Frontiers in Ecology and the Environment

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***Front Ecol Environ* 2012; doi:10.1890/110185**

Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs

Mary M Gardiner[1*], Leslie L Allee[2], Peter MJ Brown[3], John E Losey[2], Helen E Roy[4], and Rebecca Rice Smyth[2]

Citizen scientists have the potential to play a crucial role in the study of rapidly changing lady beetle (Coccinellidae) populations. We used data derived from three coccinellid-focused citizen-science programs to examine the costs and benefits of data collection from direct citizen-science (data used without verification) and verified citizen-science (observations verified by trained experts) programs. Data collated through direct citizen science overestimated species richness and diversity values in comparison to verified data, thereby influencing interpretation. The use of citizen scientists to collect data also influenced research costs; our analysis shows that verified citizen science was more cost effective than traditional science (in terms of data gathered per dollar). The ability to collect a greater number of samples through direct citizen science may compensate for reduced accuracy, depending on the type of data collected and the type(s) and extent of errors committed by volunteers.

Front Ecol Environ 2012; doi:10.1890/110185

The first scientists were, by definition, amateurs, or "citizen scientists" (Silvertown 2009). However, citizen scientists have continued to make major contributions to ecological research following the transformation of scientific study into a professional discipline (Droege 2007; Bonney *et al*. 2009; Silvertown 2009). With recent reductions in research funding and increases in the scale and severity of environmental issues, interest in the application of citizen science is now greater than ever (Bonney *et al*. 2009). Citizen science clearly differs from traditional science, which is carried out by professional scientists, in that the data are collected by volunteers. However, within citizen science we identify two types of programs: *direct citizen science* and *verified citizen science*. In direct citizen science, data are studied without verification, whereas in verified citizen science only observations confirmed by trained experts are analyzed.

The use of traditional science, direct citizen science, or verified citizen science to collect data will influence factors such as: (1) the cost per observation, (2) the time from observation to analysis/dissemination, and (3) the accuracy of the resulting data. In general, projects based on traditional science will incur the highest cost and the longest lag time between observation and dissemination, but will yield the most accurate data. Programs involving direct citizen science probably yield the lowest expense per observation, facilitating a larger number of observations and potentially the shortest lag time (given that data are directly reported). Yet the use of direct citizen-science data to test hypotheses may result in reduced accuracy. Errors due to misidentification are of particular concern in recently established programs (Dickinson *et al*. 2010) and programs focused on small or cryptic organisms (Bonney *et al*. 2009). Verified citizen science is likely to incur lower costs per observation than traditional science but higher costs compared to direct citizen science, because this requires an additional step – the verification of the citizen-submitted data by professional researchers (Figure 1).

We compared the accuracy of direct versus verified citizen science to determine how verification influenced the interpretation of ecological data. We used data collected in three current programs that monitor the diversity and/or relative abundance of lady beetles (Coccinellidae; also known as "ladybirds" and "ladybugs", hereafter "lady beetles"): the UK Ladybird Survey (UKLS; www.ladybird-survey.org), the Lost Ladybug Project (LLP; http://lostladybug.org), and the Buckeye Lady Beetle Blitz (BLBB; http://ladybeetles.osu.edu). Lady beetles were chosen as a focal taxon for these programs in part because they provide important biocontrol services (Dixon 2000; Gardiner *et al*. 2009) but also because of concerns that historically widespread and common lady beetle species have declined dramatically in both the US and UK (Harmon *et al*. 2007; Roy *et al*. 2012). There are many potential reasons for these declines, but one plausible cause is enhanced direct and indirect competition from exotic coccinellid species. By examining data from the three programs, we assessed the ability of citizen scientists to provide information that can help to address lady beetle declines.

Methods

The UKLS (formerly Coccinellidae Recording Scheme) has been active since 1971, when it was established to

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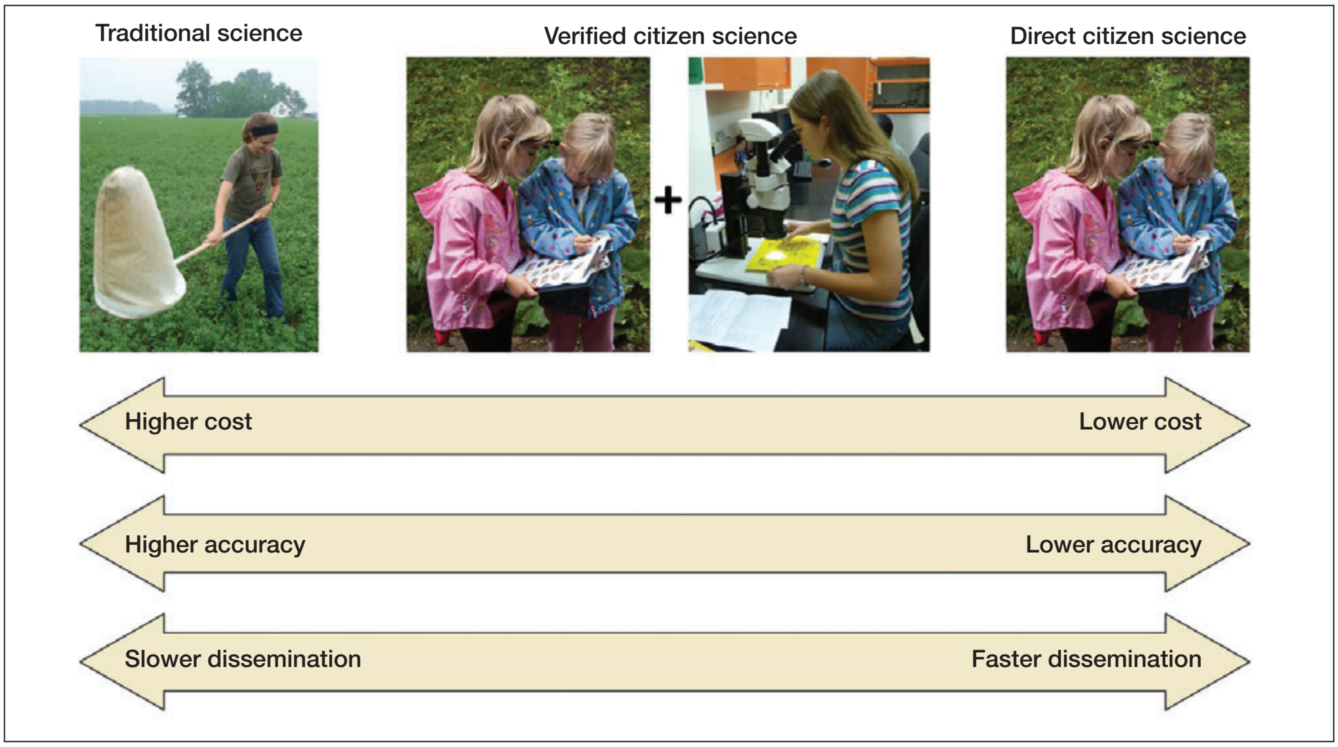

Figure 1. *The application of traditional scientific methods, where researchers collect, analyze, and interpret data, is likely to provide greater accuracy but at a higher cost per sample as compared to citizen science. Some citizen-science programs use direct citizen science, where data are interpreted without being verified by researchers. This method of data collection is likely to be the least expensive but also the least accurate. Verified citizen science, where volunteers collect and submit data that are checked by researchers, will improve error rates in comparison to direct citizen science but adds expense as well.*

provide a focus for collation of lady beetle distribution data across the British Isles. In 2005, an online survey was launched in response to the arrival of the exotic lady beetle *Harmonia axyridis*. The UKLS has more than 100 000 verified records. The LLP has been active since 2008 and was initiated to document changing distributions of lady beetles across North America. The LLP has over 10 000 verified records from all 50 states in the US, four Mexican states, and seven Canadian provinces. The BLBB program began in 2009 to monitor lady beetle communities within residential gardens across the US state of Ohio. A total of 450 citizen scientists participated in the BLBB program from 2009–2010.

Volunteer data collection and verification procedures

Citizen scientists participating in the UKLS and LLP programs accessed an online protocol that described how to collect and submit lady beetle data. These volunteers also had access to online identification guides to monitored species. To report a lady beetle sighting to either of these programs, citizen scientists provided their contact information, a digital photograph of the insect, suggested identification (required by UKLS but not by LLP), location details, habitat information, and comments via an online form. To measure volunteer accuracy for the UKLS and LLP programs, researchers checked these submissions by examining each photograph. In the BLBB program, participants attended an in-person training session and received a toolkit containing an identification guide, protocol guidelines, data sheets, a step-in plastic fence post, and yellow sticky card traps. Participants collected lady beetles using the sticky card traps suspended at a height of 0.5 m by way of the provided step-in fence post. Citizen scientists who participated in the BLBB program during 2009–2010 sent their data sheets with identifications of all specimens found on their sticky cards together with the trap itself to the BLBB for verification and to measure volunteer accuracy. In all three programs, participants were notified of the accuracy of their reports.

Data analysis

We examined the relationship between the number of citizen scientist reports for each lady beetle and species identification accuracy using a logistic regression model with a binomial distribution (PROC GENMOD; SAS Institute Inc 2009). This analysis was completed for each program separately for the 14 most common lady beetle species (13 were included in the BLBB analysis, because only 13 species were reported). We investigated the effects of volunteer error on researcher interpretation of lady beetle relative abundance using data submitted to the BLBB program. We compared the mean number of each lady beetle species reported by citizen scientists with the actual mean number of each species per sticky card trap, as verified by researchers using a logistic regression model with a negative binomial distribution (PROC GENMOD).

Species richness and diversity were calculated for direct citizen-science and verified citizen-science data. The Menhinick's index was used to calculate species richness, because this can account for the differences in sample sizes that were present between direct citizen science and verified datasets within each program (Magurran 2004). Species diversity was measured by the Simpson's diversity index (reported as 1-D; Simpson 1949). We used a two-tailed *t* test to determine whether there was a significant difference in the species diversity (1-D) calculated using the data submitted by citizen scientists versus the data verified by researchers.

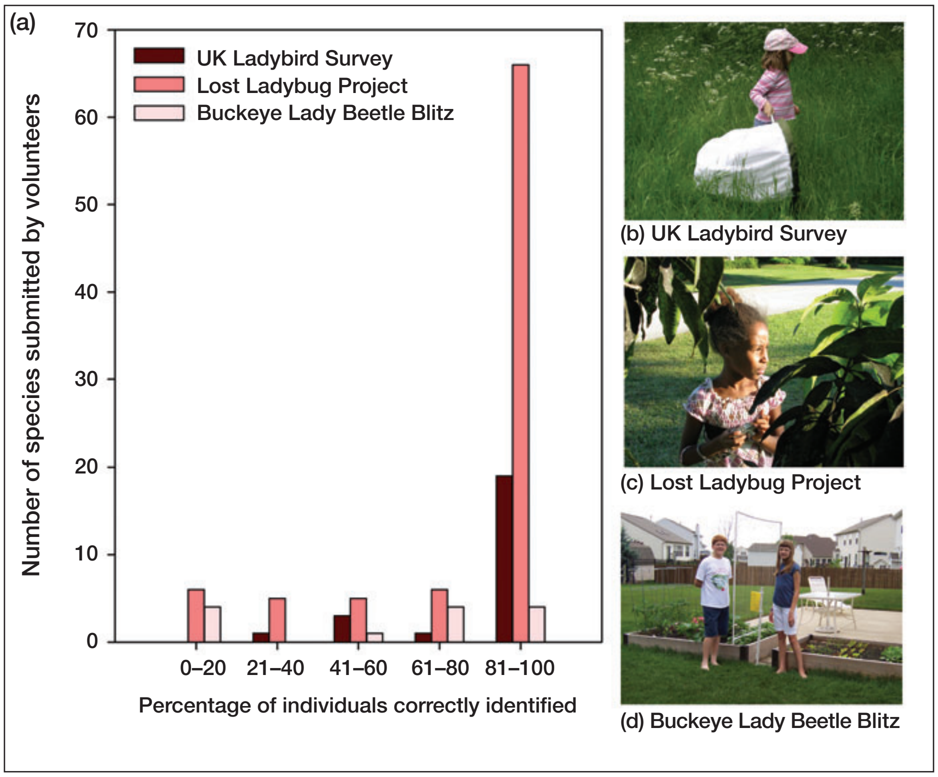

Figure 2. *(a) The percentage of individual specimens of each species correctly identified by citizen scientists submitted to (b) the UK Ladybird Survey, (c) the Lost Ladybug Project, and (d) the Buckeye Lady Beetle Blitz.*

Iterative simulations based on computer-generated random data were used to estimate the sample sizes needed to detect differences in relative abundance among lady beetle species, given potential volunteer error. This was done through the use of data from the BLBB. We assumed that a researcher's goal was to detect a 10% significant difference ($\alpha = 0.05$, power = 0.80) in relative abundance between two species (means of 0.3 versus 0.2 beetles per trap). Traditional science was assumed to be 100% accurate and volunteers contributing direct citizen-science data were assumed to miss individuals on traps at a rate of 25%. A Minitab macro was used to conduct the simulations with Type I and Type II errors of 0.05 and 0.20.

Results and discussion

Direct citizen-science identification accuracy

Citizen scientists submitted 2937, 5034, and 445 lady beetle specimens as part of the UKLS, LLP, and BLBB, respectively (WebTable 1). Within the UKLS and LLP, the majority of species were correctly identified by the citizen scientists 81–100% of the time (Figure 2). Volunteer identification accuracy varied widely in the BLBB, with an equal proportion of species accurately identified between 0–20%, 61–80%, and 81–100% of the time (Figure 2). Across all programs, we found a positive correlation between the number of reports of a species and citizen identification accuracy (UKLS [$P < 0.0001$], LLP [$P = 0.027$], and BLBB [$P < 0.0001$]). Species that had a volunteer identification accuracy rate of less than 50% constituted less than 10% of the specimens submitted to any of the three programs.

Influences of error on researcher interpretations

Relying on direct citizen-science data would have substantially influenced researcher interpretation of lady beetle richness, diversity, and relative abundance. Errors in the direct citizen-science data resulted in an underestimate of common species, an overestimate of rare species, an inflated level of species richness, and a statistically significant increase in species diversity.

Underestimation of H axyridis

The most common lady beetle species collected in all three programs was *H axyridis*. A high percentage of insects identified by citizen scientists as this common exotic species were verified to be *H axyridis* (99% UKLS, 97% LLP, and 96% BLBB). However, its actual abundance was underreported resulting from citizen scientists misidentifying *H axyridis* for another species. Misidentifications of *H axyridis* accounted for 41.1–69.6% of volunteer identification errors.

Overestimation of species diversity

Within the LLP and BLBB, citizens reported greater species richness than that confirmed by researchers

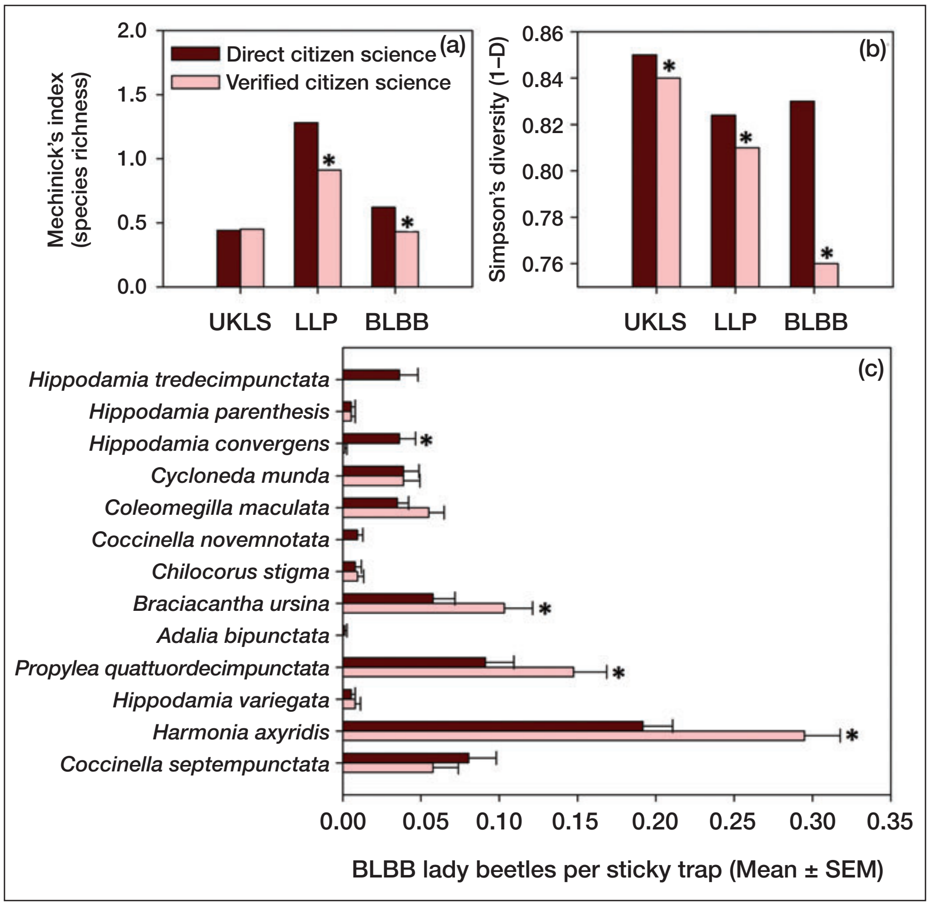

Figure 3. *(a) Lady beetle species richness calculated via direct citizen-science data appeared to be significantly* ($P < 0.05$) *greater than that calculated via verified citizen-science data within the LLP and BLBB. (b) The species diversity (Simpson's diversity index, reported as 1-D) of direct citizen-science data was greater* ($P < 0.05$) *than the verified data within all programs. (c) These differences resulted from citizen scientists underreporting common species and overreporting rare species. For example, in the BLBB, the mean number of lady beetles per sticky card trap (mean ± standard error of the mean [SEM]) reported by citizen scientists included significantly fewer* ($P < 0.05$) *specimens of common* H axyridis, P quattuordecimpunctata, *and* B ursina *and a higher number of the rare* H convergens. *Citizen scientists also reported three native species –* H tredecimpunctata, C novemnotata, *and* A bipunctata *– although no specimens were actually present. Asterisks represent significant differences between direct and verified citizen-science data.*

(Figure 3a). The diversity of the lady beetle community reported by citizen scientists in all programs was significantly greater ($P < 0.05$) than that found by researchers (Figure 3b). This difference was due to underreporting of common species, primarily *H axyridis*, and overreporting of rare native species. For example, within the BLBB program, the mean number of the two most common exotic species (*H axyridis* and *Propylea quattuordecimpunctata*) and the most common native species (*Brachiacantha ursina*) were significantly underreported ($P < 0.05$), whereas the locally rare *Hippodamia convergens* was overreported ($P < 0.05$). In addition, three native species (*Adalia bipunctata*, *Coccinella novemnotata*, and *Hippodamia tredecimpunctata*) reported by citizen scientists were not actually present (Figure 3c).

Factors contributing to error in direct citizen science

The identification errors detected within the UKLS, LLP, and BLBB programs were probably a consequence of several factors, including the polymorphic nature of lady beetles, lack of experience among participants, sampling protocol complexity, and training effectiveness. Misidentification of *H axyridis* had a significant impact on our findings. These errors may be due to the difficulty in accurately identifying this species, given its phenotypic variation: specimens may be black with red spots or yellow to red with or without black spots. In the UKLS, the majority of *H axyridis* specimens misidentified were submitted as the pine ladybird (*Exochomus quadripustulatus*) or kidney-spot ladybird (*Chilocorus renipustulatus*). These beetles are black with red spots, which may explain why citizen scientists identified black color forms of *H axyridis* as these native species. Incorrectly identified *H axyridis* were most frequently submitted as *C novemnotata* (42.9% of misidentifications) and *H convergens* (25% of misidentifications) to the LLP and BLBB, respectively. These misidentifications may also be attributed to the difficulty in differentiating one species from another; however, we question whether efforts to highlight conservation concerns for particular species may also inadvertently have influenced volunteer accuracy. For example, the LLP highlights the plight of the rare *C novemnotata*, and participants in the BLBB learn that Ohio's state insect, *H convergens*, has declined rapidly within the state. Few citizen-science programs have documented an overestimation of rare species within their data (eg Harnick and Ross 2003; Galloway *et al.* 2006). Nevertheless, the possibility for such potential bias highlights the utility of data verification in accounting for false positive or false negative reports (Bois *et al.* 2011; Miller *et al.* 2011). In some cases, such misidentifications could have important implications for conservation policy and decision making.

We also found variation in overall identification accuracy among the three examined programs. The higher identification error rate detected within the BLBB as compared to either the UKLS or LLP may be due in part to different levels of protocol complexity. Protocols with long, repetitive, or complex methods can be challenging for volunteers, resulting in reduced accuracy (Dickinson *et al.* 2010). BLBB volunteer errors stemmed from both misidentified individuals and sampling problems (eg some lady beetles were not recorded as present) on sticky card traps, whereas the UKLS and LLP relied on citizen scientists submitting photos of specimens via a project website. Thus, protocols requiring volunteers to identify all specimens (BLBB), rather than selecting specimens to submit (UKLS and LLP), could increase the error rate of direct citizen science. Dickinson *et al.* (2010) also discussed "learner" or "first-year" effects, where data accuracy improves with volunteer experience. Only the first two data-collection years were analyzed for the BLBB; thus, ongoing training may improve accuracy over time.

Costs of citizen science versus traditional science

Data collection cost is a major consideration of traditional and citizen-science programs. We estimated the cost (including equipment, travel, researcher and student wages, training workshops, and website development) of collecting lady beetles from one location using a sticky card trap at US$126.62 per trap for traditional science, US$40.29 for verified citizen science, and US$31.44 for direct citizen science (WebTable 2). Therefore, by using direct or verified citizen science, a program can collect 3–4 times the number of samples provided by traditional research for the same cost. If researchers can perform data verification, the use of verified citizen science may represent a cost-effective means of increasing the scope of investigation without sacrificing accuracy.

Direct citizen science was the most cost-effective approach in our analysis, but researcher confidence in their data is paramount. Given the potential for error, we examined whether researchers could estimate the number of additional samples needed to accurately detect relative abundance differences using direct citizen science. We determined the number of samples necessary to detect a 10% significant difference in relative abundance among two lady beetles using sticky card traps. We assumed that students working as part of a traditional science program were 100% accurate; however, this is probably an overestimate of accuracy, given that paid student researchers do make mistakes and their accuracy often improves with experience (Barratt *et al.* 2003; Droege 2007). We also assumed that volunteers participating in a citizen-science program reported 75% of the specimens of each species that were actually present. On the basis of these assumptions, we determined that a total of 320 observations would be needed through traditional science, whereas direct citizen science would require 450 observations to attain the same degree of data accuracy. Given our cost estimations for these methods, direct citizen science would cost US$14 148, while the use of traditional science would cost US$40 460 to test the same hypothesis. In some cases, therefore, the ability to collect a larger number of samples with direct citizen science could reduce the influence of volunteer error on data interpretations, providing a cost-effective method for collecting reliable data.

Increasing publication of citizen-science data

The effect of volunteer error on researcher interpretation is a major issue. For citizen science to contribute to ecological research, both the scientific community and the general public must have confidence in the accuracy of the findings. Currently, the number of studies published that rely on citizen-science data does not reflect the diversity and number of operating programs (Hilchey and Conrad 2011). This could be related to issues affecting data quality, either real or perceived, by peer reviewers (Silvertown 2009; Hilchey and Conrad 2011). The use of verified citizen science can improve researcher and reviewer confidence in the quality of citizen-collected data. Verification can be applied to all collected data or to a subset thereof. Verifying a subset of submitted data allows researchers to establish error rates and determine the number of additional samples needed to test hypotheses using direct citizen science. These measures may increase the proportion of citizen-collected data published in peer-reviewed journals, thereby documenting the contributions of thousands of amateur scientists.

Acknowledgements

We thank all our volunteers for contributing lady beetle data. LLP is supported by a grant from the Informal Science Education Program of the National Science Foundation. HER is funded through the NERC Centre for Ecology & Hydrology and the Joint Nature Conservation Committee. The development of the online surveys in Britain was funded in part by the Department for Environment, Food and Rural Affairs. MMG thanks B Hunt, S Prajzner, C Smith, and H Edgington, who verified volunteer identifications. BLBB is funded by an OSU-OARDC SEEDS Grant to MMG. B Bishop, OSU-OARDC, provided assistance with statistical analyses.

References

Barratt BIP, Derraik JBB, Rufaut CG, *et al.* 2003. Morphospecies as a substitute for Coleoptera species identification, and the value of experience in improving accuracy. *J Roy Soc New Zeal* **33**: 583–90.

Bois ST, Silander Jr RA, and Mehrhoff LJ. 2011. Invasive plant atlas of New England: the role of citizens in the science of invasive alien species detection. *BioScience* **61**: 763–70.

Bonney R, Cooper CB, Dickinson J, *et al.* 2009. Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience* **59**: 977–84.

Dickinson JL, Zuckerberg B, and Bonter DN. 2010. Citizen science as an ecological research tool: challenges and benefits. *Annu Rev Ecol Evol S* **41**: 149–72.

Dixon AFG. 2000. Insect predator–prey dynamics: ladybird beetles and biological control. Cambridge, UK: Cambridge University Press.

Droege S. 2007. Just because you paid them doesn't mean their data are better. Citizen Science Toolkit Conference. Ithaca, NY.

Galloway AWE, Tudor MT, and Vander Haegen WM. 2006. The reliability of citizen science: a case study of Oregon white oak stand surveys. *Wildlife Soc B* **34**: 1425–29.

Gardiner MM, Landis DA, Gratton C, *et al.* 2009. Landscape diversity enhances biological control of an introduced crop pest in the north-central USA. *Ecol Appl* **19**: 143–54.

Harmon JP, Stephens E, and Losey J. 2007. The decline of native coccinellids (Coleoptera: Coccinellidae) in the United States and Canada. *J Insect Conserv* **11**: 85–94.

Harnick PG and Ross RM. 2003. Assessing data accuracy when involving students in authentic paleontological research. *J Geosci Edu* **51**: 76–84.

Hilchey KG and Conrad CC. 2011. A review of citizen science and community-based environmental monitoring: issues and opportunities. *Environ Monit Assess* **176**: 273–91.

Magurran AE. 2004. Measuring biological diversity. Malden, MA: Blackwell Science.

Miller DA, Nichols JD, McClintock BT, *et al.* 2011. Improving occupancy estimation when two types of observational error occur: non-detection and species misidentification. *Ecology* **92**: 1422–28.

Roy HE, Adriaens T, Isaac NJB, *et al.* 2012. Invasive alien predator causes rapid decline of native European ladybirds. *Divers Distrib* **18**: 717–25.

SAS Institute Inc. 2009. What's new in SAS 9.0, 9.1, 9.1.2, 9.1.3. Cary, NC: SAS Institute Inc.

Silvertown J. 2009. A new dawn for citizen science. *Trends Ecol Evol* **24**: 467–71.

Simpson EH. 1949. Measurement of diversity. *Nature* **163**: 688.

WebTable 1. The number of lady beetle submissions by volunteers (VST), the actual number verified by researchers (verified total), and the percentage of volunteer submissions that were correctly identified by volunteers (% of VST)

	Verified total			*Volunteer-submitted total (VST)*			*Individuals correctly identified by volunteers (% of VST)*		
	UKLS	*LLP*	*BLBB*	*UKLS*	*LLP*	*BLBB*	*UKLS*	*LLP*	*BLBB*
Adalia bipunctata	*	121	0	*	102	1	*	74	0
Adalia decempunctata	361	–	–	374	–	–	97	–	–
Anatis labiculata	–	12	–	–	3	–	–	100	–
Anatis lecontei	–	7	–	–	4	–	–	100	–
Anatis mali	–	23	–	–	10	–	–	100	–
Anatis ocellata	72	–	–	72	–	–	100	–	–
Anatis rathvoni	–	4	–	–	3	–	–	33	–
Anisosticta bitriangularis	–	4	–	–	4	–	–	100	–
Anisosticta novemdecimpunctata	9	–	–	11	–	–	82	–	–
Aphidecta obliterata	17	–	–	17	–	–	100	–	–
Axion plagiatum	–	4	–	–	1	–	–	0	–
Azya orbigera	–	3	–	–	2	–	–	100	–
Brachiacantha albifrons	–	2	–	–	0	–	–	**	–
Brachiacantha decempustulata	–	1	–	–	0	–	–	**	–
Brachiacantha decora	–	25	–	–	5	–	–	100	–
Brachiacantha tau	–	1	–	–	0	–	–	**	–
Brachiacantha testudo	–	4	–	–	4	–	–	100	–
Brachiacantha ursina	–	26	77	–	19	43	–	95	88
Brumoides septentrionis	–	1	–	–	1	–	–	100	–
Calvia quatuordecimguttata	217	17	–	224	7	–	97	71	–
Cephaloscymnus occidentalis	–	1	–	–	1	–	–	100	–
Chilocorus bipustulatus	4	–	–	4	–	–	100	–	–
Chilocorus cacti	–	27	–	–	10	–	–	100	–
Chilocorus circumdatus	–	1	–	–	1	–	–	100	–
Chilocorus kuwanae	–	1	–	–	4	–	–	25	–
Chilocorus orbus/fraternus	–	12	–	–	8	–	–	100	–
Chilocorus renipustulatus	89	–	–	103	–	–	86	–	–
Chilocorus stigma	–	24	7	–	23	6	–	52	67
Coccidula lepida	–	1	–	–	1	–	–	100	–
Coccinella californica	–	21	–	–	20	–	–	85	–
Coccinella difficilis	–	13	–	–	0	–	–	**	–
Coccinella hieroglyphica	4	0	–	5	0	–	80	**	–
Coccinella magnifica	3	–	–	6	–	–	50	–	–
Coccinella monticola	–	15	–	–	1	–	–	100	–
Coccinella novemnotata	–	47	0	–	164	7	–	23	0
Coccinella prolongata	–	1	–	–	0	–	–	**	–
Coccinella quinquepunctata	14	–	–	25	–	–	56	–	–
Coccinella septempunctata	*	1725	43	*	641	60	*	94	58
Coccinella transversoguttata	–	160	–	–	41	–	–	83	–
Coccinella trifasciata	–	46	–	–	17	–	–	94	–
Coccinella undecimpunctata	22	1	–	25	0	–	88	**	–
Coelophora inaequalis	–	416	–	–	401	–	–	100	–
Coleomegilla maculata	–	376	41	–	101	26	–	96	85
Cryptolaemus montrouzieri	–	24	–	–	4	–	–	100	–
Curinus coeruleus	–	18	–	–	9	–	–	100	–
Cycloneda munda	–	–	29	–	–	29	–	–	62
Cycloneda spp (all species)	–	551	–	–	411	–	–	98	–
Delphastus pusillus	–	1	–	–	1	–	–	100	–
Diomus terminatus	–	2	–	–	2	–	–	100	–
Epilachna borealis	–	32	–	–	14	–	–	100	–

continued

WebTable 1. – *continued*

	Verified total			*Volunteer-submitted total (VST)*			*Individuals correctly identified by volunteers (% of VST)*		
	UKLS	*LLP*	*BLBB*	*UKLS*	*LLP*	*BLBB*	*UKLS*	*LLP*	*BLBB*
Epilachna varivestis	–	6	–	–	4	–	–	100	–
Exochomus aethiops	–	8	–	–	7	–	–	100	–
Exochomus childreni	–	22	–	–	9	–	–	100	–
Exochomus quadripustulatus	146	–	–	175	–	–	83	–	–
Halmus chalybeus	–	13	–	–	2	–	–	100	–
Halyzia sedecimguttata	354	–	–	358	–	–	99	–	–
Harmonia axyridis	922	3319	220	932	1242	143	99	97	96
Harmonia dimidiata	–	1	–	–	1	–	–	100	–
Harmonia quadripunctata	40	–	–	41	–	–	98	–	–
Henosepilachna argus	4	–	–	4	–	–	100	–	–
Hippodamia apicalis/expurgata	–	2	–	–	0	–	–	**	–
Hippodamia caseyi	–	215	–	–	0	–	–	**	–
Hippodamia convergens	–	1969	1	–	1451	27	–	97	4
Hippodamia glacialis	–	23	–	–	3	–	–	67	–
Hippodamia moesta	–	4	–	–	0	–	–	**	–
Hippodamia parenthesis	–	66	4	–	72	4	–	67	75
Hippodamia quinquesignata	–	7	–	–	2	–	–	50	–
Hippodamia sinuata	–	10	–	–	21	–	–	24	–
Hippodamia tredecimpunctata	3	54	0	6	12	27	50	42	0
Hippodamia variegata	23	32	6	24	7	4	96	100	75
Hippodamia washingtoni	–	1	–	–	0	–	–	**	–
Hyperaspidius spp	–	1	–	–	1	–	–	100	–
Hyperaspis bigeminata	–	2	–	–	2	–	–	50	–
Hyperaspis connectens	–	1	–	–	1	–	–	100	–
Hyperaspis fastidiosa	–	1	–	–	1	–	–	100	–
Hyperaspis gemma	–	6	–	–	6	–	–	100	–
Hyperaspis globula	–	3	–	–	3	–	–	100	–
Hyperaspis medialis	–	1	–	–	1	–	–	100	–
Hyperaspis octavia	–	1	–	–	1	–	–	100	–
Hyperaspis pantherina	–	2	–	–	2	–	–	100	–
Hyperaspis quadrioculata	–	1	–	–	0	–	–	**	–
Hyperaspis rotunda	–	2	–	–	2	–	–	100	–
Hyperaspis signata	–	10	–	–	2	–	–	100	–
Hyperaspis trifurcata	–	2	–	–	2	–	–	100	–
Macronaemia episcopalis	–	1	–	–	1	–	–	100	–
Microweisea spp	–	1	–	–	1	–	–	100	–
Mulsantina hudsonica	–	2	–	–	2	–	–	100	–
Mulsantina picta	–	12	–	–	9	–	–	89	–
Myrrha oblongoguttata	6	–	–	18	–	–	33	–	–
Myzia interrupta	–	1	–	–	1	–	–	100	–
Myzia oblongoguttata	17	–	–	19	–	–	89	–	–
Myzia pullata	–	5	–	–	6	–	–	33	–
Myzia subvittata	–	3	–	–	3	–	–	100	–
Naemia seriata	–	2	–	–	1	–	–	100	–
Neoharmonia venusta	–	5	–	–	2	–	–	100	–

continued

WebTable 1. – *continued*

	Verified total			Volunteer-submitted total (VST)			Individuals correctly identified by volunteers (% of VST)		
	UKLS	LLP	BLBB	UKLS	LLP	BLBB	UKLS	LLP	BLBB
Nephus flavifrons	–	1	–	–	1	–	–	100	–
Olla v-nigrum	–	47	–	–	36	–	–	75	–
Paranaemia vittigera	–	4	–	–	4	–	–	100	–
Propylea quattuordecimpunctata	273	187	110	280	40	68	98	95	91
Psyllobora borealis	–	7	–	–	2	–	–	100	–
Psyllobora parvinotata	–	3	–	–	2	–	–	100	–
Psyllobora renifer	–	5	–	–	5	–	–	100	–
Psyllobora vigintiduopunctata	98	–	–	99	–	–	99	–	–
Psyllobora vigintimaculata	–	19	–	–	14	–	–	93	–
Scymnus loewii	–	6	–	–	6	–	–	100	–
Subcoccinella vigintiquatuorpunctata	50	2	–	57	1	–	88	100	–
Tytthaspis sedecimpunctata	50	–	–	58	–	–	86	–	–
Total	**2798**	**9869**	**538**	**2937**	**5034**	**445**	**–**	**–**	**–**
Average accuracy							**85.6**	**88.5**	**53.9**

Notes: UKLS = UK Ladybird Survey; LLP = Lost Ladybug Project; BLBB = Buckeye Lady Beetle Blitz. The "verified total" lists the actual number of lady beetles verified by researchers submitted by citizen scientists to the UKLS, LLP, and BLBB programs. The "volunteer-submitted total" (VST) lists the number of correct and incorrect specimens identifications submitted by volunteers. The "individuals correctly identified by volunteers" indicates the percentage of the VST that was correctly identified. * Indicates common species excluded from analyses, because records of these were accepted without verification; ** Indicates volunteers provided images of species but did not provide identification.

WebTable 2. The costs associated for collecting one yellow sticky card trap (YSCT) sample through traditional science, direct citizen science, or verified citizen science (all currency in US$)

	Type of science		
	Traditional	*Direct*	*Verified*
[1]YSCT and fence post	$4.17	$4.17	$4.17
[2]Travel to field site to collect YSCT	$85.46	$0.00	$0.00
[3]Student salary to collect YSCT from the field	$34.00	$0.00	$0.00
[4]Student salary to collect data from YSCT	$0.00	$0.00	$4.25
[5]Researcher investment to train student	$2.99	$0.00	$2.99
[6]Mailing costs	$0.00	$0.00	$1.61
[7]Hosting volunteer training workshops	$0.00	$9.89	$9.89
[8]Website development and annual maintenance	$0.00	$17.38	$17.38
Total cost per YSCT	**$126.62**	**$31.44**	**$40.29**

Notes: [1]Sampling equipment cost. [2]Travel to field sites to conduct traditional science was calculated at $0.50 per mile (all dollar amounts in US$). To determine the average distance to a field site, 20 BLBB participants were selected at random, and the cost to collect data from their location was determined. Travel cost was then averaged across these locations. [3]Student wages to collect a YSCT using traditional science was estimated at a pay rate of $8.50 per hour, assuming two students working 4 hours to collect each trap. [4]Student wages to count and identify lady beetles on a YSCT using traditional science or verified citizen science was estimated at a pay rate of $8.50 per hour, assuming it would take one student 30 minutes to process one trap. [5]A researcher's time to train a student worker was calculated using a base salary of $70 000 for the researcher and the assumption that it would take 40 hours of training time per student. This cost was divided by the number of traps one student would process working on the BLBB project for one summer. [6]Cost to mail one YSCT and data sheet from a volunteer to researchers for verification. [7]The cost of training volunteers was estimated by calculating the average roundtrip cost ($0.50 per mile) to travel to workshops held across Ohio in 2010. The time spent to prepare and present each workshop was estimated at 24 hours of time for one researcher. These costs were divided by the number of volunteers trained per workshop (estimated at 20 individuals) to get an estimate per volunteer. [8]Website development was estimated at $3000 and annual updates and maintenance of the site at 40 hours of researcher time. This was divided by the number of volunteers using the site annually (estimated at 250 per year).