noon-flower
Flax-lily
Correa
Swamp-daisy
Banksia
Wattle

Table 3.1 Interaction matrix between pollinator observatories and insect pollinator and other flower-visiting insect taxa. Cell values represent the number of times a given interaction was recorded during the research and citizen science direct observation surveys.

	Hop goodenia	Austral stok's-bill	Snowy daisy-bush	Large river buttercup	Woodland swamp daisy	Black paperbark	Rounded noon-flower	Costal banksia	Golden wattle	Common correa	Pale flax-lily	Running postman	**Total per insect taxa**	**Count of observatories used by each insect taxa**
Native flies	13	7	15	10	15	5	5	6	4	8	3	3	**94**	**12**
European honeybee	19	13	8	6	0	8	7	9	5	3	1	3	**82**	**11**
Cabbage white	11	13	13	11	5	6	7	1	0	0	3	0	**70**	**9**
Hoverflies	11	4	8	8	10	3	6	2	6	1	1	1	**61**	**12**
Native bees	7	11	4	6	4	5	6	3	1	0	4	0	**51**	**10**
Native butterflies	4	10	4	7	5	3	3	0	0	0	0	1	**37**	**8**
European wasp	3	2	5	0	0	3	0	3	0	2	0	0	**18**	**6**
Native wasps	0	2	1	0	2	2	0	1	2	1	0	0	**11**	**7**
Blue-banded bees	2	4	0	0	0	0	0	0	0	0	3	0	**9**	**3**
Total per observatory	**70**	**66**	**58**	**48**	**41**	**35**	**34**	**25**	**18**	**15**	**15**	**8**	**433**	

Table 3.2 Number of insect species per insect group recorded in the study by both the direct observation and sweep-netting surveys.

	Species
Parasitoid wasps	62
Flies	43
Beetles	39
Heteropteran bugs	29
Bees	8
Leafhoppers/Treehoppers	5
Planthoppers	4
Butterflies	5
Ants	3
Jumping plant lice	2
Stinging wasps	2
	202

for example, was first documented by a citizen scientist. This interaction was also documented posteriorly during a research direct observation survey.

How many insect species were recorded in the study by both the direct observation and sweep-netting surveys?

202

Which insect group had the highest diversity of species?

Parasitoid wasps, followed by flies and beetles (Figure 3.11; Table 3.2).

Which was the most common species in the study?

The most common species was a Minute brown scavenger beetle [Latriidae: Cortinicara], accounting for almost 10% of all records (Figure 3.12). The minute brown scavenger beetle has been recently reported as the most commonly occurring species across the City of Melbourne, where it was found in association with 102 different plant species (Mata et al. 2016).

Which was the most common ant?

The most common ant species was a rainbow ant [Formicidae: Iridomyrmex], accounting for almost 8% of all records (Figure 3.12).

Which was the most common bee?

The introduced European honeybee *Apis mellifera* (Figures 2.5C & 3.3) was the most frequently recorded bee in the study, accounting for approximately 7% of all records (Figure 3.12).

How many indigenous bee species were documented during the study?

At least seven indigenous bee species were documented during the study, including two species of sweet bee in genus *Lassioglossum*, the blue-banded bee *Amegilla chlorocyanea* (Figures 1.1, 2.5A & 3.2), a leafcutter bee in genus *Megachile* (Figure 3.4) and a masked bee in genus *Hylaeus*.

Which were the most common indigenous bees?

The most common indigenous bee species were a sweet bee [Halictidae: Lassioglossum] (Figure 1.5) and blue-banded bees [Apidae: Amegilla] (Figures 1.1, 2.5A & 3.2, each accounting for approximately 1% of all records (Figure 3.12).

Which was the most common butterfly?

The introduced cabbage white *Pieris rapae* (Figures 2.5Q & 3.8) was the most frequently recorded butterfly in the study, accounting for approximately 6% of all records (Figure 3.12).

How many indigenous butterflies were documented during the study?

At least four indigenous butterfly species were documented during the study, including the blue grass *Zizina labradus* (Figures 1.3 & 2.5R), the yellow-banded dart *Ocybadistes walkeri* (Figure 1.7), the white caper *Belenois java* (Figure 1.2) and the Australian painted lady *Vanessa kershawi* (Figure 2.5L).

Which was the most common indigenous butterfly?

The most common indigenous butterfly species was the blue grass *Zizina labradus* [Lepidoptera: Lycaneidae] (Figures 1.3 & 2.5R), accounting for approximately 2% of all records (Figure 3.12).

Which was the most common fly?

The most common fly species were hoverflies [Diptera: Syrphidae] (Figures 1.6 & 2.5I), accounting for almost 6% of all records (Figure 3.12). The hoverflies documented during the study include the yellow-shouldered stout hoverfly *Simosyrphus grandicornis* (Figure 3.13) and at least one other currently unidentified species.

Which was the most common heteropteran bug?

The most common heteropteran bug species was the harlequin bug *Dindymus versicolor* [Hemiptera:

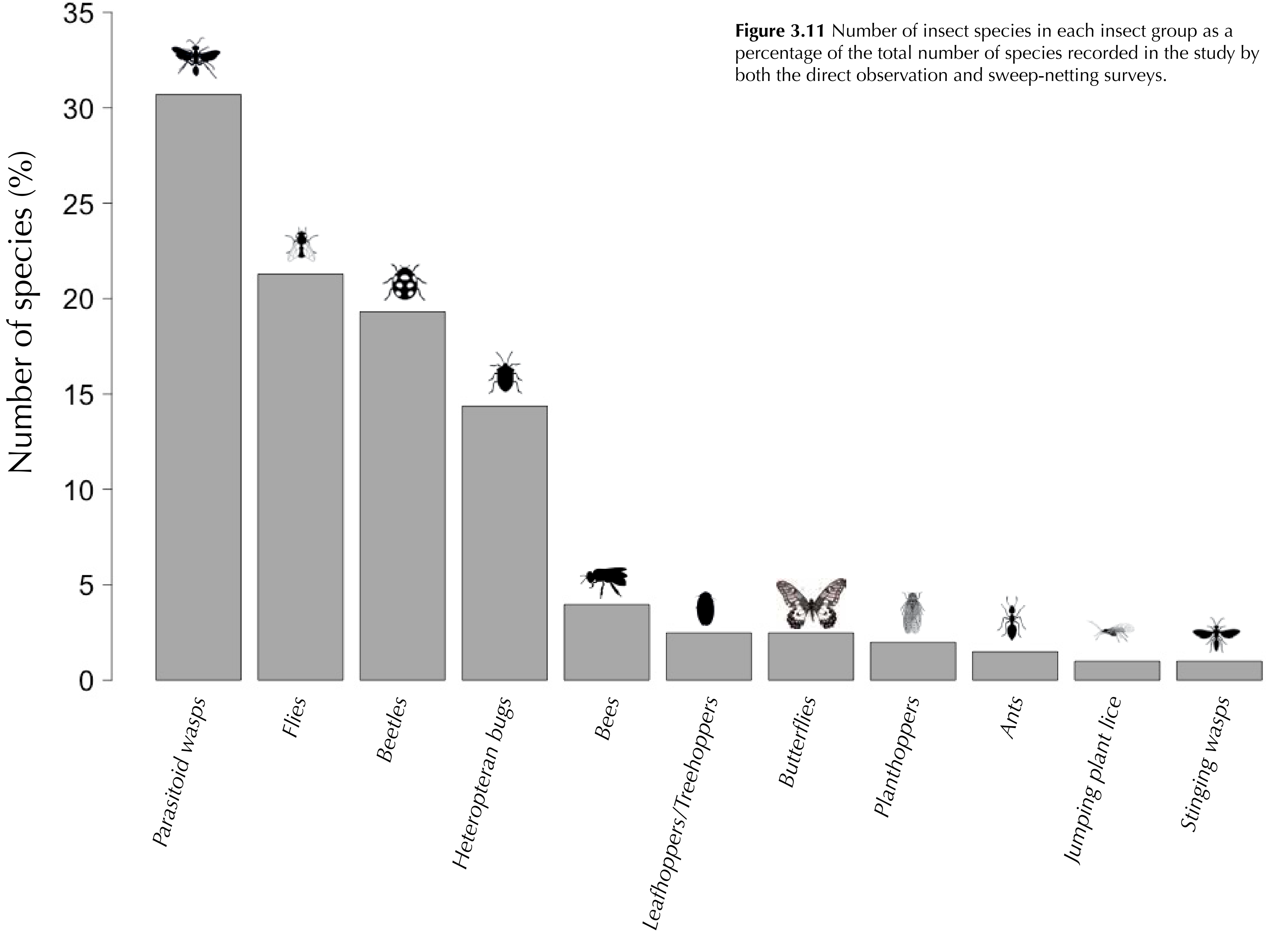


Figure 3.11 Number of insect species in each insect group as a percentage of the total number of species recorded in the study by both the direct observation and sweep-netting surveys.

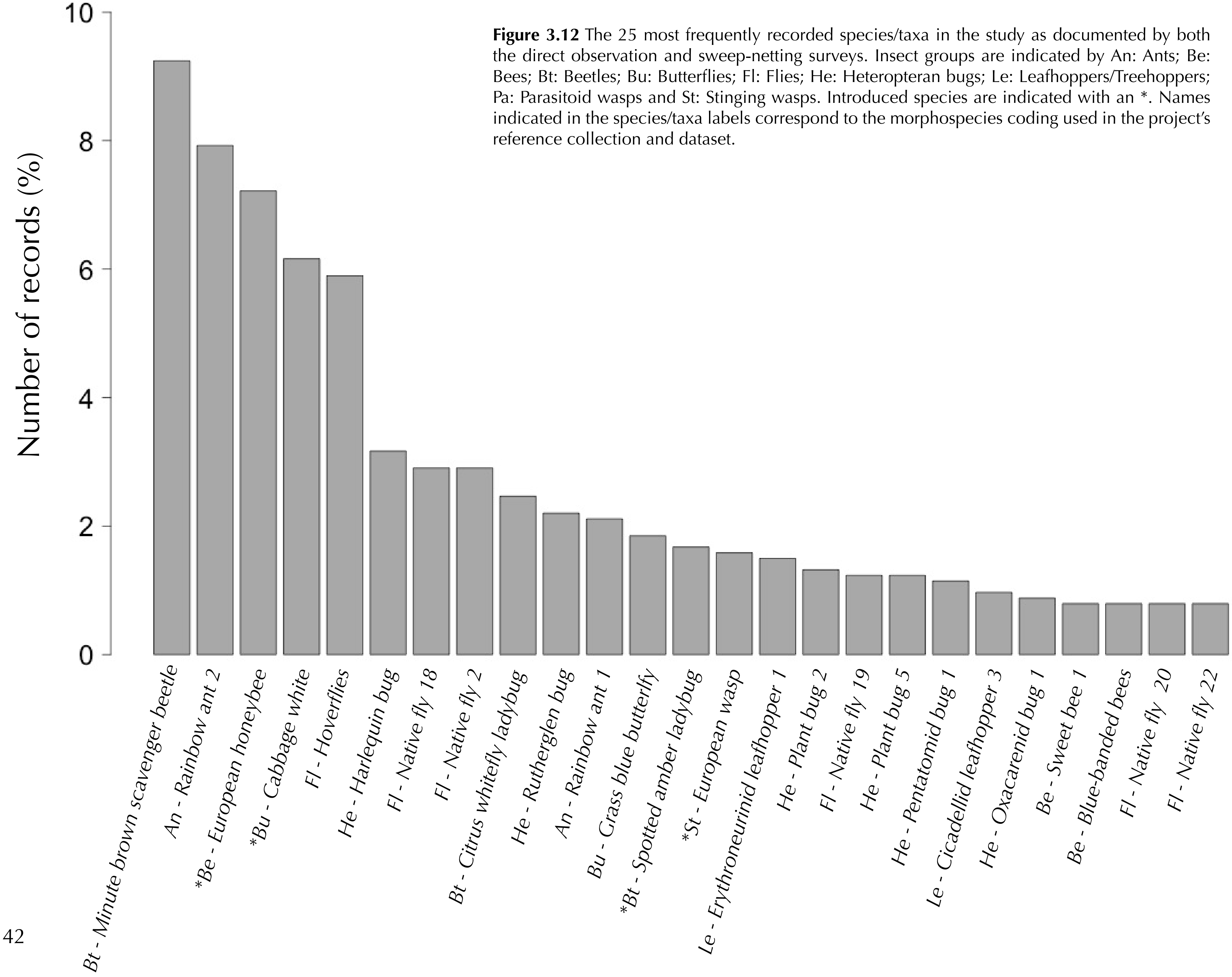


Figure 3.12 The 25 most frequently recorded species/taxa in the study as documented by both the direct observation and sweep-netting surveys. Insect groups are indicated by An: Ants; Be: Bees; Bt: Beetles; Bu: Butterflies; Fl: Flies; He: Heteropteran bugs; Le: Leafhoppers/Treehoppers; Pa: Parasitoid wasps and St: Stinging wasps. Introduced species are indicated with an *. Names indicated in the species/taxa labels correspond to the morphospecies coding used in the project's reference collection and dataset.

Figure 3.13 The yellow-shouldered stout hoverfly *Simosyrphus grandicornis* on fennel Foeniculum vulgare in Westgate Park.

Pyrrhocoridae] (Figure 1.4), accounting for approximately 3% of all records (Figure 3.12).

Which was the most common stinging wasp?

The most common stinging wasp species was the European wasp *Vespula germanica* [Hymenoptera: Vespidae] (Figures 2.5G & 3.5), accounting for approximately 1.6% of all records (Figure 3.12).

Which was the most common leafhopper?

The most common leafhopper species was an erythroneurinid leafhopper [Hemiptera: Cicadellidae], accounting for approximately 1.5% of all records (Figure 3.12).

Which were the most common parasitoid wasps?

All of the 62 parasitoid wasp species recorded in the study were rare, accounting each for less than 0.5% of all records.

Which pollinator observatories had the largest number of associated insect species as documented by the direct observation and sweep-netting surveys?

Hop goodenia As many as 35% of all species were recorded at the hop goodenia pollinator observatory (Figures 3.14). This was followed closely by the snowy daisy-bush observatories, in which approximately 34% of all species were recorded (Figure 3.14). The third pollinator observatory with the largest number of associated insect species was Austral stork's-bill, with approximately 27% of all recorded species (Figures 3.14).

How many plant-insect interactions were recorded during the direct observation and sweep-netting surveys?

1136

In which pollinator observatory was the largest number of interactions recorded during the direct observation and sweep-netting surveys?

Snowy daisy-bush As many as 18% of all observed interactions were recorded at the snowy daisy-bush pollinator observatory (Table 3.3). The following observatories with the largest number of observed interactions were hop goodenia (16%) and austral stork's-bill (13%) (Table 3.3).

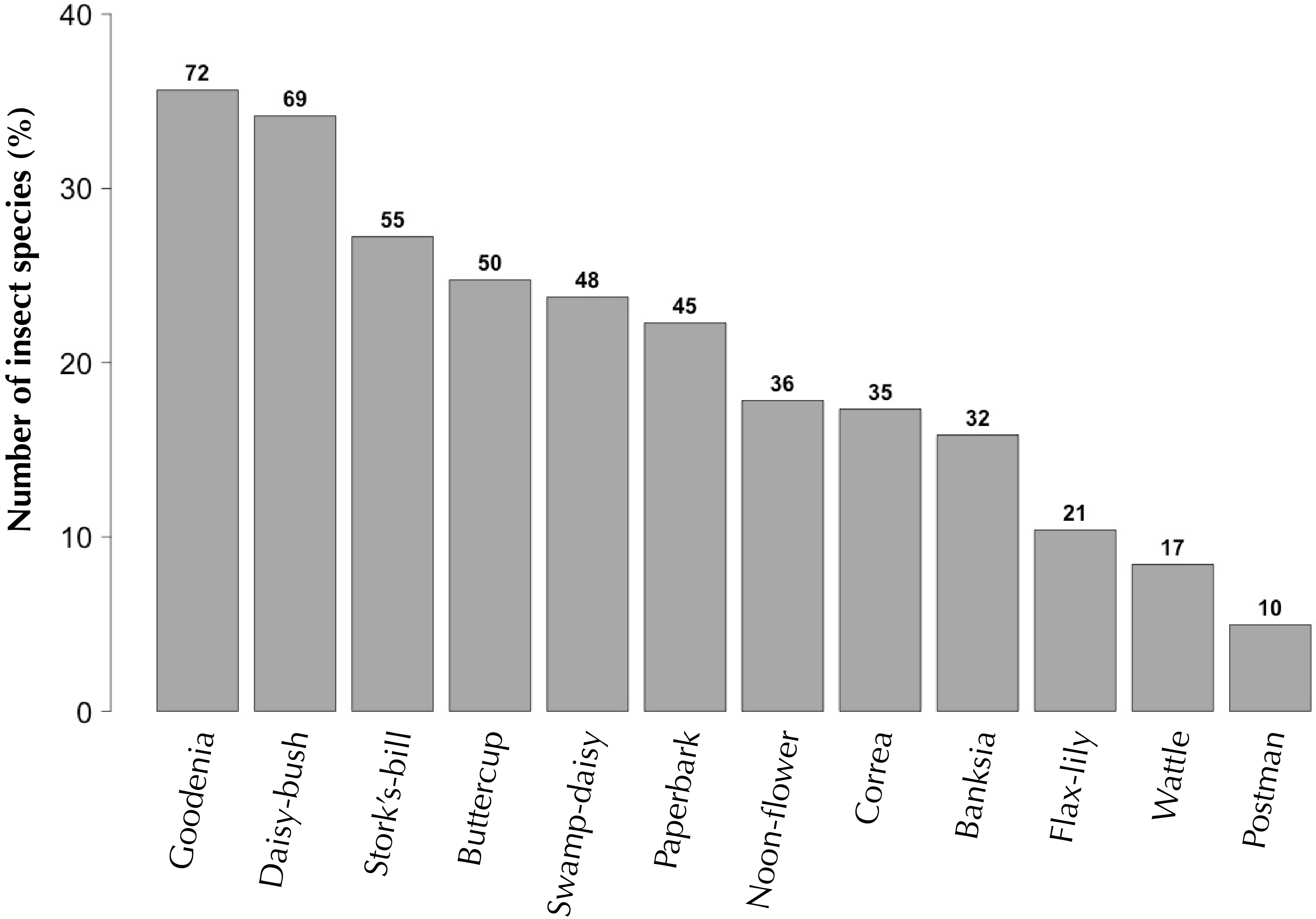


Figure 3.14 Number of insect species recorded in each pollinator observatory as a percentage of the total number of species recorded in the study. Bold numbers in top of each bar indicate the total number of insect species recorded in each pollinator observatory.

Figure 3.15 A pair of Rutherglen bugs (*Nysius vinitor*) mating on milky beauty-heads Calocephalus lacteus in Westgate Park.

Figure 3.16 An example of a peacock fly (Kosciuszko National Park, New South Wales, Australia).

Table 3.3 Interaction matrix between pollinator observatories and insect groups. Cell values represent the number of times a given interaction was recorded during the direct observation and sweep-netting surveys.

	Snowy daisy-bush	Hop goodenia	Austral stok's-bill	Large river buttercup	Woodland swamp daisy	Black paperbark	Rounded noon-flower	Common correa	Costal banksia	Pale flax-lily	Golden wattle	Running postman	**Total per insect taxa**	**Count of observatories used by each insect group**
Beetles	53	45	31	16	20	20	16	11	11	11	6	3	**243**	**12**
Flies	31	29	14	50	35	15	15	14	14	1	9	3	**230**	**12**
Heteropteran bugs	49	23	37	10	10	28	0	7	7	4	2	0	**177**	**10**
Ants	19	17	13	15	13	12	9	3	7	6	1	0	**115**	**11**
Bees	8	24	19	6	2	12	10	3	9	8	6	3	**110**	**12**
Parasitoid wasps	18	21	12	10	7	5	10	6	9	1	2	1	**102**	**12**
Butterflies	17	12	21	17	9	8	10	0	1	3	0	0	**98**	**9**
Leafhoppers/Treehoppers	4	5	3	6	7	1	2	2	0	0	0	2	**32**	**9**
Stinging wasps	6	3	2	0	0	3	0	2	3	0	0	0	**19**	**6**
Planthoppers	0	1	0	3	2	0	0	1	1	0	0	0	**8**	**5**
Jumping plant lice	0	0	0	0	1	0	0	0	0	0	1	0	**2**	**2**
Total	**205**	**180**	**152**	**133**	**106**	**104**	**72**	**49**	**62**	**34**	**27**	**12**	**1136**	

Table 3.4 Number of insect species per insect functional group recorded in the study by both the direct observation and sweep-netting surveys.

Insect functional group	Species
Herbivores	83
Parasitoids	63
Detritivores	52
Flower-visitors/pollinators	26
Predators	26

Which was the most frequent pollinator observatory – insect group interaction documented by the direct observation and sweep-netting surveys?

The most frequent pollinator observatory – insect group interaction documented by the direct observation and sweep-netting surveys was that between snowy-daisy bush and beetles, which was observed 53 times (Table 3.3).

Did each insect group interact with each pollinator observatory?

No Only about 75% of all potential interactions between the insect groups and the pollinator observatories were documented through the direct observation and sweep-netting surveys (Table 3.3). The remaining 25% (zeros in Table 3.3) are due to either 'Forbidden links' – interactions that do not happen in natural conditions due to eco-evolutionary reasons (e.g. the mouthparts of heteropteran bugs might not be adapted to pierce the leaf tissues of succulent plants) – or inherent limitations of the survey protocols.

Which insect groups interacted with the largest number of pollinator observatories?

As shown in Table 3.3, beetles, flies, bees and parasitoid wasps interacted with all 12 pollinator observatories.

Which insect group interacted with the least number of pollinator observatories?

Jumping plant lice were recorded in only two pollinator observatories: woodland swamp-daisy and golden wattle (Table 3.3). Jumping plant lice may be considered 'herbivore specialists'; that is, they are eco-evolutionarily adapted to interact with (i.e. feed on) a limited range of plant species.

How many species were flower-visitors/ pollinators?

26 Besides the five targeted insect pollinators and other flower-visiting insect taxa considered at the species or morphospecies level in the direct observation surveys (European honeybee (Figures 2.5C & 3.3), the cabbage white (Figures 2.5R & 3.8), hoverflies (Figures 1.6, 2.5I & 3.13), the European wasp (Figures 2.5G &3.5) and blue-banded bees (Figures 1.1, 2.5A & 3.2)), another 21 species may be considered as flower-visiting/pollinator taxa. These included: six native bees (Figures 1.5, 2.5F & 3.4); one native wasp (a flower wasp (Figure 3.6)); five native beetles (a leaf beetle, a pintail beetle, a soft-wing flower beetle and two carpet beetles); four native butterflies (the grass blue (Figures 1.3 & 2.5R), the yellow-banded dart (Figure 1.7), the white caper (Figure 1.2) and the Australian painted lady (Figure 2.5L)); two heteropteran bugs (the harlequin bug (Figure 1.4) and the Rutherglen bug (Figure 3.14); and three native flies (three peacock flies (Figure 3.15)). Most fly and wasp species in the study's reference collection however remain to be identified to a taxonomical level at which the status of flower-visiting/pollinator can be confidently assigned. Thus, this figure of 26 species is in all likelihood a large underestimate of the actual flower-visiting/pollinator diversity associated with the studied pollinator observatories.

How many species belonged to functional groups other than pollinators?

As many as 83 species were herbivores, which is as many as 40% of all recorded species (Table 3.4). This group was represented by a diverse array of ant, bee, beetle, butterfly, fly, heteropteran bug, leafhopper/treehopper, planthopper and stinging wasp species. Parasitoids represented approximately 30% of all recorded species (Table 3.4.) and included all 62 recorded parasitoid wasps plus one species of stinging wasp – a flower wasp in family Scoliidae (Figure 3.6). Detritivores represented approximately 25% of all recorded species (Table 3.4) and included 52 ant, beetle, fly and stinging wasp species. As flower-visitors/pollinators, predators accounted for approximately 13% of all recorded species (Table 3.4). Predators were represented by 26 ant, beetle, fly, heteropteran bug and stinging wasp species. While the research was originally conceived to focus on insect pollinators, the above findings highlight the unintended additional benefit of the research in yielding invaluable data on a range of other key insect functional groups.

4 Management recommendations and future directions

Which management actions will be of most benefit to provide for taxonomically and functionally diverse insect communities in Westgate Park?

We provide below two recommended management actions to provide for taxonomically and functionally diverse insect communities in Westgate Park:

1. Increase the cover and spatial distribution throughout the park of plant species that provide resources for a taxonomically (e.g. ants, beetles, bees, butterflies, bugs) and functionally (e.g. pollinators, herbivores, predators) diverse range of insect species. Based on our findings, these would include hop goodenia, Austral stork's-bill, snowy daisy-bush, large river buttercup and woodland swamp daisy.

2. Continue to foster vegetation structural complexity throughout the park by planting a diverse array of midstorey plant growth forms, with a particular focus on indigenous forbs, lilioids, graminoids and shrubs. Based on this and previous studies (e.g. Mata et al. 2016) some of the midstorey species associated with the highest insect species richness would include fragrant saltbush, sweet bursaria, gold-dust wattle, hop goodenia, spiny-headed mat-rush, tussock-grass, wallaby grass and kangaroo grass.

Which management actions will be of most benefit to provide for indigenous insect pollinators in Westgate Park?

We provide below two recommended management actions specifically tailored to provide for indigenous insect pollinators in Westgate Park:

1. Increase the cover and spatial distribution throughout the park of plant species that provide resources for specialist indigenous insect pollinators. For example, our findings indicate that only three of the studied plant species provided

for blue-banded bees. These were hop goodenia, Austral stork's-bill and pale flax-lily.

2. Increase the cover and spatial distribution throughout the park of plant species that provide resources for rare indigenous insect pollinators. For example, our findings indicate that amongst the studied plant species only the rounded noon-flower provided for the white caper butterfly.

Could these management recommendations to provide for pollinators and other insect species be potentially detrimental to other non-insect species?

We acknowledge and advocate for the conservation principle that every management decision tailored to benefit a specific taxon or group of related taxa should be ethically crafted to carefully consider the potential detrimental ramifications for other, non-targeted taxa. The management actions we recommend here for insects are comparable to processes such as plant recruitment, plant propagation and ecological succession that would occur under natural conditions throughout the life cycle of most terrestrial ecosystems. We therefore believe that our recommended management actions to benefit taxonomically and functionally diverse insect communities should not have detrimental effects on other non-insect taxa occurring in the park.

Are these management recommendations transferable to other greenspace types in the City of Melbourne and adjacent municipalities?

Yes Our recommendations should apply to any type of greenspace, including well-established public greenspaces such as parks and reserves, but also less traditional permanent (e.g. nature strips, road verges, greenroofs) and temporal (e.g. pop-up parks) greenspaces. Our recommendations are equally transferable to the private realm and would be ideally uptaken by initiatives aimed at bringing indigenous nature back into private greenspaces such as residential gardens (e.g. gardens for wildlife).

What steps could be taken to facilitate engagement between the park's visitors and its insect pollinators?

We provide below six recommended steps that

Figure 4.1 (Opposite page) Example of a pollinator observatory signage board.

Pollinator observatory 1

Hop goodenia

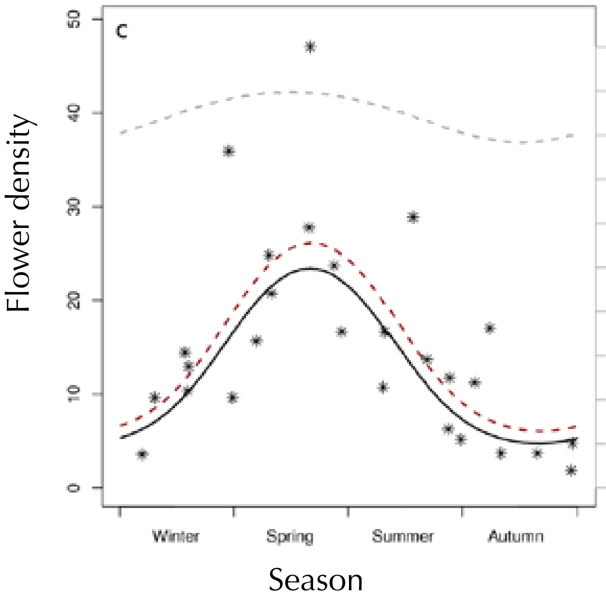
Goodenia ovata

[Asterales: Goodeniaceae]

Shrub

Indigenous

Flowering phenology and resources



Insect pollinators

<u>Indigenous</u>

Blue-banded bees

Sweet bees

Leafcutter bees

Hoverflies

Yellow-banded dart butterfly

<u>Introduced</u>

European honeybee

Cabbage white butterfly

Insect community

A total of 72 different ant, bee, beetle, butterfly, fly, heteropteran bug, leafhopper/treehopper, parasitoid wasp, planthopper and stinging wasp species have been recorded in association with hop goodenia in Westgate Park.

we believe would generate engagement between Westgate Park visitors and its insect pollinators and other flower-visiting insect taxa:

1. Place a map of the park's network of pollinator observatories and information about the study and the park's insect pollinators on the park's information board.

2. Pay special attention to the maintenance requirements of the pollinator observatories to guarantee as much as possible that they remain healthy throughout all seasons. For example, remove known detrimental weeds from areas adjacent to the observatories and provide supplementary water inputs during droughts.

3. At each pollinator observatory, add a signage board – during its flowering season – to indicate the location of the observatory and to communicate to park visitors key information about the observatory and associated insect pollinators and community. An example of how this signage board might look like is given in Figure 4.1.

4. Initiate a long-term 'Insect pollinators of Westgate Park' citizen science program. This program should focus on the following two main aspects: (1) providing periodic training sessions to interested citizen scientists on how to identify the park's key insect pollinators and other flower-visiting taxa, and on how to conduct research-grade timed surveys at the currently established pollinator observatories, as well as other flowering plant throughout the park; and (2) encouraging park visitors to record opportunistic observations of plant-insect pollinator interactions throughout the park through an interactions-based app such as the CAUL Hub's Urban Wildlife 'Beneficial Insects' app or an online social network of naturalist citizen science project such as iNaturalist (https://www.inaturalist.org/).

5. Conduct a yearly special 'Insect Pollinators' BioBlitz event to draw nature photographers, enthusiast citizen scientists and expert insect taxonomists and ecologists to further document the richness of plant-insect pollinator interactions occurring throughout the park.

6. Summarise all background and ongoing plant-insect pollinator interactions knowledge into a 'Plant-insect pollinator interaction of the month' poster series. Advertise these through social media and at the park's notice board.

Would further studies like Pollinator Observatories add to our knowledge of plant-pollinator interactions in Westgate Park?

We provide below three suggested options for future research we believe may contribute to capture the complex nature of plant-insect pollinator interactions across a greenspace site with such a diversity of plant species and habitats as Westgate Park:

1. Expand the network of pollinator observatories to include a wider range of plant species, with a balanced representation of growth forms and flowering seasons. At the same time, use the knowledge learned in the study to expand the number of insect pollinators and other flowering-visiting insect taxa used to train the research and citizen scientists. Ideally, increase the periodicity of both the research and citizen science surveys.

2. Develop parallel studies focused specifically at the immature stages of known insect pollinators. These could include studies to (1) elucidate which plant species may be acting as host for butterfly caterpillars; and (2) explore which types of soils, ground covers and vegetation are being used by native bees for nesting.

3. Use the network of pollinator observatories to synergistically survey for plant-bird pollinator interactions.

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Appendix I
Pollinator Observatories field guide

This field guide was based on *An identification guide to some of the most beneficial insects in Australian urban greenspaces – the CAUL Hub 'Beneficial Insects' app training module* (Mata et al. 2018).

Pollinator observatories – Field guide

Blythe Vogel and Luis Mata | Clean Air and Urban Landscapes Hub

Field research protocol:

1. Locate pollinator observatory to be surveyed;
2. Record metadata; and
3. Conduct timed survey - 7 min!

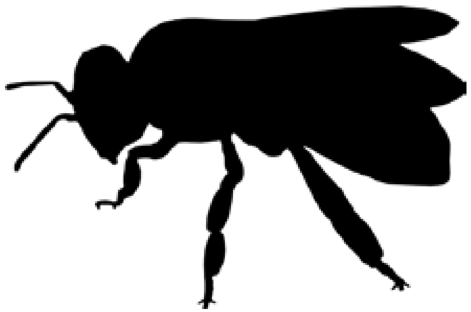
Guidelines:

1. Avoid disturbing the targeted flower(s) while filling in the metadata;

2. Try your best to be quiet and mindful while conducting the timed surveys as this will greatly increase your chances of spotting pollinators; and

3. Bees and wasps have been known to sting people, do not attempt to touch them!

Insect pollinators

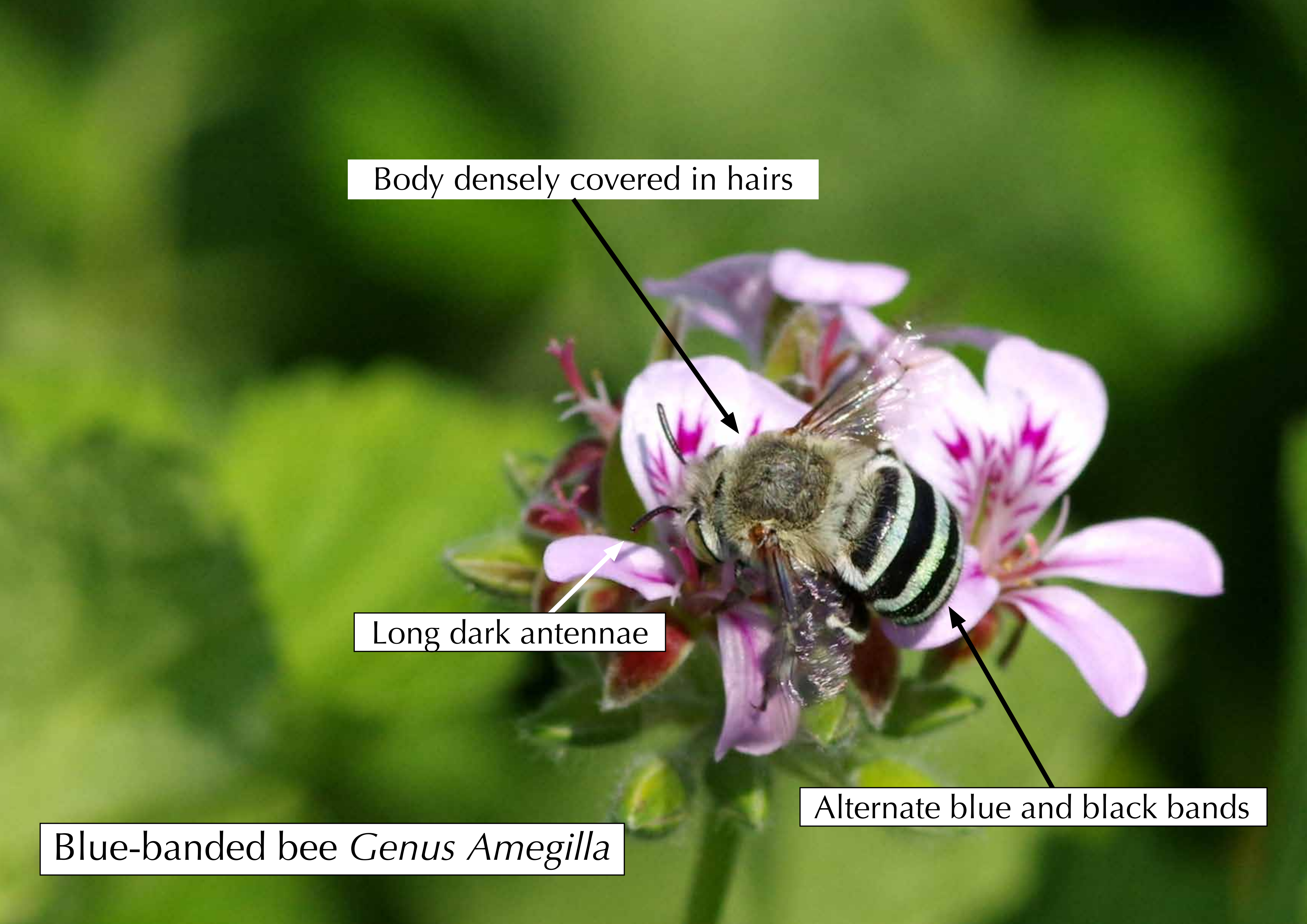


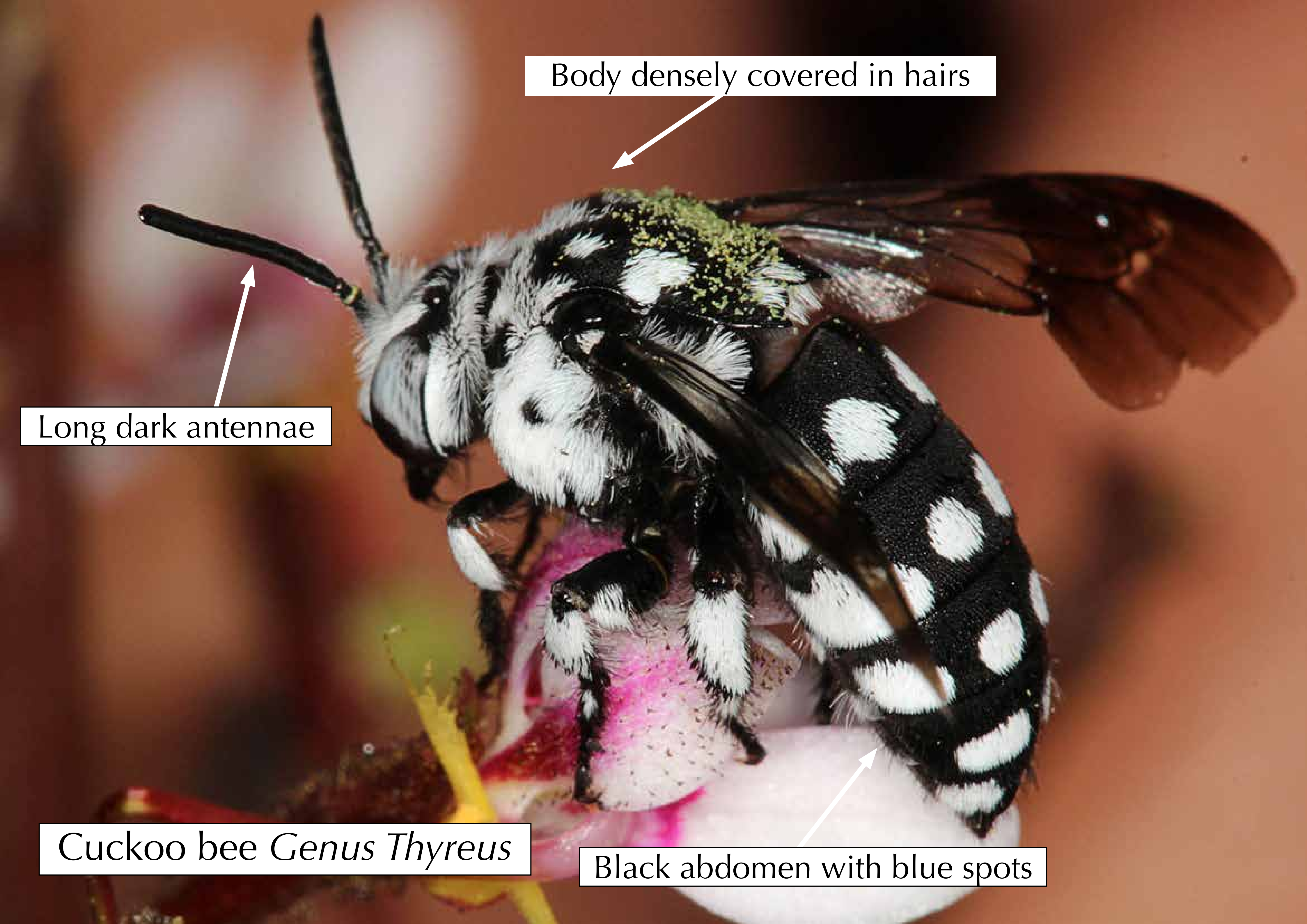
Bees

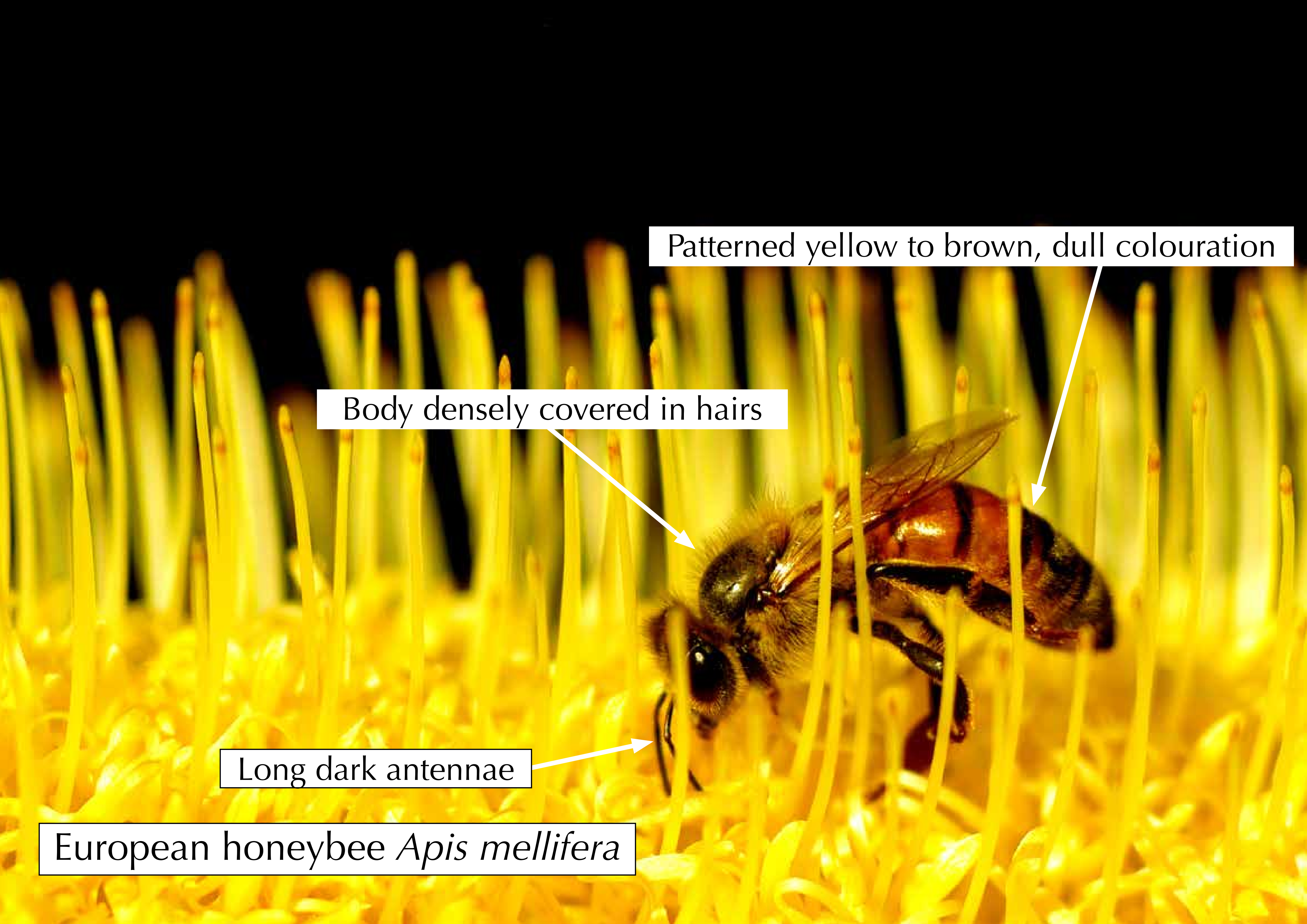
Butterflies

Flies

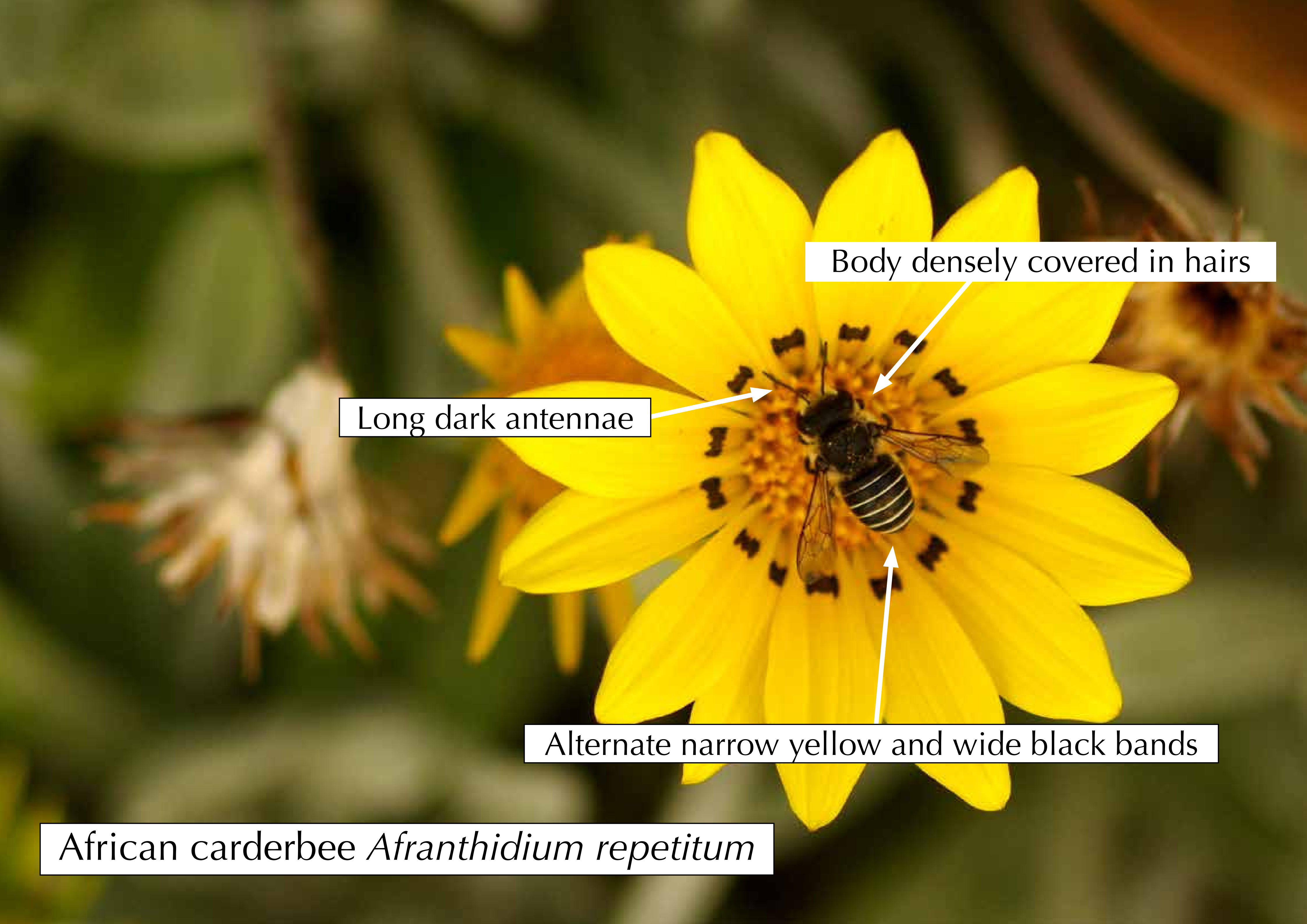
Wasps


Body densely covered in hairs
Long dark antennae
Alternate blue and black bands
Blue-banded bee *Genus Amegilla*

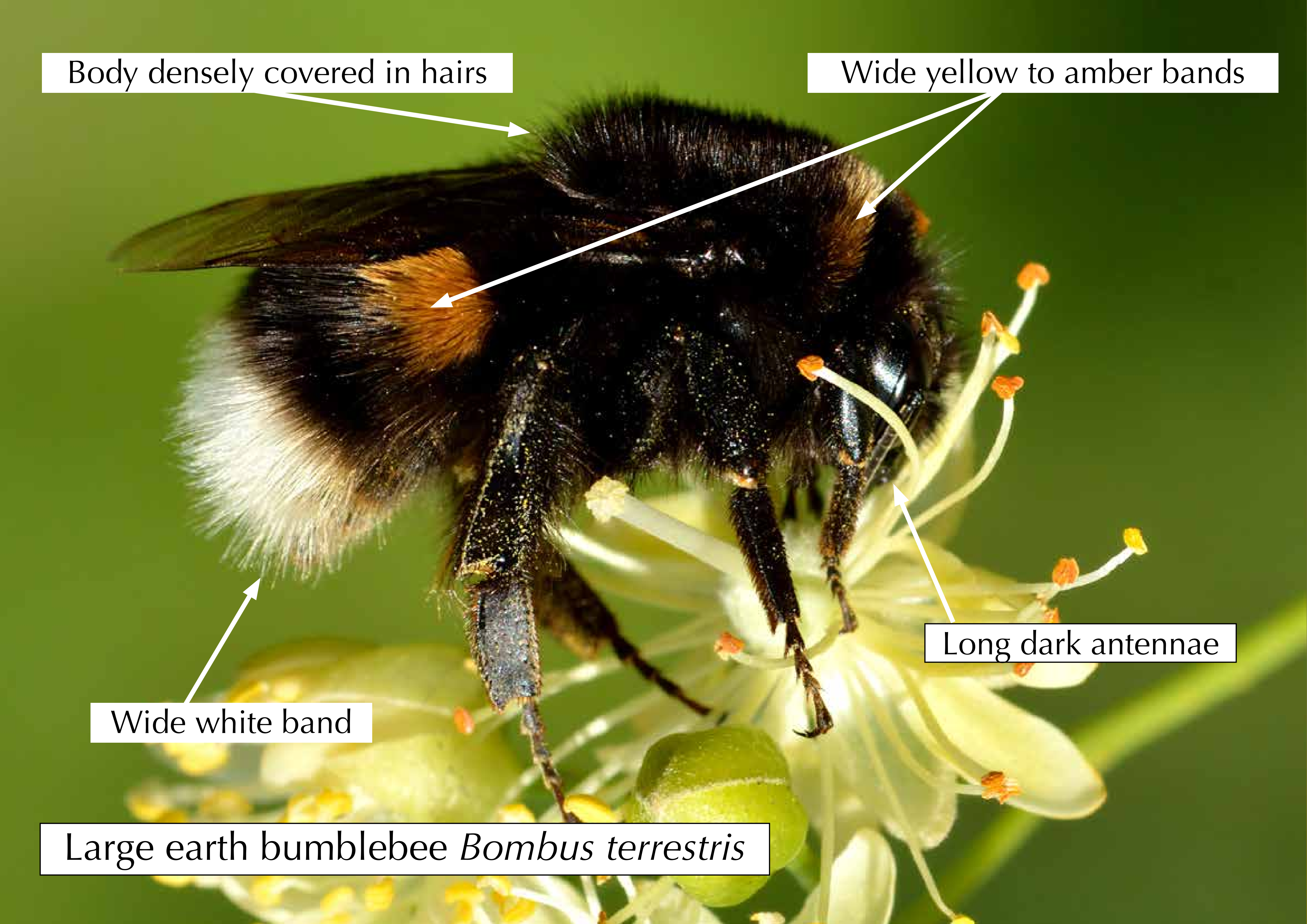

Body densely covered in hairs
Long dark antennae
Cuckoo bee *Genus Thyreus*
Black abdomen with blue spots



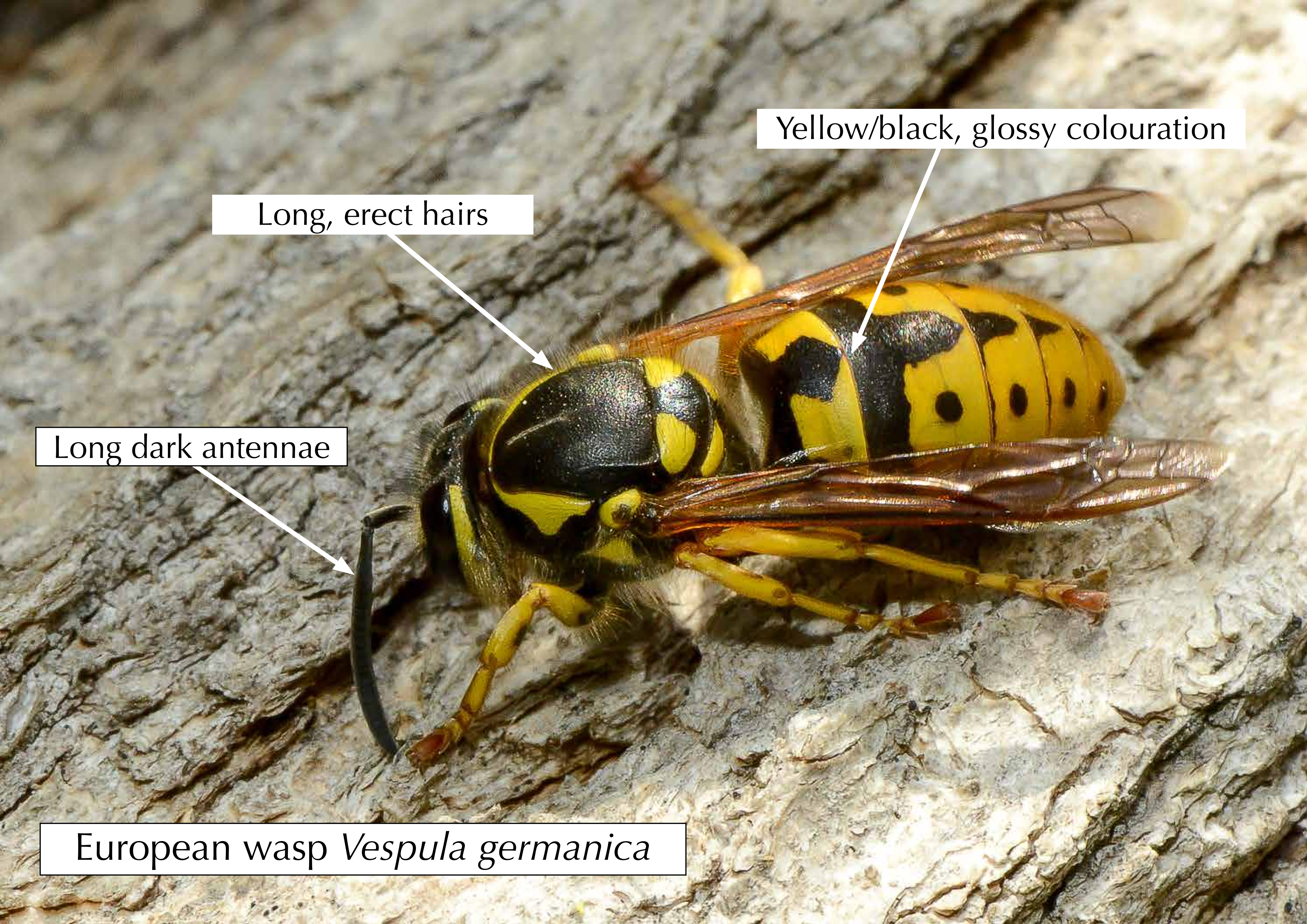
European honeybee *Apis mellifera*



African carderbee *Afranthidium repetitum*


Body densely covered in hairs
Wide yellow to amber bands
Long dark antennae
Wide white band
Large earth bumblebee *Bombus terrestris*

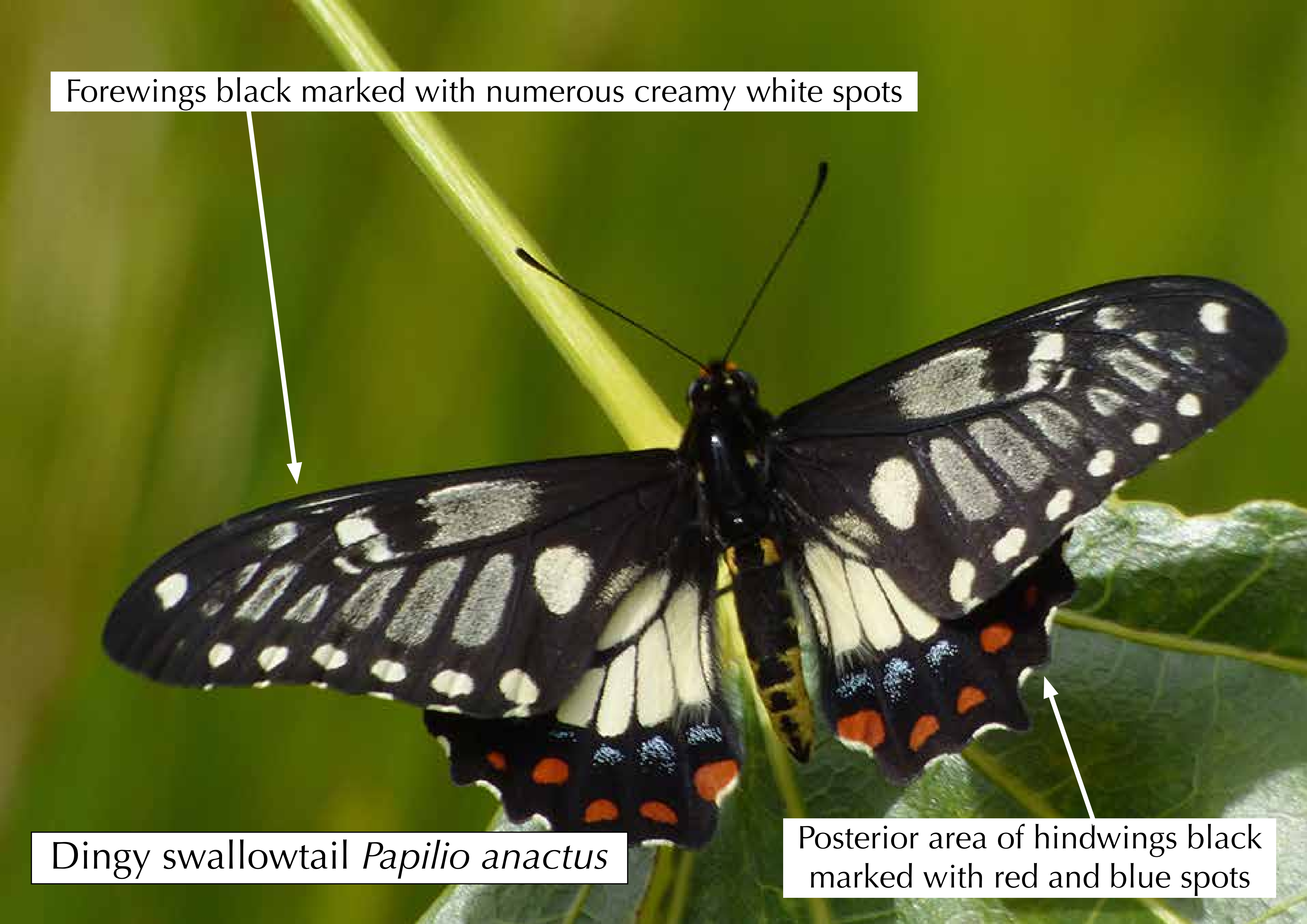
Other native bees

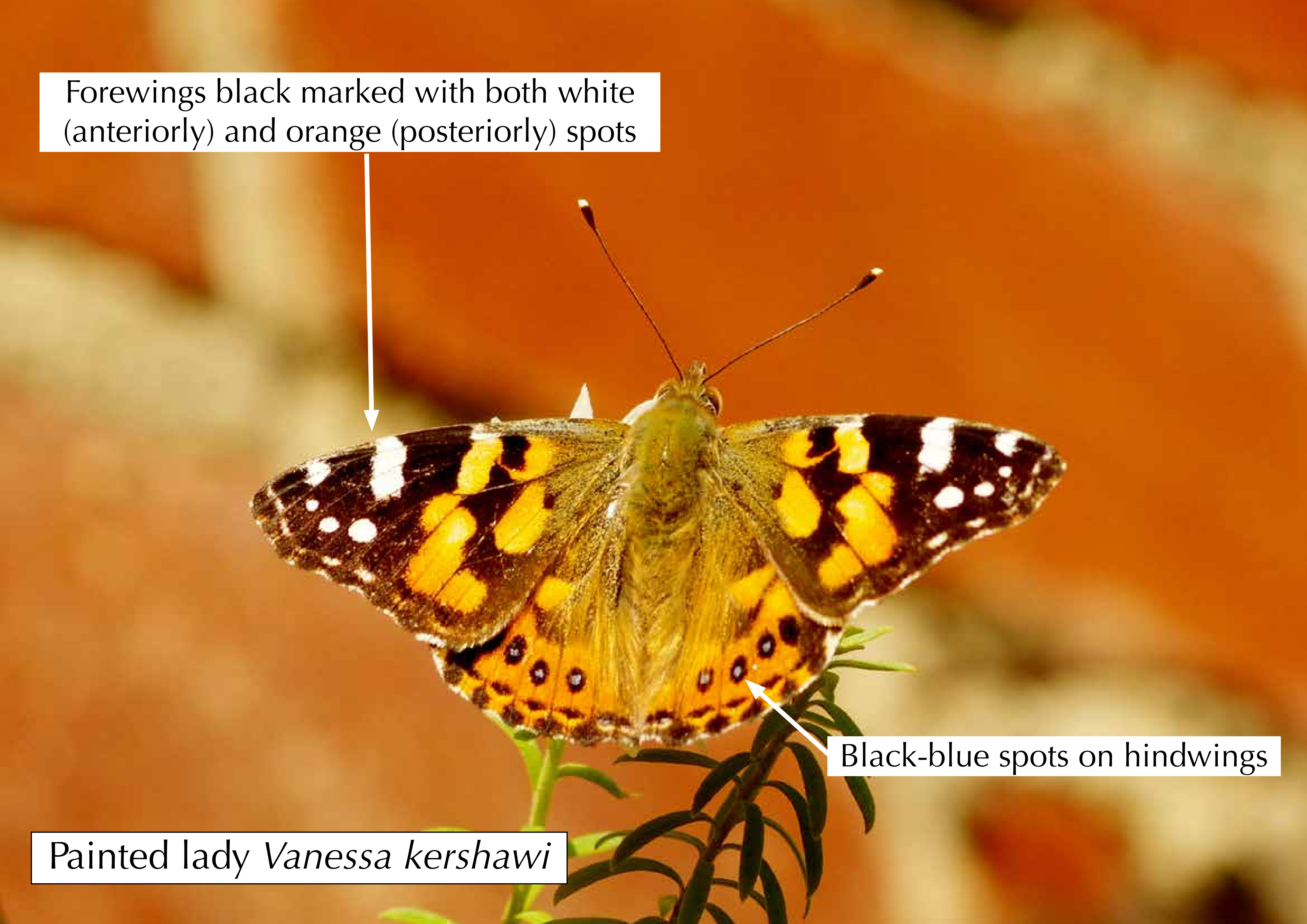

Yellow/black, glossy colouration
Long, erect hairs
Long dark antennae
European wasp *Vespula germanica*

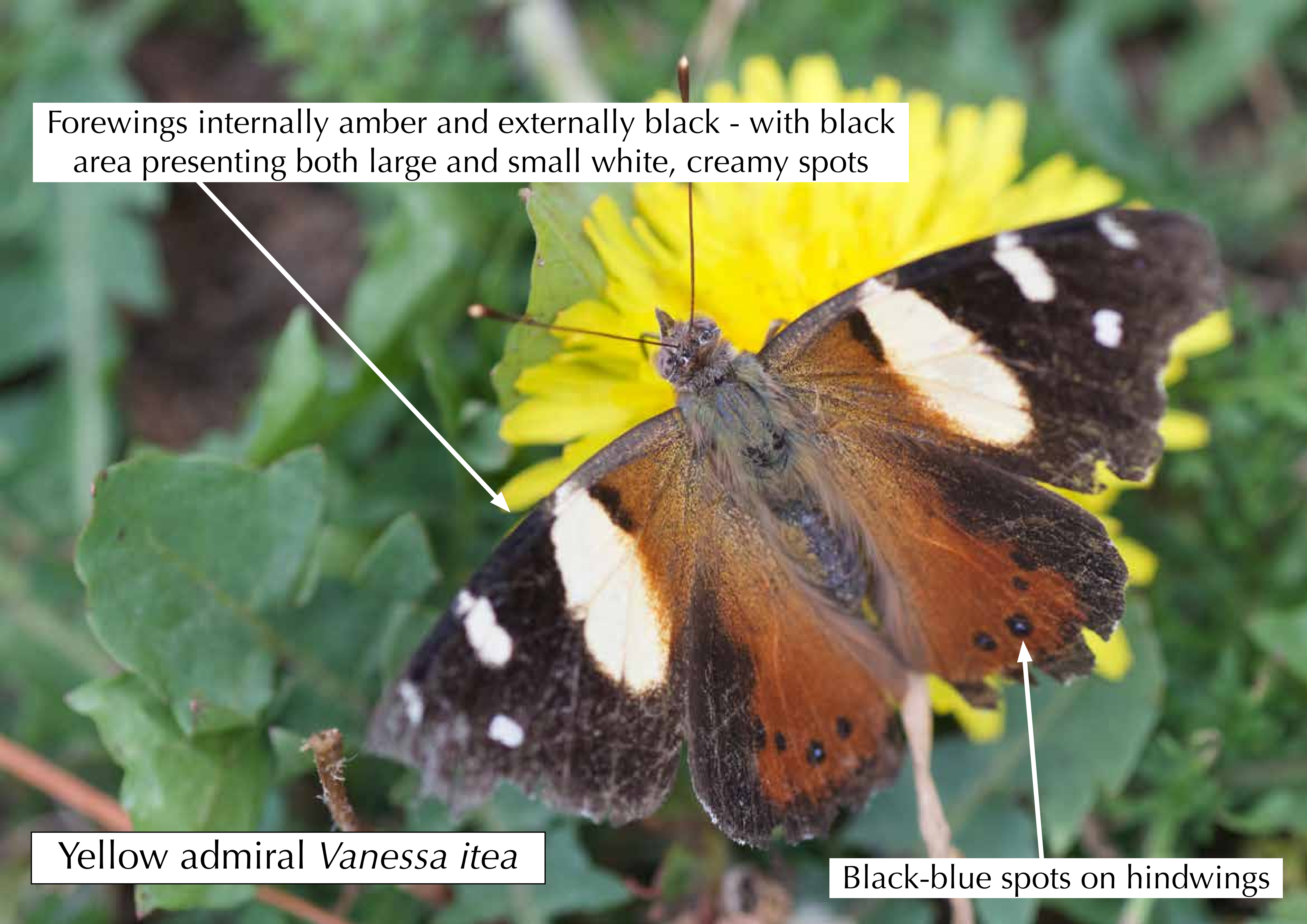
Other native wasps

Hoverflies *Family Syrphidae*

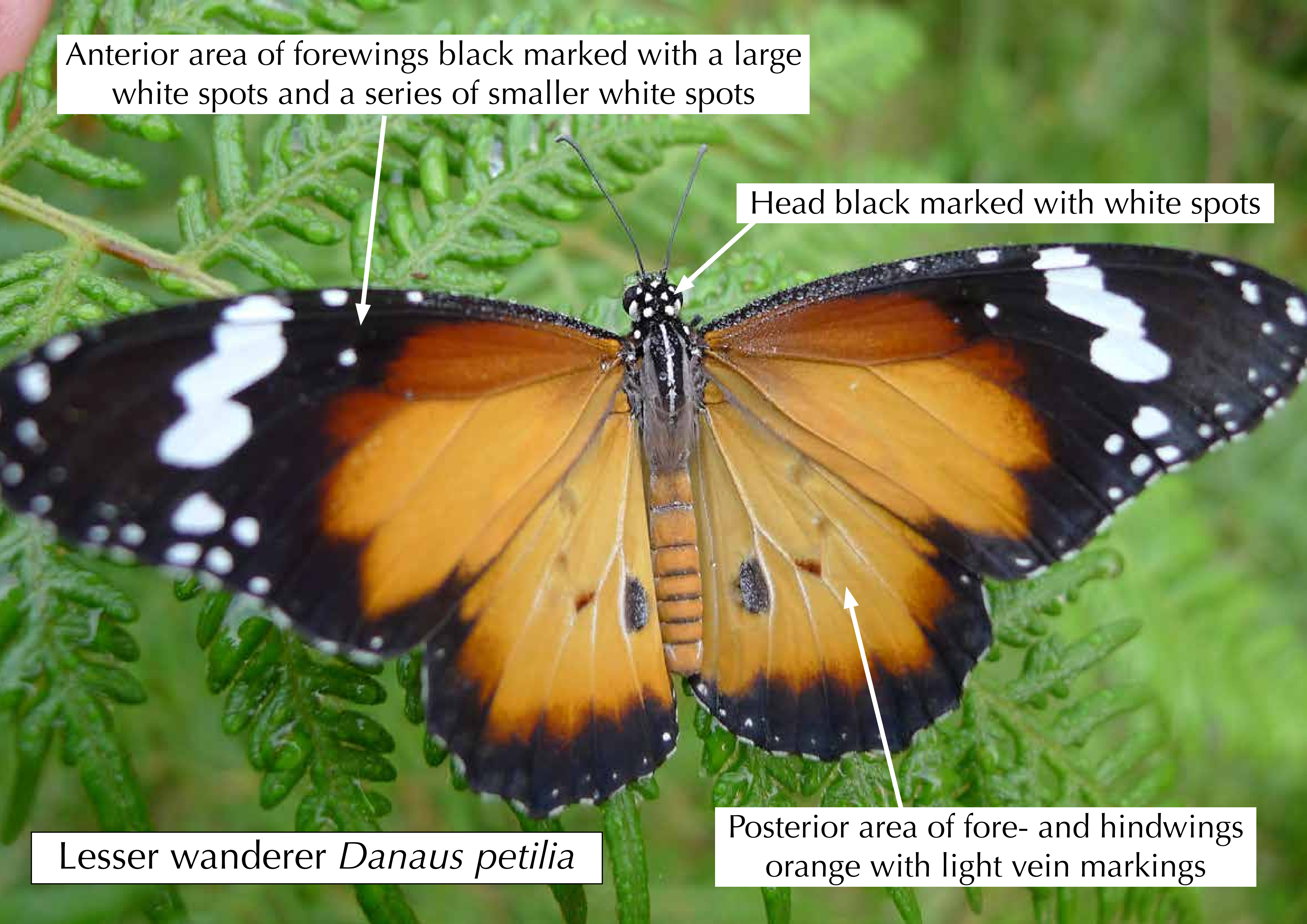
Other native flies

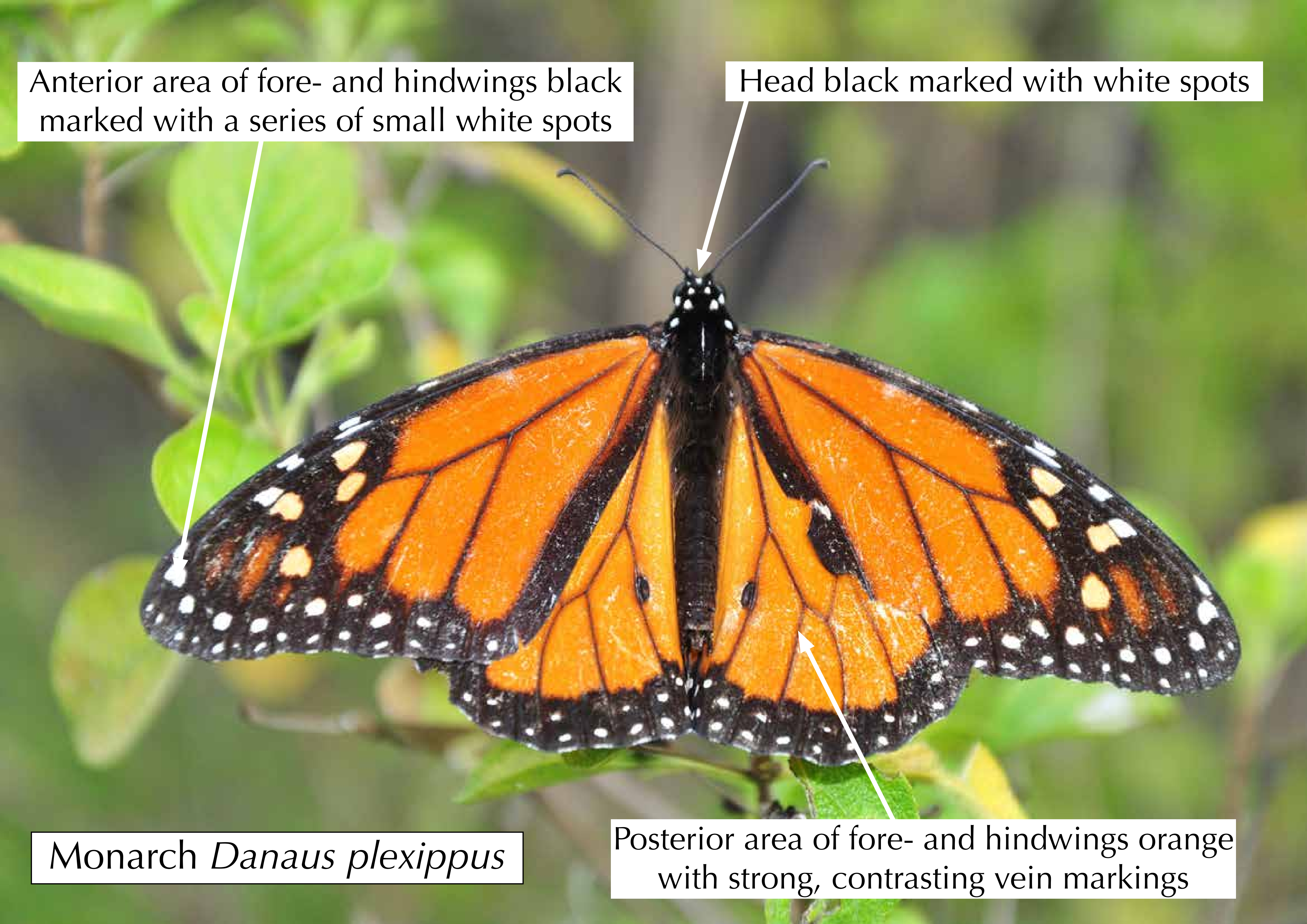

Forewings black marked with numerous creamy white spots
Dingy swallowtail *Papilio anactus*
Posterior area of hindwings black marked with red and blue spots

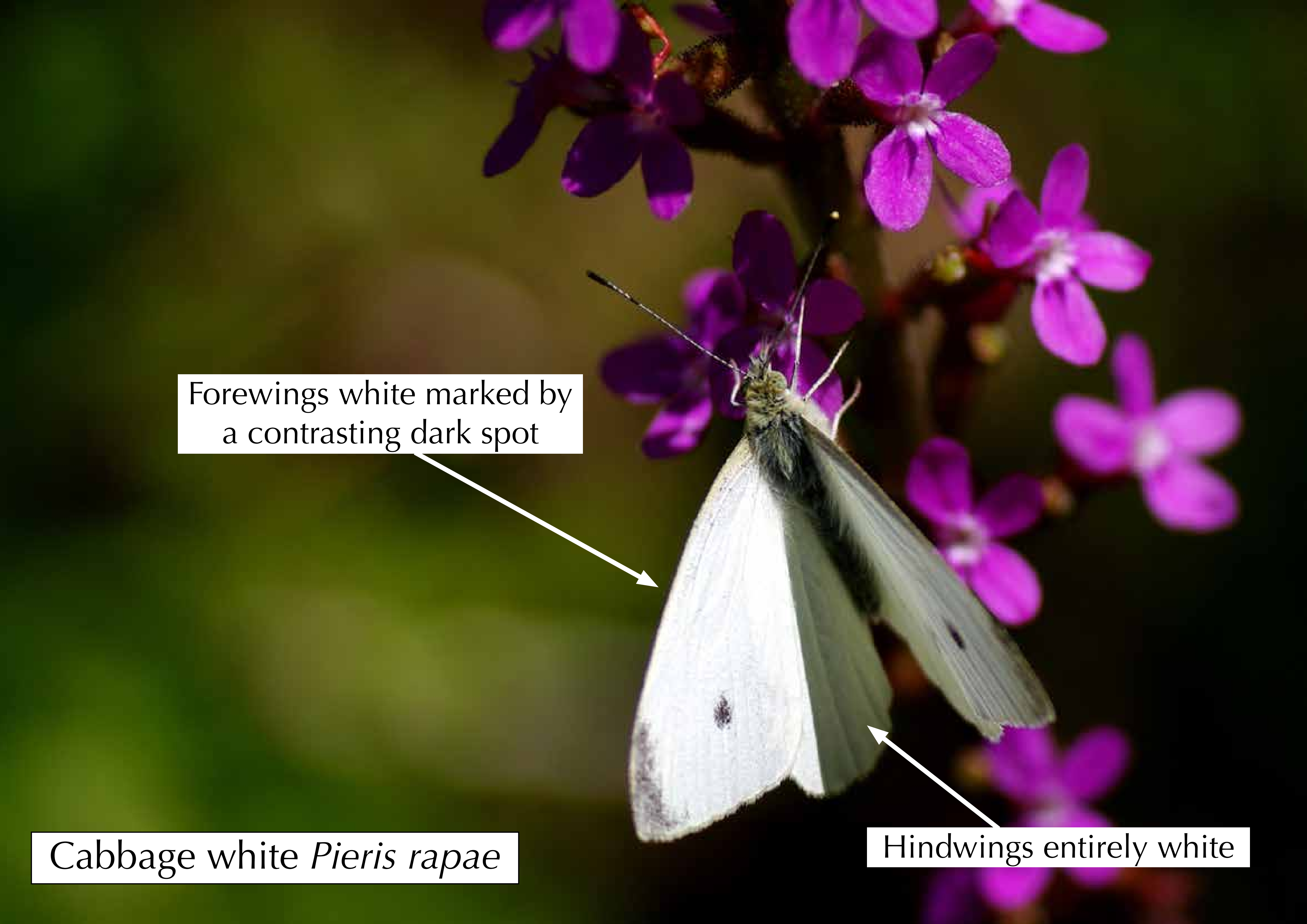

Forewings black marked with both white (anteriorly) and orange (posteriorly) spots
Black-blue spots on hindwings
Painted lady *Vanessa kershawi*


Forewings internally amber and externally black - with black area presenting both large and small white, creamy spots
Yellow admiral *Vanessa itea*
Black-blue spots on hindwings

Meadow argus *Junonia villida*


Anterior area of forewings black marked with a large white spots and a series of smaller white spots
Head black marked with white spots
Posterior area of fore- and hindwings orange with light vein markings
Lesser wanderer *Danaus petilia*


Anterior area of fore- and hindwings black marked with a series of small white spots
Head black marked with white spots
Posterior area of fore- and hindwings orange with strong, contrasting vein markings
Monarch *Danaus plexippus*



Cabbage white *Pieris rapae*

Other butterflies