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6  
7 **How to work with children and animals: A guide for school-based citizen science in wildlife**  
8 **research**

9 Kylie Soanes<sup>1\*</sup>, Kate Cranney<sup>2</sup>, Marie C. Dade<sup>3</sup>, Amy M Edwards<sup>4</sup>, Ravindra Palavalli-Nettimi<sup>5</sup> and  
10 Tim S. Doherty<sup>6</sup>

11 1 School of Ecosystem and Forest Sciences, The University of Melbourne, Parkville, Victoria, 3010

12 2 Centre of Excellence for Biosecurity Risk Analysis, The University of Melbourne, Parkville,

13 Victoria, 3010 [Current address: CSIRO, Research Way, Clayton, Victoria, 3168]

14 3 School of Earth and Environmental Sciences, The University of Queensland, St Lucia, Queensland,

15 4072, Australia [Current address: Department of Geography, McGill University, Montreal, QC H3A

16 0B9, Canada]

17 4 Department of Ecology, Environment and Evolution, La Trobe University, Bundoora, Victoria, 3086

18 [Current address: New South Wales National Parks and Wildlife Service, Dubbo, New South Wales.]

19 5 Department of Biological Sciences, Macquarie University, Sydney, NSW, 2109

20 6 Centre for Integrative Ecology, School of Life and Environmental Sciences (Burwood Campus),

21 Deakin University, Geelong, Victoria, 3126, Australia

22 \*corresponding author: [ksoanes@unimelb.edu.au](mailto:ksoanes@unimelb.edu.au)

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### 39 **Abstract**

40 Engaging school students in wildlife research through citizen science projects can be a win-win for scientists  
41 and educators. Not only does it provide a way for scientists to gather new data, but it can also contribute to  
42 science education and help younger generations become more environmentally aware. However, wildlife  
43 research can be challenging in the best of circumstances, and there are few guidelines available to help scientists  
44 create successful citizen science projects for school students. This paper explores the opportunities and  
45 challenges faced when developing school-based citizen science projects in wildlife research by synthesising two  
46 sources of information. First, we conducted a small, school-based citizen science project that investigated the  
47 effects of supplementary feeding on urban birds as a case study. Second, we reviewed the literature to develop a  
48 database of school-based citizen science projects that address questions of wildlife ecology and conservation.  
49 Based on these activities, we present five lessons for scientists considering a school-based citizen science  
50 project. Overall, we found that school-based citizen science projects must be carefully designed to ensure  
51 reliable data is collected, students remain engaged, and the project is achievable under the logistical constraints  
52 presented by conducting wildlife research in a school environment. Ultimately, we conclude that school-based  
53 citizen science projects can be a powerful way of collecting wildlife data while also contributing to the  
54 education and development of environmentally aware students.

55

56 **Key words:** citizen science, urban biodiversity, school students, environmental education, bird feeding,

57 **Introduction**

58 Researchers within the fields of ecology and conservation have embraced citizen science for its potential to  
59 generate scientific knowledge, engage the community in environmental issues, and foster connection to nature  
60 (Dickinson *et al.* 2012; Frigerio *et al.* 2018; Pocock *et al.* 2017; Wals *et al.* 2014). There have been numerous  
61 efforts to describe the breadth of citizen science research, understand how and why projects are undertaken, and  
62 their scientific value (Kleinke *et al.* 2018; Kobori *et al.* 2016; Parsons *et al.* 2018; Pocock *et al.* 2017;  
63 Silvertown 2009). Approaches are diverse and range from long-term ecological monitoring and nation-wide  
64 species observations, to recording behaviours or sources of mortality (e.g. Frigerio *et al.* 2018; Gardiner *et al.*  
65 2012; Vercayie and Herremans 2015). Projects may differ in their emphasis on educational goals, scientific  
66 outputs, engagement and awareness raising, behaviour or environmental change, participant roles and level of  
67 participation (Bonney *et al.* 2009; Dickinson *et al.* 2010; Wiggins and Crowston 2011). Despite the wide variety  
68 of approaches, contexts and goals, a cornerstone of all citizen science projects is their capacity to generate  
69 robust scientific data. Scientific outputs must remain a central goal in order for a project to be considered a  
70 citizen science, as opposed to a science education, conservation volunteering, or awareness raising exercise.

71  
72 Involving schools in citizen science projects represents an opportunity to engage younger audiences in  
73 environmental research (Kobori *et al.* 2016). The benefits of engaging school students as citizen scientists  
74 include improved scientific literacy, environmental awareness, leadership skills, and the potential to inspire new  
75 generations of environmentally aware and active citizens (Ballard *et al.* 2017; Pitt and Schultz 2018; Wals *et al.*  
76 2014). Alongside the scientific outputs, school-based citizen science projects should also provide educational  
77 benefits to the student participants (Zoellick *et al.* 2012). However, striking the right balance between scientific  
78 and educational outcomes may be difficult (Zoellick *et al.* 2012). Trade-offs occur when the needs of scientists  
79 and the needs of students are at odds, and the project may be pulled to suit one goal at the expense of the other.

80  
81 School-based citizen science projects in the field of wildlife research can engage younger audiences in  
82 environmental science by tapping into children's natural fascination with animals. However, wild animals can  
83 be difficult to work with and scientists may be cautious about bringing these challenges into a school setting.  
84 For example, some study species and associated survey methods may be more appealing or feasible than others,  
85 and the types of projects best suited to younger students are likely to differ to those for adults. Concern about  
86 the degree to which the data will be reliable and publishable is another perceived barrier to the involvement of

87 school students in citizen science, particularly for younger age-groups (Burgess *et al.* 2017; Pitt and Schultz  
88 2018; Trautmann *et al.* 2012). While students of all ages are often excited to work with wildlife, they may  
89 quickly lose interest when faced with the reality that some methods of data collection are monotonous,  
90 uneventful or indirect, which may compromise the integrity of the research findings. This concern is particularly  
91 relevant to long-term wildlife monitoring programs, complicated experimental designs (e.g. before-after,  
92 control-impact designs), methods that require accurate and repeated timing, or situations where the study species  
93 is difficult to observe or detect. Operating within the constraints of a school environment also presents  
94 operational and logistical challenges that may compromise data collection. For instance, field observations that  
95 are required outside of school hours, or outside of the school grounds require an extra level of organisation.  
96 Finally, the scientists themselves may have limited training in engaging and communicating with school-aged  
97 children to deliver educational outcomes that align with curriculum requirements (McKeown 2003).

98  
99 Understanding the possible challenges and benefits of embarking on a school-based citizen science project will  
100 assist researchers to make an informed decision on whether to such a project is appropriate for their research  
101 question, and to design projects that generate scientific data while providing an engaging and educational  
102 experience to student scientists. Here, we explore the potential opportunities and challenges of school-based  
103 citizen science in the field of wildlife research. We ask: 1) Can school-aged children contribute reliable data to a  
104 citizen science project in wildlife research? 2) What factors influence the success of schools-based citizen  
105 science in wildlife research? To address these questions, we first present the results of, and discuss our  
106 experience from, a citizen science research project conducted in six schools across Australia (Part 1). We then  
107 review the literature to build a database of school-based citizen science projects involving wildlife research (Part  
108 2). Finally, we synthesise this information into a set of five lessons to guide researchers who are considering  
109 school-based citizen science.

110

## 111 **PART 1: Field case study. An urban bird feeding experiment through the Scientists in Schools Program**

### 112 *Aims and context*

113 We established a school-based citizen science project as part of the Commonwealth Scientific and Industrial  
114 Research Organisation (CSIRO) Scientists in Schools Program, in collaboration with the Ecological Society of  
115 Australia and the New South Wales Office of Environment and Heritage. The goal was to engage primary

116 school students in ecological research by pairing six early-career ecologists (the authors) with schools across  
117 Australia and conduct a research project in which the students collected the data as citizen scientists.

118

119 Our research project investigated how supplementary feeding affects wild birds in urban areas, as measured by  
120 the presence, abundance, and richness of species before and after adding seed to feeding stations. Bird-feeding  
121 is a common activity in urban environments and a topical conservation issue (Galbraith *et al.* 2015; Jones 2018)  
122 and thus presented a good opportunity to teach students about urban biodiversity, ecology and wildlife  
123 management. Supplementary feeding may affect the composition of bird communities by favouring larger,  
124 aggressive birds to the detriment of other species, or by attracting new species to the area (Galbraith *et al.* 2015;  
125 Reynolds *et al.* 2017). The research question posed to the students: how does adding bird seed change the  
126 number and type of birds observed at school? We expected to see an increase in observations of granivorous  
127 bird species after seed was added.

128

#### 129 *Methods*

130 We used a before-after experiment to assess how supplementary feeding influenced bird species richness and  
131 abundance. During the 'before' phase, 2–4 feeding stations (20 cm dishes suspended by wire chain) were hung in  
132 trees at each school but no food was added. During the 'after' phase, students added a wild bird seed mix to the  
133 feeding stations each morning. Six schools participated in the project: Wattle Park Primary School, Burwood,  
134 Victoria; Montmorency South Primary School, Montmorency, Victoria; Princes Hill Primary, Parkville,  
135 Victoria; Coburg West Primary School, Victoria; Lake Clarendon State School, Lake Clarendon, Queensland;  
136 and Northside Montessori School, Sydney, New South Wales (Figure 1). This involved approximately 185  
137 students (aged 9–12) in the data collection. Researchers guided the project during 3–5 visits throughout the  
138 term, however the students collected the data independently following the initial training without the presence of  
139 the researchers.

140

141 The students conducted 10-minute bird surveys at feedings stations for three weeks before and three weeks after  
142 seed was added (allowing a one week 'habituation' period in between) during a single 10-week school term (1<sup>st</sup>  
143 May – 22<sup>nd</sup> July 2017). Two or three students collected data independently at each feeder during each survey.  
144 Students were encouraged to conduct surveys each morning, however the frequency varied. For example, the  
145 degree to which the project was allocated class time differed among schools and as a result some students had to

146 adjust the timing of surveys to fit with their other school commitments. The total number of survey days at each  
147 school ranged from 17 to 30. The number of survey days before and after seed was added ranged from 9 to 19  
148 days before, and 6 to 15 days after. We collated the data collected by the students, adjusting counts to account  
149 for multiple observers at the same feeder, and excluding all entries where the date and feeder location were not  
150 provided.

151

152 We took several steps to help the students engage with the project and collect accurate data throughout the  
153 course of the study. Prior to the data collection, each researcher visited their assigned school to meet the  
154 students and introduce the project. Researchers discussed the arguments for and against bird feeding, the  
155 underlying ecological principles, the aim of the project and study design. Students were encouraged to think  
156 through why measurements should be taken before and after seed was added, and devise hypotheses about  
157 which types of birds would likely respond to the feeders (e.g. birds that eat seeds). We toured the school  
158 grounds as a group, and the students were asked to identify the best locations to place the bird feeders based on  
159 their understanding of the aims of the study. During this tour, we further discussed the before-after approach and  
160 the students' expectations of what changes they might observe, when, and why. During the first school visits,  
161 we also trained the students in basic bird identification and survey methods, including a 'practice run' around  
162 the school grounds using a draft datasheet. We observed how the students counted and identified species, used  
163 group exercises to explore how counts were conducted and compared, and explained how to record bird size,  
164 colour and behaviour to help identify species from field guides back in the classroom. This initial phase helped  
165 us identify where the datasheet needed to be streamlined or clarified to allow for easy and accurate  
166 identifications and counts before the official data collection commenced. For example, students had difficulty  
167 distinguishing between sulphur-crested cockatoos and corellas, however as the difference between these species  
168 was not critical to our research question, we provided the simpler category of 'white cockatoos' on the data  
169 sheet (Supplementary Material). This allowed us to maintain a focus on the aspects of the data collection that  
170 were important to the research question, and discard those that led to unnecessary confusion. We developed an  
171 easy-to-use data sheet with photos and checkboxes for each species likely to be observed in the local area  
172 (Supporting Information). A five-metre 'bird watch zone' was marked out around each feeding station using  
173 either temporary spray paint on the ground or by assigning landmarks which guided students to only count birds  
174 that were close to the feeding station.

175

176 *Reflection on scientific outcomes*

177 A total of 2,803 observations of 25 species were recorded during 328 survey days at the 16 feeders. The most  
178 common species observed were the Rainbow Lorikeet *Trichoglossus moluccanus* (n = 416 observations),  
179 Crested Pigeon *Ocyphaps lophotes* (380), Noisy Miner *Manorina melanocephala* (349), introduced House  
180 Sparrow *Passer domesticus* (286), Galah *Eolophus roseicapilla* (282), Raven *Corvus* spp. (114) and introduced  
181 Spotted Dove *Spilopelia chinensis* (108). Of the remaining species, 1–97 observations were recorded. A further  
182 90 and 192 observations were assigned to "Other" and "Unknown bird", respectively. Mean species richness  
183 across all surveys and feeders ranged from 0.89 species at Wattle Park to 4.85 at Montmorency South. Visual  
184 inspection of the data (Figure 2) reveals mixed responses of bird abundance and species richness to the  
185 provision of food and high variability within some schools. However, we had some concerns about the  
186 ecological nature of these responses due to the limitations of the study design and data collection, and do not  
187 consider the data appropriate for addressing our research question.

188

189 A key challenge in this project was maintaining the students' interest in the experimental component of the  
190 study, which compromised the reliability of the before-after comparison and our confidence in the results. While  
191 the students understood the goal of a before-after comparison, many were less interested when there was little or  
192 no bird activity, particularly during the 'before' phase. During site visits, we noticed that some students were  
193 enthusiastically recording all the birds they saw, regardless of whether they were within the 'bird watch zone'.  
194 At four schools, we responded to this behaviour by amending the methods to also include 'around school'  
195 surveys, where birds not within the 'bird watch zone' could be recorded on a separate sheet and thus not affect  
196 the experiment. This allowed students to develop their bird watching and identification skills, even when  
197 activity at the feeders was low. However, as we were only able to introduce this approach mid-way through the  
198 study and at only four out of the six schools, we are not confident that the before-after bird observations were  
199 collected as intended; birds who were unlikely to have ever encountered the feeding stations were included in  
200 the total counts. Another concern was the sparse nature of the records. While the study was intended to consist  
201 of daily, morning surveys over a seven-week period, most schools had fewer observation days than this. This  
202 was particularly the case when the project was not embedded within designated class time and other school  
203 requirements took precedence (e.g. roll call, sports days). In hindsight, we believe our study design was not  
204 appropriate for the student's age and the low frequency of investigator visits.

205

206 *Reflection on educational outcomes for students*

207 Notwithstanding the above, the students were very engaged in the project and capable of independently  
208 conducting the bird surveys. We did not formally assess the student's engagement, enjoyment or learning  
209 outcomes as part of our study, and acknowledge that this would be a useful addition to future school-based  
210 citizen science projects. Still, we noticed that very few students could identify bird species during the first  
211 school visit and by the end of the project students could confidently identify common bird species by sight, call  
212 or flight pattern. When birds could not be identified at first sight, the students developed the skills to note down  
213 the defining features (such as size, call, behaviour and shape) and drew the birds so that we could search field  
214 guides and identify them afterwards. We also found that it was important to maintain a flexible approach that  
215 allowed us to respond to the changing needs of the students and school environment. For example, while we had  
216 a base lesson plan for the project, each researcher tailored this based on the age, size and interests of their  
217 classes, and the time available at each school. Some students created species 'fact sheets', bird watching clubs,  
218 collected feathers, or completed other side projects to complement the research.

219

## 220 **PART 2: Review of literature on wildlife research projects using school-based citizen science**

### 221 *Search methods and criteria*

222 We searched the scientific literature for articles describing school-based citizen science projects involving  
223 wildlife research to identify the degree to which such projects have led to published science. We defined  
224 'school-based citizen science' as a project in which students at primary or secondary schools were primarily or  
225 solely responsible for collecting data (as opposed to a broader citizen science program that may involve school-  
226 aged children). We acknowledge that many such programs will not be described within the scientific literature,  
227 but we use peer-reviewed publications as a simple indicator of the degree to which school-scientist partnerships  
228 generate scientific outcomes that are accessible to the broader research and management communities (Burgess  
229 *et al.* 2017). We defined 'wildlife research' as any research project in which vertebrate or invertebrate fauna  
230 were the response organism, with a specific focus on ecological and conservation research (i.e. not laboratory or  
231 domestic animals).

232

233 We searched Scopus using the terms "citizen science" OR "citizen scientist" AND "ecol\*" OR "conserv\*" (10<sup>th</sup>  
234 July 2018), which yielded 950 documents. Further refining this search using the terms "children" or "student"  
235 returned 74 and 77 documents, respectively. We screened the title and abstract of each paper to create a shortlist

236 of articles in which school students conducted research and fauna were the response measure. We inspected the  
237 literature cited within these documents to identify additional articles of relevance. Articles were excluded from  
238 consideration if the data was not collected by school students, the measured response was something other than  
239 fauna (i.e. flora, abiotic conditions), the work was presented in a language other than English, or the full text  
240 was not accessible. We excluded several projects that were peripherally related to the topic but were out of the  
241 scope of our main investigation. These included projects that were school-based but not focused on wildlife,  
242 such as research into the fields of forestry and urban trees (e.g. Galloway *et al.* 2006), marine debris (e.g.  
243 Hidalgo-Ruz and Thiel 2013), or water and air quality (e.g. Giles and Parson 2001; Nali and Lorenzini 2007).  
244 Several other projects included young people and students among the participants, but were not focused on  
245 citizen science in a school environment (e.g. Gardiner *et al.* 2012; Parsons *et al.* 2018), or presented classroom  
246 modules for broader citizen science projects of which the results were not yet published (e.g. Ezran *et al.* 2017;  
247 Lucky *et al.* 2014; Wells 2010).

248

#### 249 *Overview of projects*

250 We identified 18 school-based citizen science projects from 15 documents in which students from primary or  
251 secondary schools collected data that contributed to research on the ecology or conservation of wildlife (Table  
252 1). These occurred as standalone papers or were presented as case-studies in reviews or editorial pieces.

253

#### 254 Taxa studied and research activities

255 The school-based studies described research on benthic intertidal communities, lizards, large ungulates and  
256 carnivores, migratory birds, small mammals, macroinvertebrates, butterflies, bees and other pollinating insects  
257 (Table 1). Observations were not limited to within the school grounds, with several research projects using field  
258 trips, school-bus commutes, or the students' backyards as sources of data. The diversity of methods allowed  
259 students to conduct research on species that might otherwise be difficult or dangerous to observe. For example,  
260 Weckel *et al.* (2010) investigated the distribution of human-coyote interactions in suburban New York by  
261 asking school students to interview their parents, and Galloway *et al.* (2011) had students count large mammals  
262 observed during their morning bus commute.

263

264 Most studies engaged students in simple observational methods to report animal behaviour, human-wildlife  
265 relationships, or exploring relationships between environmental features and species occurrence. Only two

266 studies included more complex manipulative experiments, one investigating the influence of colour signals on  
267 foraging in bumblebees (Blackawton *et al.* 2011), and the other investigating the influence of substrate  
268 characteristics on maternal nest site choice in lizards (Reedy *et al.* 2012). In studies of invertebrates, such as  
269 garden insects or intertidal communities, students had direct contact with wildlife and conducted the trapping,  
270 handling and observations (e.g. Cox *et al.* 2012; Osborn *et al.* 2005; Saunders *et al.* 2018). Students were rarely  
271 in direct contact with vertebrate wildlife, and instead observed the behaviours of individuals that had been  
272 previously marked by researchers, recorded tracks and other signs of wildlife, or interviewed local residents  
273 about their perspectives on wildlife (e.g. Frigerio *et al.* 2018; Weckel *et al.* 2010). Only two articles described  
274 students handling vertebrate wildlife, in which students were involved in trapping, handling and processing  
275 lizards (Matthews *et al.* 2014; Reedy *et al.* 2012). One study included DNA barcoding, in which the students  
276 collected the samples and sent them away to laboratory for analysis (Henter *et al.* 2016).

277

#### 278 Models of scientist-student interaction

279 The degree of contact and engagement between scientists and students varied widely. Examples ranged from  
280 students filling out and returning simple proforma and having little contact with the scientist (Henter *et al.* 2016;  
281 Weckel *et al.* 2010), to supervised field-trips where the scientists were present during the data collection  
282 (Freiwald *et al.* 2018), to student-led research where students wrote the final published paper (Blackawton *et al.*  
283 2011). Lower input from scientists was often associated with programs that provided intensive teacher training  
284 and curriculum resources, or those had simpler methods that could be easily completed with minimal  
285 supervision. The more intensive school-scientist relationships usually involved internships or were supported by  
286 dedicated citizen science programs (e.g. Matthews *et al.* 2014; Pitt and Schultz 2018) Several studies co-  
287 developed the research questions with the school or involved the students in the data analysis and writing of the  
288 paper (Blackawton *et al.* 2011; Saunders *et al.* 2018). Other programs included teacher training and formal  
289 curriculum support to foster long-term partnerships (Cox *et al.* 2012; Freiwald *et al.* 2018; Frigerio *et al.* 2018)  
290 or published ‘teaching notes’ to help guide implementation across multiple schools (Matthews *et al.* 2014).  
291 Providing this additional support to teachers helped to improve the longevity of the project and quality of data.

292

#### 293 Approaches to maintaining scientific outcomes

294 The school-based citizen science projects we reviewed clearly demonstrated the scientific value of research  
295 conducted by student citizen scientists. Data generated through these projects resulted in an improved

296 understanding of species ecology and behaviour (Blackawton *et al.* 2011; Reedy *et al.* 2012), contributions to  
297 large-scale biodiversity databases (Henter *et al.* 2016; Matthews *et al.* 2014), and were used to inform wildlife  
298 management (Pitt and Schultz 2018; Zoellick *et al.* 2012). For example, students citizen scientists in the School  
299 Malaise Trap Project helped add the DNA barcodes of more than 1000 new species to the Barcode of Life  
300 Database (Henter *et al.* 2016). Several researchers explicitly note that the quality of data collected by students  
301 was comparable to that collected by professional scientists (Frigerio *et al.* 2018; Osborn *et al.* 2005; Pitt and  
302 Schultz 2018).

303

304 Common approaches to maintaining data quality included age-appropriate training; protocols with well-defined,  
305 relevant parameters; regular visits from the partner scientist; recording inter-observer reliability; and verifying  
306 data using experts (Cox *et al.* 2012; Freiwald *et al.* 2018; Frigerio *et al.* 2018; Le Féon *et al.* 2016). Cross-  
307 validation methods were an important approach to ensuring confidence in the data collected by student citizen  
308 scientists. Approaches to data validation were described for 11 projects, and included the use of multiple  
309 observers and replicate counts (Cox *et al.* 2012; Freiwald *et al.* 2018; Osborn *et al.* 2005), comparison to data  
310 collected by scientists (Osborn *et al.* 2005), or verification of data points by teachers or scientists (Frigerio *et al.*  
311 2018; Pitt and Schultz 2018). Several studies introduced frameworks for obtaining high-quality data through  
312 school-based citizen science, highlighting the importance of exciting students and allowing buy-in, training,  
313 simplified and tailored protocols, cross-validation methods, and validity assessment (Cox *et al.* 2012; Osborn *et*  
314 *al.* 2005; Zoellick *et al.* 2012).

315

316 A key source of uncertainty in wildlife research was the capacity of students to distinguish between similar  
317 looking species, identify rare species, or record nuanced behavioural responses. Some researchers tackled this  
318 problem by simplifying the list of species under observation. For example, students were directed to record  
319 observations from a prescribed list that included only those species which could be reliably identified, excluding  
320 species that were uncommon, or grouping together those that were difficult to distinguish (Freiwald *et al.* 2018;  
321 Osborn *et al.* 2005). Other researchers adopted a community-level rather than species-level approach, grouping  
322 insects into simpler categories (e.g. flies, bees and wasps) based on features that were simpler to accurately  
323 identify (Saunders *et al.* 2018). Simplifying the data collection in this way was an attempt to minimise errors by  
324 collecting only the information that is critical to answering the research question rather than a 'laundry list' of  
325 observations just in case they are useful. However, oversimplification may limit the capacity of conservation

326 studies that need to record rare species, studies where species of similar appearance have different ecological  
327 responses, or studies of subtle behaviours (Freiwald *et al.* 2018). Alternative approaches were to train students  
328 in the subtleties of each species through repeated exposure (Cox *et al.* 2012; Matthews *et al.* 2014) or have more  
329 complicated identifications completed by scientists (Le Féon *et al.* 2016). For example, in Matthews *et al.*  
330 (2014), researchers were concerned that students would not be able to distinguish between three similar-looking  
331 species of skink. To combat this, the researchers first used a pet bearded dragon to familiarise students with the  
332 general anatomical features of lizards on a larger scale. The researchers then brought native skinks into the  
333 classroom, allowing the students to observe and compare the distinguishing features of each species first-hand  
334 and refine their identification skills, even if the subsequent field surveys turned out to be unsuccessful.

335

### 336 Constraints and opportunities for scientists

337 There were several benefits to scientists engaging in school-based citizen science programs. For example, such  
338 programs provide the opportunity to access biodiversity in urban areas that would typically be unavailable or  
339 difficult to access, such as school grounds and urban backyards (Frigerio *et al.* 2018; Saunders *et al.* 2018;  
340 Weckel *et al.* 2010). Perhaps most promising is the opportunity for school-based citizen science projects to  
341 increase the temporal or spatial scales of data collection, with projects continuing over many years or including  
342 multiple schools. For example, the monitoring of species in rocky intertidal habitats in California's Monterey  
343 Bay National Marine Sanctuary (USA) will form part of a long-term monitoring program generating data for the  
344 National Oceanic and Atmospheric Administration, with new classes visiting the sites using the same protocols  
345 each year. Similarly, the Acadia Learning Project has involved eleven schools and thousands of students over  
346 large spatial scales to identify landscape-scale patterns of mercury levels in stream macroinvertebrates (Zoellick  
347 *et al.* 2012).

348

349 However, the school environment also placed constraints on the type of species and study that can be conducted.  
350 The rigidity of the school environment or curriculum can be a barrier to obtaining reliable data (Frigerio *et al.*  
351 2018; Saunders *et al.* 2018). For example, surveys to observe social interactions of northern bald ibis  
352 (*Geronticus eremita*) were best conducted in the early morning, however the class time allocated for this activity  
353 occurred in the late-morning, meaning the data collected by the students were not informative (Frigerio *et al.*  
354 2018). Researchers noted a trade-off between making it easy for school students to be involved and maintaining  
355 the integrity of the data, and, thus, the capacity of the program to achieve the scientific outcomes as intended

356 (Freiwald *et al.* 2018; Le Féon *et al.* 2016; Osborn *et al.* 2005). For example, Osborn *et al.* (2005) provided  
357 flexible lesson plans, enabling teachers to tailor their involvement in the monitoring of benthic intertidal  
358 communities based on the needs of the class. However, they cautioned that too much flexibility may  
359 compromise the consistency of the monitoring, with some sites surveyed more frequently than others due to  
360 ease of access. Similarly, simplifying the methods to enhance student participation can lead to the loss of  
361 valuable information and limit the types of research questions that can be explored (Freiwald *et al.* 2018; Le  
362 Féon *et al.* 2016; Osborn *et al.* 2005). Finally, access to the target species may also limit the capacity of school-  
363 based citizen science in wildlife research. When the target species can only be found outside of the school  
364 grounds, field trips and excursions can be logistically difficult and costly (Cox *et al.* 2012).

365

#### 366 Engagement and educational outcomes

367 Six of the 18 examples of school-based citizen science projects described an evaluation of student or teacher  
368 experience of the program (Frigerio *et al.* 2018; Henter *et al.* 2016; Pitt and Schultz 2018; Zoellick *et al.* 2012).  
369 Educational and engagement outcomes were most commonly assessed through before-after surveys of students  
370 or teachers, determining the degree to which students learned (Zoellick *et al.* 2012), the aspects of the science  
371 that they found most interesting (Frigerio *et al.* 2018), or the teachers' perspectives of how the program could be  
372 improved in future iterations (Cox *et al.* 2012). For example, Pitt and Schultz (2018) found that students showed  
373 a greater interest in careers in natural resource management after participating in research projects with the US  
374 Forest Service, while Frigerio *et al.* (2018) found that students were least interested in data entry and most  
375 excited by tasks involving specialised equipment. Researchers also noted the project's alignment with the  
376 mandated curriculum requirements, either by embedding the project within the curriculum (Cox *et al.* 2012;  
377 Freiwald *et al.* 2018; Henter *et al.* 2016; Pitt and Schultz 2018) or informal feedback from teachers after the  
378 work was completed (Saunders *et al.* 2018).

379

380 While formal assessments were rarely described, anecdotal examples of student engagement were common  
381 (Cox *et al.* 2012; Osborn *et al.* 2005; Saunders *et al.* 2018). There were several examples of students taking  
382 ownership of the projects and independently pursuing their own research questions (Osborn *et al.* 2005; Zoellick  
383 *et al.* 2012). Scientists often took additional steps to enhance engagement and learning for students including art  
384 and drawing assignments, interactive presentations and quiz games, field excursions, and emphasising their role  
385 as citizen scientists (Frigerio *et al.* 2018; Osborn *et al.* 2005). In Blackawton *et al.* (2011), the students were

386 engaged throughout the entire process, not only devising the research questions and carrying out the data  
387 collection, but also writing the published paper, complete with hand-drawn figures.

388

## 389 **SYNTHESIS**

390 Overall, our review suggests that school-based citizen science projects that result in peer-reviewed scientific  
391 publications are relatively rare, but the few examples we found illustrate the potential for student citizen  
392 scientists to generate robust data and indicate that many of the perceived obstacles can be overcome through  
393 careful project design. The scarcity of school-based citizen science projects may reflect the infrequency with  
394 which such projects take place, the degree to which such projects generate publishable results, or the frequency  
395 with which they intend to generate data for peer-reviewed publications. Certainly, both our case study and the  
396 literature review highlight the difficulties in generating robust data from school-based citizen science projects  
397 and there are undoubtedly many unpublished examples of school-based citizen science projects that failed to  
398 generate the quality of data expected. These difficulties may lead scientists to avoid engaging with schools, or to  
399 do so for educational rather than scientific reasons. However, our research suggests that the main reasons  
400 school-based citizen sciences fail is because the science was not tailored to engage students to collect quality  
401 data, or the educational and engagement aspects were over-emphasised at the expense of data integrity. Through  
402 careful consideration, these challenges can be overcome, enabling student citizen scientists to generate robust  
403 scientific data. To that end, we synthesise five key lessons from our experience and the broader literature to help  
404 researchers maximise both the scientific and educational outcomes of school-based citizen science projects.  
405 These are of particular relevance to wildlife research but will also be valuable to school-based citizen science  
406 projects more broadly.

407 **1. Most species can be suitable subjects with creative methods:** While there are some practical and  
408 ethical considerations to bear in mind, most wildlife taxa can be appropriate study subjects for school-  
409 based citizen science. The methods should be tailored to ensure that they are appropriate to the age of  
410 the students, allowing them to engage with the species in a way that is safe and interesting, yet still  
411 contributing to reliable data. The use of virtual-based activities, camera-traps, and non-invasive  
412 sampling methods could further expand the range of taxa under investigation. However, the  
413 misidentification of rare species has important implications of many conservation studies, and therefore  
414 should be carefully managed through training if this is a key goal.

415       **2. Robust data can be collected if appropriate measures are used:** Age-appropriate training, regular  
416 validation, and simplified protocols all serve to enable robust data collection, allowing the data  
417 collected by student citizen scientists to be comparable with other studies. Striking the right balance  
418 between independent data collection and scientist oversight is critical to ensuring that the data collected  
419 meet the scientific goals of the project, and that the students benefit from meaningful engagement with  
420 a working scientist (Gardiner *et al.* 2012; Le Féon *et al.* 2016; Zoellick *et al.* 2012). When deciding  
421 how much time to invest, it is worth remembering that the interactions with the working scientists are  
422 often the student’s most popular and important aspects of the experience (Henter *et al.* 2016;  
423 Trautmann *et al.* 2012; Zoellick *et al.* 2012).

424       **3. Engagement and educational outcomes should be explicitly measured:** Educational outcomes are an  
425 important component of school-based citizen science projects and as such the ability of the project to  
426 deliver these outcomes should be formally assessed rather than assumed. Simple before-after surveys  
427 that assess learning, interest, and behaviour change can be used to improve the design and delivery of  
428 programs by determining which aspects of the research were enjoyable, well-understood, or easy to  
429 complete within the school routine (e.g. Frigerio *et al.* 2018; Pitt and Schultz 2018). However, it should  
430 be noted that when the students become the data, rather than the data collectors, appropriate ethics  
431 approvals and processes should be considered, and we recommend consulting or collaborating with  
432 social scientists or education researchers where possible.

433       **4. Establish curriculum support and formal partnerships:** Formal partnerships can ensure that both the  
434 schools and scientists have access to the infrastructure and administrative support required to develop  
435 meaningful and sustainable projects. This can be achieved by working with organisations that have  
436 existing science education and outreach programs (Ballard *et al.* 2017; Zoellick *et al.* 2012) or  
437 establishing initiatives within the university to support scientists in schools (e.g. Henter *et al.* 2016;  
438 Matthews *et al.* 2014). Some training may be required to assist teachers to lead the students through the  
439 scientific aspects of the project, or to help scientists improve their teaching and communication skills  
440 (Frigerio *et al.* 2018; McKeown 2003). Working with schools to embed the research project within the  
441 curriculum can also help to ensure that the data collection is given adequate time and suits the survey  
442 methods for the target species, and that the project is designed to meet educational outcomes  
443 (McKeown 2003; Trautmann *et al.* 2012; Zoellick *et al.* 2012).

444 **5. Keeping students interested is critical to success:** If the student citizen scientists find their role in the  
445 research tedious, confusing or too difficult, they may disengage from the project and be unlikely to  
446 generate robust data. Allowing the students to be part of the process by contributing ideas and research  
447 questions helps to improve learning outcomes, and fosters a sense of ownership and investment in the  
448 project (Trautmann *et al.* 2012; Zoellick *et al.* 2012). Researchers should make an effort to engage  
449 students by ensuring data is fed back into the classroom and providing students the opportunity to  
450 analyse and present the data themselves (e.g. Blackawton *et al.* 2011; Henter *et al.* 2016). Consider  
451 including simple methods that maintain interest and engagement, such as collection of feathers and  
452 shed exoskeletons, or observations of tracks and scats.

453

454 While our case study did not deliver the scientific outcomes intended, careful review of the process in light of  
455 the lessons above suggests how we could design a more successful approach in future. Changes would include:  
456 increasing the level of scientist-supervision to match the complexity of the experimental; formally comparing  
457 student engagement and learning outcomes before and after the project; more clearly communicating the  
458 research findings back to the schools and highlighting each school's contribution in the scope of the broader  
459 study (e.g. "What did the other schools find out?"). We would also work to establish a longer-term relationship  
460 with the schools to co-develop the project, gaining a better understanding of the research methods and scientific  
461 outcomes that would be possible, and the educational outcomes that would best match the current curriculum  
462 requirements. Such approaches could help achieve more robust scientific results, as well as improved  
463 educational outcomes for students.

464

465 Bringing citizen-science programs into schools has the capacity to deliver research, education and  
466 environmental outcomes, and taps into student's natural fascination with wildlife. School-based citizen science  
467 can also benefit researchers by providing the capacity to conduct long-term studies (e.g. working with multiple  
468 classes over multiple years, Freiwald *et al.* 2018), coordinated distributed experiments (e.g. implementing the  
469 same research protocol across multiple schools, Henter *et al.* 2016), and access to sites that are rarely studied yet  
470 may have important biodiversity value and conservation opportunities (e.g. private land or urban environments,  
471 Frigerio *et al.* 2018; Saunders *et al.* 2018). However, it is important that researchers maintain clear goals and  
472 realistic expectations—not all projects, or all species, will be suitable—and we recommend starting with a pilot  
473 program so that the approach and expectations can be revised early on. The database of studies provided here

474 serve as an excellent source of reference for researchers embarking on school-based citizen science projects, and  
 475 further guidance on educational and curriculum aspects can be found here (McKeown 2003; Trautmann *et al.*  
 476 2012). Ultimately, engaging school students in wildlife research will be a balancing act between scientific and  
 477 educational outcomes.

478

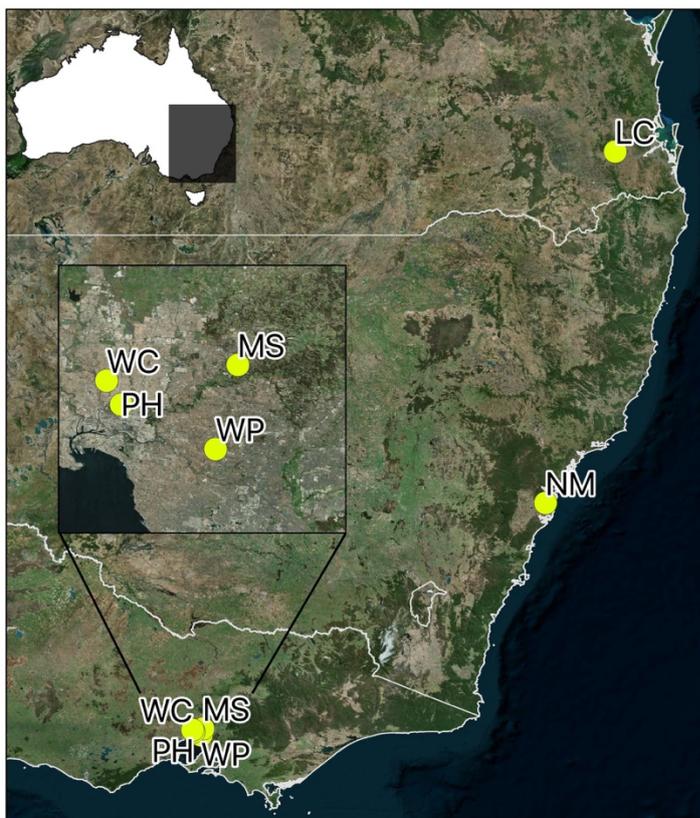
## 479 Tables and Figures

480 **Table 1. Results of literature search for school-based citizen science projects involving wildlife.**

Project	Aim of wildlife research	Student level	Country	Reference
The year of the greylag geese	Long-term research into social behaviour of greylag geese at the Konrad Lorenz Research Station	Primary and secondary school	Austria	In Frigerio <i>et al.</i> (2018)
Nature in your backyard	Investigating the role of gardens in enhancing backyard biodiversity, including surveys for hedgehogs, birds and pollinating insects.	Primary and secondary school	Austria	In Frigerio <i>et al.</i> (2018)
Social alliance in bald ibis	Movement ecology, social behaviour, stress and parasite load of bald ibis.	Primary and secondary school	Austria	In Frigerio <i>et al.</i> (2018)
Our Project in Hawaii's Intertidal (OPIHI)	Describe the distribution and abundance of introduced and native species in benthic rocky intertidal communities	Secondary school	Hawaii	Cox <i>et al.</i> (2012)
School Malaise trap program	Explore insect diversity around school yard using Malaise traps and DNA barcoding	Primary and secondary school	Canada	Henter <i>et al.</i> (2016); Steinke <i>et al.</i> (2017)
Long-term Monitoring Program and Experimental Training for Students (LiMPETS)	Monitoring rocky shore and sandy beach intertidal habitats, measuring presence-absence and number of species such as sea stars, limpets and crabs within National Marine Sanctuaries.	Primary and secondary school	USA	Freiwald <i>et al.</i> (2018); Ballard <i>et al.</i> (2017)
Monterey Bay National Marine Sanctuary	Monitoring long-term changes in rocky intertidal communities	Secondary	USA	Osborn <i>et al.</i> (2005)
Herpetological Research Experience	Mark-recapture study of lizards to investigate species diversity and distribution.	Secondary school	USA	Matthews <i>et al.</i> (2014)
Alaska Natural Science Course	A range of longitudinal research projects, including collecting data on wildlife abundance, density and distribution. Students develop research projects over semesters in collaboration with the US Forest Service,	Secondary school	USA	Pitt <i>et al.</i> (2018)
Montana Youth Forest Monitoring Program	Student internships with the US Forest Service to learn about forest management and help conduct a variety of wildlife monitoring projects.	Secondary school	USA	Pitt <i>et al.</i> (2018)
Delta Science Apprenticeship (Colorado)	Student apprenticeships with the US Forest Service, focusing on learning habitat restoration and wildlife monitoring skills.	Secondary school	USA	Pitt <i>et al.</i> (2018)
Human coyote interface	Mapping human-coyote interaction in urban environment through students interviewing their parents.	Primary and secondary school	USA	Weckel <i>et al.</i> (2010)
Acadia Learning Project	Long-term sampling and mapping of mercury levels in macroinvertebrates.	Secondary school	USA	Zoellick <i>et al.</i> (2012)
Bees in agricultural landscapes	Students collected wild bees to investigate changes in species assemblages under global change in agricultural landscapes	Secondary school	France	Le Feon <i>et al.</i> (2016)

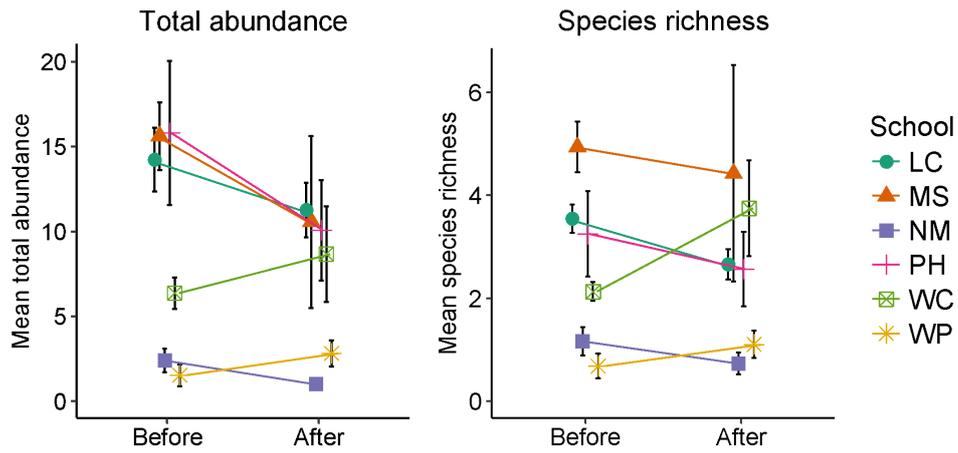
Habitat for urban pollinators	Effect of habitat type and trap colour on urban insect pollinator communities	Primary school	Australia	Saunders <i>et al.</i> (2018)
Maternal nest site choice in lizards	Experimental test of the effect of maternal nest site choice (substrate moisture content) on offspring fitness in anole lizards.	Secondary school	USA	Reedy (2012)
Blackawton bees	Behavioural ecology, including colour vision and foraging in bumblebees	Primary	UK	Blackawton <i>et al.</i> (2011)

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**Figure 1. Location of the six schools where bird data was collected. LC, Lake Clarendon State School; MS, Montmorency South Primary School; NM, Northside Montessori School; PH, Princes Hill Primary; WC, Coburg West Primary School; WP, Wattle Park Primary School.**



490

491 **Figure 2. Mean ( $\pm$ SE) bird abundance and species richness before and after seed was added to feeders.**

492 **The values for each school are means across all feeders and surveys within each of the before and after**

493 **periods. LC, Lake Clarendon State School; MS, Montmorency South Primary School; NM, Northside**

494 **Montessori School; PH, Princes Hill Primary; WC, Coburg West Primary School; WP, Wattle Park**

495 **Primary School.**

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