Austral ECOLOGY A Journal of ecology in the Southern Hemisphere

Austral Ecology (2018) **43**, 635–642

Citizen science in schools: Engaging students in research on urban habitat for pollinators

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Abstract Citizen science can play an important role in school science education. Citizen science is particularly relevant to addressing current societal environmental sustainability challenges, as it engages the students directly with environmental science and gives students an understanding of the scientific process. In addition, it allows students to observe local representations of global challenges. Here, we report a citizen science programme designed to engage school-age children in real-world scientific research. The programme used standardized methods deployed across multiple schools through scientist–school partnerships to engage students with an important conservation problem: habitat for pollinator insects in urban environments. Citizen science programmes such as the programme presented here can be used to enhance scientific literacy and skills. Provided key challenges to maintain data quality are met, this approach is a powerful way to contribute valuable citizen science data for understudied, but ecologically important study systems, particularly in urban environments across broad geographical areas.

Key words: citizen science, pollinators, science education, science engagement, urban ecology.

INTRODUCTION

Citizen science is gaining in popularity, and a large body of research now demonstrates its applicability and role in advancing scientific knowledge (Bonney *et al.* 2014; Kobori *et al.* 2016). Three factors have been attributed to the growth of citizen science over the past decade: (i) easily available technical tools for disseminating information and gathering data (such as mobile phone apps and citizen science websites); (ii) recognition among professionals that the public represent a source of skills, data and computational power (Krasny & Bonney 2005); and (iii) citizen science is recognized as a tool to engage the community in science (Bird *et al.* 2014). In addition to contributing valuable data and information, citizen science can also improve understanding of scientific concepts and the scientific process through firsthand experience (Trumbull *et al.* 2000; Bonney *et al.* 2009). Authentic scientific projects that address questions for which the answers are not known in advance are likely to be more engaging for students than pre-prepared school experiments that run year after year (Paige *et al.* 2016). Recently, the important

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Accepted for publication 12 March 2018.

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doi:10.1111/aec.12608

link between citizen science and environmental education was made by Wals *et al.* (2014) as a way to not only help address current environmental sustainability challenges by engaging the public in environmental science, but also as a tool to increase science capital by providing individuals with a new way of learning and collaborating with science.

Opening access to scientific research through formal education increases opportunities to improve interest and knowledge of young people in science, and to increase student engagement with STEM (science, technology, engineering and mathematics) subjects (Bonney *et al.* 2009; Wals *et al.* 2014; OECD 2015; Paige *et al.* 2016). Some key competencies that have been attributed to citizen science include: science and technology skills and understanding; digital competence; and, a sense of initiative and entrepreneurship (Bonney *et al.* 2009; Kobori *et al.* 2016; Paige *et al.* 2016). Citizen science activities can be organized to match current school programmes, as activities can have greater impact if they are built into current curricula to enhance learning, rather than being treated as an extra-curricular activity to fit in around core programmes (Bates *et al.* 2015). In addition, the research process should be at the forefront of activities, to ensure students appreciate they are contributing to 'real' science and scientific understanding (Bonney *et al.* 2009; Paige *et al.* 2016; Steinke *et al.* 2017).

Here, we report on a citizen science education programme targeted at school-age children across eastern Australia. This programme was launched by the New South Wales Office of Environment and Heritage (OEH) and the Ecological Society of Australia (ESA) as a means of ongoing engagement between school-age children and ecologists with an interest in science communication or outreach. The projects that the OEH/ESA grant supports will vary from year to year in terms of scientists involved, schools partnered with and ecological questions addressed (e.g. study systems and organisms or ecological relationships). The longer-term objectives of the programme are to strengthen partnerships between universities, OEH, and the public, and to build a repository of data available to these groups for educational and research purposes. Over time, we hope that a wealth of ecological data gathered through scientist-school partnerships will be created and made available to both scientific and public communities, potentially creating further opportunities and inspiration for scientist-school partnerships. For example, future partnerships will have the option to provide another instalment from previous experiments, or to pursue one of the future directions identified by the findings of a previous round of partnerships.

We employed standard methods across multiple schools to engage students with an important conservation problem: habitat for pollinator insects in urban environments. Urban landscapes have high potential as pollinator habitat (Hall *et al.* 2017), yet there is currently a paucity of knowledge of pollinator insects in Australian urban environments. Current literature on urban pollinator communities has a strong focus on bees and mostly considers nesting habitat or floral resources available in parks, community gardens and reserves within individual cities, for example Threlfall *et al.* (2015), Matteson and Langellotto (2016). There has been less focus on comparing pollinator communities across different types of urban environments, or considering the role of non-bee pollinators, like flies and wasps, in urban environments (Harrison & Winfree 2015).

We addressed two research questions: (i) In which habitats were most insects caught? (ii) In which trap colours were most insects caught?

MATERIALS AND METHODS

Programme objectives and approach

The five scientists who participated in the programme were part of a group of recipients and organizers of the OEH/ESA Prize for Outstanding Outreach. One of the conditions of this prize is that the winners participate in a science outreach project with school students. Prior to engaging with students, the recipients of the prize worked together to choose a scientific question, and to establish the research design, analysis approach and implementation logistics of the school citizen science project. The methods had to be simple and engaging enough so that students ranging in age from 7 to 17 could easily accomplish the activities. After formulating the approach the scientists connected with a school class in their local urban area and briefed them on the methods. Prior to commencing with schools, students were told they would be collecting insects around the school grounds using standardized methods involving placing coloured traps in four habitat types.

School students involved

In total there were five schools involved spanning from Sydney to Melbourne in south-eastern Australia (Fig. 1). All schools gave informed consent for their students to participate in the scientific study. Schools were selected due to the localities of the collaborating scientists and the availability of the school to host the project. Given the aims of this paper, selecting participating schools in this manner did not detract from the conclusions made. The participants from Canberra Girls Grammar were from year 11 (aged between 16 and 17), the Kinglake students were years five and six (aged 10–12), the St Joseph's Primary School were in years two though to six (aged between 7 and 11), Trinity Anglican College year five (aged 10–11) and Kambala in year seven (aged between 11 and 12).

School visits

Once a collaborating scientist located a participating school, they conducted between one and two visits during April

doi:10.1111/aec.12608

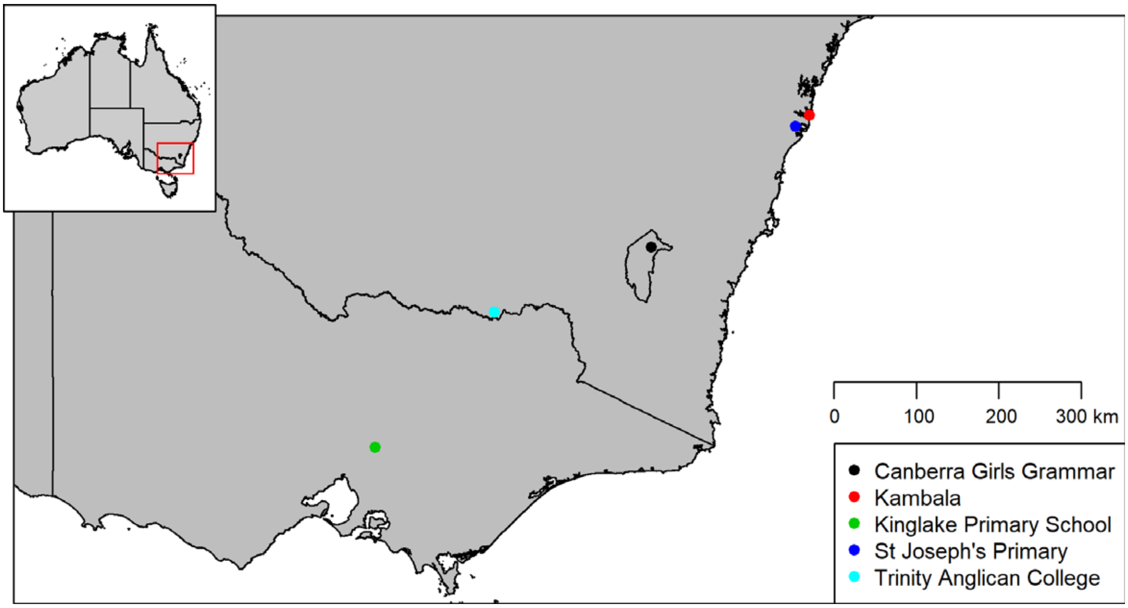

Fig. 1. Location of the five schools in southeastern Australia in which surveys were conducted. (Figure prepared by students at Canberra Girls' Grammar School.) [Colour figure can be viewed at wileyonlinelibrary.com]

and May 2016 to conduct the survey. In the first instance, students and teachers were informed of the project aims and were briefed in the general survey method. In several cases surveys were conducted immediately, but in other cases scientists returned to the school at a more appropriate time for students and teachers. Still, in all cases the collaborating scientist assisted the students to deploy the pan traps and ensure the study was replicated across schools accurately. We considered the students as the 'citizen scientists' and not the subject of the research themselves. Henceforth 'we' is used to include both scientists and students.

Sampling method

We deployed coloured pan traps to collect insects. This is a standard method recommended for pollinator monitoring surveys where data collectors have limited taxonomic knowledge (Westphal *et al.* 2008). Insects see colour in the UV spectrum, and pan traps attract flying insects using UV-reflective colours in the same way that flowers attract pollinators with colour.

Four sites were chosen at or near each school to represent four general habitat types: one paved site with no vegetation (e.g. assembly ground or basketball court), one open grassy site, one garden site (e.g. a landscaped garden or kitchen garden) and one 'forest' area with tall trees.

The collection method was standardized across all schools and sites and all collections occurred between 30 March and 15 April 2016 on a day that suited each school location. All collections were done on fine days with light or no cloud cover and temperatures above 18 degrees. At each site, a set of 12 coloured plastic picnic bowls (two each of dark blue, light blue, white, yellow, pink and orange) was placed on the ground in an array with approximately 1 m between bowls. Bowls were approximately 18 cm diameter (Amscan brand, purchased from Spotlight stores). Each bowl was filled with water and a drop of unscented detergent to break surface tension. Bowls were left in place for 1.5 h. Insects were collected from bowls and arranged on absorbent paper in sealed plastic containers, keeping collections from different coloured bowls separate. Containers were frozen until students were ready to sort them.

On the second (sometimes third) visit to the schools, insects from each collection were counted and sorted into the following taxonomic groups based on the number of wings: Diptera (flies; one pair of wings) and Hymenoptera (bees and wasps; two pairs of wings). Bees and wasps were further identified as either European honey bees (*Apis mellifera* L.) or native bees, as *A. mellifera* is distinctive from Australian native bee species. Other insects were counted and identified to taxonomic order if possible.

Data analysis

Scientists collated all data from each school after insect identification and shared the full dataset with each scientist-school partnership. Differences in insect groups between habitat types and trap colours were identified by schools that organized a third visit. Scientists guided students into considering how they would analyse results to address the research questions using standard parametric statistical tests. To answer the first question, 'In which habitats were most insects caught?' the total number of insects caught in each habitat was compared with a one-way ANOVA (total invertebrates caught ~ habitat type). Total invertebrates caught were compared across schools and bowl colours. Differences between habitats were explored using a Tukey's honest significant difference test. These analyses were performed with the class from St Joseph's Primary School, in the base package of R version 3.02. To answer the second question, 'In which trap colours were most

 doi:10.1111/aec.12608

insects caught?' students from Kambala ran an ANOVA in SPSS version 23. Students then prepared the figures based on their analyses to include in the paper.

RESULTS

General results

We caught 221 insects across the five schools surveyed (Appendix S1). Of these, 150 were Diptera and 71 were Hymenoptera. We caught the highest number of individual insects at Kambala (74 insects; Rose Bay, Sydney, NSW) and the lowest number at Trinity Anglican College (7 insects; Thurgoona, NSW). We caught 70 insects at Canberra Girls Grammar (Canberra, ACT), 41 at Kinglake Primary School (Kinglake, Victoria) and 29 at St Joseph Primary (Oatley, NSW).

Habitat type

Habitat types differed significantly in the total number of insects caught ($P = 0.019$, df = 3, $F = 3.47$). Consistent with our predictions, we caught the fewest insects in open paved areas (Fig. 2). These paved areas yielded significantly fewer pollinators than did open, grassy areas ($P = 0.016$). Open, grassy habitats had higher numbers of pollinators than did gardens, but this result was non-significant ($P = 0.096$). Forest habitats were intermediate in the number of pollinators trapped, and the number of pollinators in forest habitats was not significantly different to grasslands, gardens or paved areas (all $P > 0.4$).

Trap colours

Contrary to our expectations, trap colour had no significant effect on the total number of insects caught ($P = 0.712$, df = 5, $F = 0.584$; Fig. 3). To determine whether the lack of an effect was influenced by lumping different insect types together, we ran separate analyses for flies and for bees and wasps, but neither group was significantly affected by pan colour: flies ($P = 0.884$); bees and wasps ($P = 0.447$).

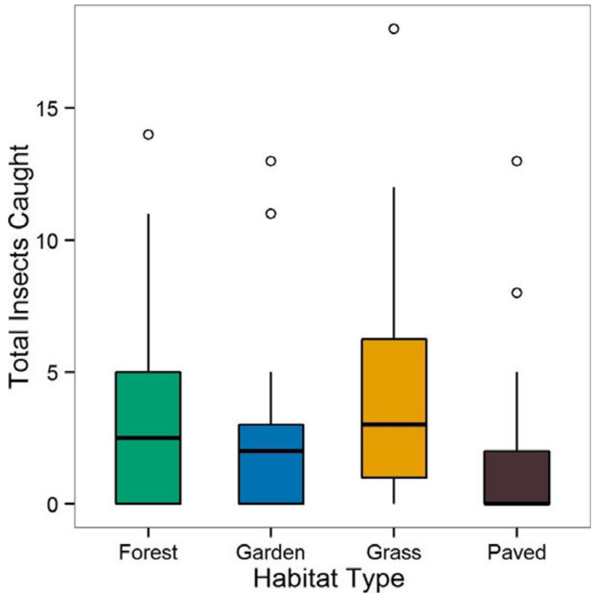

Fig. 2. Total insects caught in each habitat type across all schools. (Figure prepared by students at St Joseph's Primary School, Oatley.) [Colour figure can be viewed at wileyonlinelibrary.com]

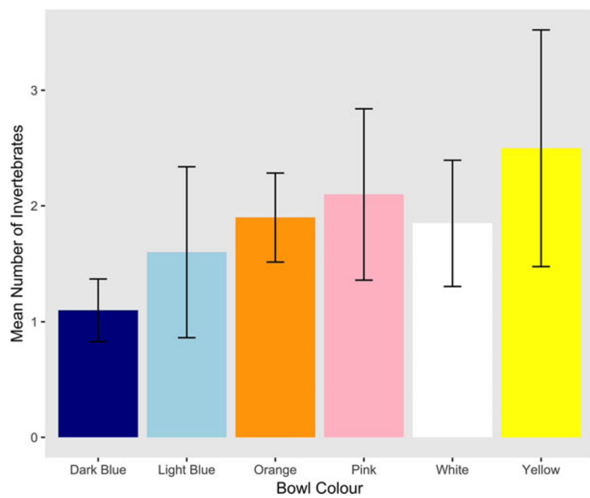

Fig. 3. Mean number of pollinators (bees, wasps and flies) caught in each bowl colour pooled across habitat type and school. (See for original hand-drawn figure prepared by students at Kinglake Primary School Appendix S2). [Colour figure can be viewed at wileyonlinelibrary.com]

DISCUSSION

Research question 1: In which habitats were most insects caught?

Habitat had a significant effect on the number of pollinator insects caught. The highest number of insects were caught in open grassy areas, and the fewest insects were caught in paved areas. Pollinator insects have previously been found to be more common in open habitats like meadows and open woodland, where floral food resources are most abundant (Gittings *et al.* 2006; Grundel *et al.* 2010). In addition, paved surfaces common in urban areas can have negative effects on pollinator populations (Fortel *et al.* 2014). Floral resources were not measured in this study. However, most of the 'grass' sites at schools

doi:10.1111/aec.12608

were located on sporting ovals, which would have limited floral resources. It is more likely that the high numbers of insects caught at the grass sites were due to high visibility of the coloured traps in the landscape.

Research question 2: In which trap colours were most insects caught?

There was no difference in the number of individuals caught in each trap colour. However, the colour of a pan trap has previously been found to influence the number and types of insects attracted to the trap, with many studies showing colour preferences for particular taxa (Saunders & Luck 2013; Moreira *et al.* 2016). One possibility is that the sample size in this study was not large enough to detect differences.

Student learning opportunities

On average, students were engaged with the project on at least three separate periods of two hours each (i.e. >6 h) with a collaborating scientist present. Throughout this time period equal proportions were spent on (i) study design and data collection, (ii) identification of pollinators and (iii) data analysis and interpretation. In between these structured periods, teachers of each class were encouraged to use the project as part of other class work. For instance, some students produced individual project reports which markedly increased their amount of time engaged with the project.

Students had the opportunity to learn the study protocols (e.g. data collection, pollinator identification) through visual and verbal demonstration from scientists and teachers. For each step in the protocol, the collaborating scientist demonstrated the method to the entire class before students were assisted individually or in small groups to deliver the method. Where possible, teachers had been briefed on the content of each structured period by the scientist prior to commencement. This allowed teachers to also aid students in understanding the project's protocols, and continue to reinforce key learnings outside of the structured sessions.

Throughout the structured sessions, students were observed by the scientists and their teachers to ensure they adhered to the protocol or performed tasks correctly (e.g. pollinator identification). Throughout this, immediate feedback was provided to students, such that they could develop and learn skills over the duration of the project. As some schools incorporated the project further into their curriculum, additional opportunities for student learning were provided through the preparation of project reports, study location map creating and interpretation of the data collected. Analysing the data provided the opportunity to challenge some of the older students. Although there was no formal assessment of learning associated with this project, teachers indicated that projects of this nature do align with the Australian curriculum's science learning requirements by teaching skills in: questioning and predicting, planning and conducting, processing and analysing data and information and evaluating (Australian Curriculum, Assessment and Reporting Authority 2010). Given the breadth of skills that can be gained from students participating in similar activities, citizen science could be an important tool in formal education curricula to teach science inquiry.

Data utility and citizen science application

This study is one of a growing number of peer-reviewed scientific publications resulting from collaborations between scientists and school groups. Previous examples include the Blackawton bees project, in which 8–10 year old school children in England researched bumblebee vision (Blackawton *et al.* 2011), and the Christmas tree project, in which Australian year 7–12 year-old students developed and tested hypotheses about how best to keep cut Christmas trees alive (Akres *et al.* 2016). That is, citizen science initiatives including school classes not only provide engaging opportunities for learning for students and their teachers, but can yield results of sufficient quality to contribute to the peer-reviewed scientific literature.

Designing programmes that are applicable across multiple regions can improve data utility as geographically broad programmes are relevant to a wide range of participants and data-users. Our project joins a growing collection of citizen science projects centred on an aspect of the natural environment that can be applied across diverse systems (e.g. Krasny & Bonney 2005; Blackawton *et al.* 2011; Akres *et al.* 2016; Kobori *et al.* 2016). These projects can focus on a specific species, habitat or ecosystem and operate across multiple spatial scales. Our programme focused on building knowledge (for both the scientific community and the participating school groups) of diverse native insect pollinator taxa and was designed around standard insect sampling methods that are independent of the species present in a local area. This contrasts with programs that take a species-centric approach based around a recognizable pollinator species that may not be locally-relevant, for example, the European honey bee (Schönfelder & Bogner 2017), which is an introduced species in Australia with significantly different life cycle and ecology to native pollinator species.

doi:10.1111/aec.12608

The utility of the data collected through our programme is restricted to understanding community-level changes in insect pollinator groups, which is understandable for citizen science programmes focused on insect identification (Kremen *et al.* 2011) due to the challenges involved in identifying species-level taxonomic resolution for insect data, even for scientists (Ball & Armstrong 2006). However, community-level data has high utility for understanding differences and similarities in insect communities across regions and time, if repeated sampling programmes are deployed (e.g. Senapathi *et al.* 2015). Online database tools that encourage ongoing participation in data collection and submission, like the BioCollect tool by Atlas of Living Australia (www.ala.org.au/biocollect/), are easy to use and can provide a means for school groups to participate in a programme where they can see the data contributions from other schools and download data to analyse and map. Our dataset is freely available (Appendix S1), and we will be working to establish this project as part of a long-term urban pollinator monitoring programme.

Challenges to broadscale implementation of this project

Programmes that facilitate communication between scientists and students, and allow school groups to participate in scientific research have the potential to improve the scientific literacy of citizens by enhancing interest and experience in science and technology from a young age (Paige *et al.* 2016). By collaborating with schools to deliver these programmes through class activities, using limited resources (i.e. equipment provided by scientists and sites located on school grounds), we removed some of the common barriers to voluntary citizen science participation, like financial costs and accessibility to equipment/facilities (Hobbs & White 2012). This programme has potential to be replicated at a broader scale across multiple schools and regions, thereby contributing meaningful data and potentially enhancing public interest in science and conservation issues. However, a number of challenges would need to be overcome for broader implementation.

Insects are highly sensitive to cold, particularly pollinator species like bees. Therefore, the optimal sampling season to collect a broad local sample of pollinator insects in Australia is late spring and summer, especially in temperate regions where most of our schools were located. However, due to logistical issues, the sampling for this study occurred in late autumn. This would have affected the abundance and richness of pollinator species collected in the study. For example, almost half (46%) of the total pollinator insects were collected at the two schools located in Sydney, which has a milder and warmer autumn climate more suited to pollinators compared to the other three school locations (Fig. 1). In addition, pollinator insects are less active during inclement weather conditions, even during appropriate seasons. Given the uncertainty associated with long range weather forecasts, identifying appropriate sampling times is a key challenge for similar programmes focused on animal species. We suggest that building the project into the school curriculum would provide the opportunity for students to learn about the ecological conditions that suit the study organism and identify a suitable sampling period well in advance, while allowing flexibility to choose the exact sampling day closer to the time.

The relationship between the school and the collaborating scientist is key for this type of project to succeed. However, it is critical to plan far in advance to allow for appropriate safety processes (e.g. police approval for scientists to be able to work in school environments), and to fit into the school's schedule, which is often determined months in advance. Building the citizen science project into the school curricula may reduce the pressure on teachers to find additional time to fit in an extra-curricular project. It is also important to consider the age of students relative to the project goals and methods and, where possible, standardize age groups if learning outcomes are part of the project goals. For example, younger students may be more flexible with their schedules than secondary schools, but may require more time to work through background subject matter before sampling occurs. Alternatively, secondary school students often have access to enhanced tools and equipment (e.g. GIS software, microscopes) compared to primary school students.

Standardization of methods is imperative for a project that aims to compare results across multiple school regions. This is one of the key challenges when identifying partnerships between scientists and schools, as all scientists need to be familiar with the scientific field and particular methods used. This can have an effect on the quality of data. For example, the data collected in this study depended on identifying insect groups. We identified insect individuals to flies (Diptera), which have one pair of wings, or bees & wasps (Hymenoptera), which have two pairs of wings, as this is an easy distinction for citizen scientists that have limited knowledge of taxonomic identification. To achieve higher taxonomic detail would require that basic identification skills were developed. Alternatively comprehensive web or app-based resources to guide students through detailed taxonomic identification could be built similar to existing resources for plant identification (e.g. PlantNet). An additional alternative is to ensure the

doi:10.1111/aec.12608

partner scientist has some taxonomic expertize and is able to spend more time to identify samples further, if needed.

CONCLUSIONS

This project used citizen science to involve school students in scientific research. Projects such as this have the potential to enhance scientific literacy, by giving students first-hand experience in the scientific process. By integrating ecological projects with long-term learning outcomes, students have the opportunity to learn ecological knowledge of their study organisms well in advance of sampling, as well as the importance of sound experimental design and sampling programmes that optimize data collection. We also involved students in data analysis which provided further learning opportunities and understanding of the scientific method. When these programmes are implemented in a coordinated way across multiple schools, the data can be analysed collectively to identify biogeographical patterns in the focal ecological interactions. This could enhance the student learning experience and build a knowledge foundation that could potentially enhance public scientific literacy. Provided key challenges to maintain data quality are met, this approach is a powerful way to contribute valuable citizen science data for understudied, but ecologically important taxa, such as pollinator insects in urban environments.

ACKNOWLEDGEMENTS

This project was made possible with funding and administrative support from the New South Wales Office of Environment and Heritage, the Ecological Society of Australia, and the CSIRO Scientists in Schools programme. This project would not have been possible without the support of staff members, students and teachers at Kambala, Canberra Girls' Grammar School, St Joseph's Primary School Oatley, Trinity Anglican College Thurgoona, and Kinglake Primary School. Not all schools gave permission for the students involved in this research project to be named as authors on the paper. Thanks to anonymous reviewers whose thoughtful comments greatly improved the paper.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Data table from pollinator surveys conducted at each school.
Appendix S2. Original hand-drawn figure for Fig. 3.

doi:10.1111/aec.12608