Evaluating promotional approaches for citizen science biological recording: bumblebees as a group vs *Harmonia axyridis* as a flagship for ladybirds

Richard F. Comont & Kate Ashbrook

R. F. Comont
Bumblebee Conservation Trust, Parkway House Business Centre, Eastleigh Works, Campbell Road, Eastleigh, Hampshire SO50 5AD, UK
e-mail: richardcomont@gmail.com

K. Ashbrook
University of Worcester, Henwick Grove, Worcester, Worcestershire WR2 6AJ, UK

Abstract

Over the past decade, the number of biological records submitted by members of the public have increased dramatically. However, this may result in reduced record quality, depending on how species are promoted in the media. Here we examined the two main promotional approaches for citizen science recording schemes: flagship-species, using one charismatic species as an umbrella for the entire group (here, *Harmonia axyridis* (Pallas) for Coleoptera: Coccinellidae); and general-group, where the group is promoted as a whole and no particular prominence is given to any one species (here, bumblebees, genus *Bombus* (Hymenoptera: Apidae)). Of the two approaches, the general-group approach produced data that was not biased towards any one species, but far fewer records per year overall. In contrast, the flagship-species approach generated a much larger annual dataset, but heavily biased towards the flagship itself. Therefore, we recommend that the approach for species promotion is fitted to the result desired.

Keywords

Biological recording, citizen science, verification, *Bombus hypnorum*, bumblebee, ladybird

Introduction

It is becoming ever more evident that the Earth's biodiversity is in crisis, even potentially entering a sixth mass extinction event (Ricciardi 2004; Thomas et al. 2004; Wilson et al. 2004; Dunn 2005; Conrad et al. 2006; Barnosky et al. 2011). At the same time, the contribution that wildlife makes to humankind's economic, social and spiritual wellbeing is becoming recognised more widely (van Lenteren 2006; Sandhu et al. 2008; Watson et al. 2011; Vanbergen et al. 2014; Straub et al. 2015). Consequently, knowledge of species' abundances and distributions, and how these are changing, is becoming ever more valued. For example, the Convention on Biological Diversity's 'Aichi target 12' covers preventing extinction and improving the conservation status of threatened species (https://www.cbd.int/sp/targets/#GoalC) and this requires assessment of the conservation status by member states (JNCC 2014).

In Britain in particular, a huge proportion of our knowledge of species' distribution and ecology comes from the work of unpaid amateurs (Preston et al. 2012; Pocock et al. 2015; Roy et al. 2015). Historically, these volunteer biological recorders have been relatively few in number, but relatively expert in identification ability. Verification of records largely rested on recording scheme organisers' knowledge of other's identification abilities, backed up by examination of specimens, generating a dataset which was highly accurate taxonomically, but which for most taxa was geographically limited (Foster 2015; Isaac and Pocock 2015).

During the 21st century, recording schemes for many taxa have begun soliciting the submission of records from the general public, aided by the development of digital cameras and the growth of online recording (Roy et al. 2012a; Lawson Handley 2015; Pescott et al. 2015; Sutherland et al. 2015). This greater involvement of the general public has the potential to generate many more records, and increasing coverage of records over any given area, but comes with a different set of challenges and limitations. In particular, most recorders' identification abilities are unknown to recording scheme organisers, and most records are backed, at most, by photographs.

Here, we investigated two approaches commonly taken in citizen-science biological recording to encourage records from the general public: flagship-species and general-group promotion. The first of these is the use of a single charismatic species as a 'flagship' for the group as a whole. Here, we used *Harmonia axyridis* (Pallas) as the flagship species for a ladybird recording scheme, in this case the 'Harlequin ladybird survey' project of the UK Ladybird Survey. *Harmonia axyridis* is a highly publicised post-millennium addition to the British fauna, first recorded in Britain in 2003 (Roy et al 2012), but quickly becoming widespread and abundant across the UK. In contrast, general-group recording does not use flagship species, but instead concentrates on the promotion of the group as a whole. Here, we examined the promotion of recording 'bumblebees' to cover the 25 British species of the genus *Bombus*, using the Bumblebee Conservation Trust's BeeWatch recording project. Within the bumblebee group, we also singled out *Bombus hypnorum* L. as a potential flagship species. Like *H. axyridis* this is a post-millennium addition to the British fauna, establishing in 2001, spread rapidly across the UK and is now abundant in gardens. However, unlike *H. axyridis, B. hypnorum* was not promoted as a flagship species for the group, although on-going interest in bee decline has meant that there has been a considerable media profile for bumblebees as a whole.

Our aim was to investigate the impact of these two approaches on the recording of two groups of British insects, bumblebees and ladybirds. First, we compared the number of biological records generated by the two approaches. Second, we examined the influence of promotional approach on recorder identification ability across time and species. Finally, we looked at biases in identification generated by the promotional approach and how this changed with time.

Material and Methods

Data

Biological record data were taken from two volunteer-focused biological recording schemes. Only sightings which were submitted with enough evidence for an independent verification (a specimen or adequate photograph) were used as data. It should be remembered that not all records submitted to the recording schemes are accounted for here, as expert recorders will often submit records without supporting evidence, but examination of these is beyond the scope of this paper.

Bumblebee data were taken from the BeeWatch recording scheme (http://homepages.abdn.ac.uk/wpn003/beewatch), which is run by the Bumblebee Conservation Trust (BBCT) and maintained by Aberdeen University (11,509 records). These cover the period from the beginning of the survey in August 2011 to 30th September 2015. Recorders are encouraged to provide an identification for their sighting using resources on the website, but it is not obligatory as all records submitted to this scheme must be supported by at least one photograph and these are identified to species (where possible) by experts at BBCT.

Ladybird data were taken from the UK Ladybird Survey, the UK's national scheme for collecting biological records of ladybirds. As with BeeWatch, only those records which were supported by and identifiable from photographs or a specimen were included. This dataset consisted of 74,058 records, all checked by national ladybird recorders and collated from records submitted to iRecord (http://www.brc.ac.uk/iRecord: 49,429 records), the Harlequin Ladybird survey website (http://www.harlequin-survey.org: 14,468 records), and other data submitted to the scheme (10,161 records, mostly via email). These data cover the years 1980 – 2015 inclusive, and are further split into data largely submitted online by the general public (the online dataset, March 2005 – September 2015: 71,390 records) and data largely submitted by expert amateur recorders (the historic dataset, January 1980 – February 2005: 2668 records). The timing of this split is based on the launch of the Harlequin survey website in spring 2005, which marked the first time that the general public had been able to take part in biological recording online, and was to assess the impact of including a high proportion of citizen science records on recorder accuracy within a dataset.

Analysis was restricted to the subset of widespread and abundant species within each group in order to have enough data on each species for valid analysis (Table 1). For bumblebees, this meant 6,302 records covering five species *(B. hypnorum*, *B. pratorum* (L.), *B. pascuorum* (Scopoli), *B. lapidarius* (L.), and *B. hortorum* (L.)) along with a species complex composed of *B. terrestris* (L.) and *B. lucorum sensu lato* (Table 1). These taxa were combined as these species are indistinguishable as workers, especially from photographs (Edwards and Jenner 2009). This meant that all records of *B. terrestris* or *B. lucorum* were treated as the *B. terrestris/lucorum* complex and thus any records submitted as *B. terrestris* and re-determined to *B. lucorum* were accepted as correct and vice versa.

In the ladybird dataset, the seven species with more than 100 records/year were included: 62,681 records of *H. axyridis*, *Coccinella septempunctata* L., *Propylea quattuordecimpunctata* (L.), *Adalia bipunctata* (L.), *Adalia decempunctata* (L.), *Halyzia sedecimguttata* (L.), and *Calvia quattuordecimguttata* (L.) (Table 1). Numbers presented through the Results and Discussion sections refer to this subset of records unless explicitly otherwise indicated.

Data analysis

To investigate changes in the number of records submitted for bumblebees, ladybirds, *H. axyridis* and *B. hypnorum* from 2000 to 2015, we carried out separate Spearman's rank correlations. For each month across the dataset period we compared the expert's determination to the recorder's original identification; recorder identifications that did not match expert identifications were classified as misidentified. We used Generalised Linear Models (GLMs) with a quasibinomial error distribution and logit link function to test for differences between the proportion of records correctly identified across years, species and species groups.

Taking an information theoretical approach, we used Akaike's Information Criterion (AIC) to select the most parsimonious model in each case (Bolker 2008; Bolker et al. 2009). Where models were determined to be over-dispersed, we calculated quasi-AIC (QAIC), adjusting for over-dispersion by dividing the residual deviance (-2 log likelihood) with the over-dispersion parameter of the most complex model as the sum of squares Pearson's residuals divided by the number of degrees of freedom (Burnham and Anderson 2002). Models with the lowest AIC or

QAIC (for quasi-error structures) were considered to be the most parsimonious models, explaining the largest proportion of the variation in the response variable. We also performed Fisher's tests on model variables to determine the relative importance of individual variables once the most parsimonious models had been determined using the information theoretic approach.

To investigate the biases in identification generated by concentrating on a flagship species, rather than the whole group, we examined the trends over time for both *H. axyridis* and *B. hypnorum*. We used Spearman's rank correlations to test for trends in: a) the proportion of other species misidentified as these species; and b) the proportion and range of other species which these were misidentified as. All analysis was performed in R 3.1.2. (R Development Core Team, 2015).

Results

Total number of records

The total number of records submitted for the ladybird species we examined (Table 1) increased from 2005 onwards (Spearman's rho = 0.93, $p < 0.001$); this included an increase in the number of *H. axyridis* records submitted (Spearman's rho = 0.87, $p < 0.001$; Fig. 3). Before the establishment of the online recording scheme in 2005, a mean of 59.2 records (SD ± 55.35) were submitted per year. In 2005 – 2015, this increased to 2850.4 records (SD ± 2334.32) per year of species other than *H. axyridis*, and a mean 5693.2 records (SD ± 4104.12) per year in total. Over this period a mean of 52.8% of the records received by the recording scheme have been of *H. axyridis*, reaching 77% in both 2008 and 2009.

In comparison, during the existence of the BeeWatch recording scheme (2011 onwards), records per year for the bumblebee species we examined (Table 1) have remained more stable, rising to a peak of 2,042 records in 2013, but decreasing since (Spearman's rho = 0.79, $p < 0.001$; Fig. 3). *Bombus hypnorum* records have increased in number (Spearman's rho = 0.80, $p < 0.001$), in line with this overall group increase, and make up 18 - 29% of the dataset per year. Considering these trends, both ladybird and bumblebee records are fewer than expected in 2015 (Fig. 3), but this is likely due to the use of data submitted from January – September of this year only.

Recorder identification ability

Once the datasets were reduced to include only records supported by photographs or specimens, and cover only the selected species, 68,983 records remained for analysis. Of these, 5,371 records were misidentified (bumblebees: 41.1% misidentified; ladybirds: 3.9% misidentified). The key factors influencing the proportion of records correctly identified were species group (bumblebee or ladybird), year and species (Table 2, model 1). Ladybirds were more likely to be correctly identified by recorders than were bumblebees (mean proportion correctly identified (± 1 SE): Ladybirds = 0.96 ± 0.003; Bumblebees = 0.59 ± 0.018; Group: $F_{1,1585} = 2369.1$, $p < 0.001$; Fig. 1).

Our models showed that some species were misidentified more than others (mean proportion correctly identified ± 1 SE; Species: $F_{12,1585} = 222$, $p < 0.001$; Fig. 1). For ladybirds, *C. septempunctata* was the most correctly identified species (mean = 0.99 ± 0.002) and *A. decempunctata* the least (mean = 0.93 ± 0.01). Variation in recorder accuracy between bumblebee species was greater: the *B. terrestris/lucorum* complex was the most correctly identified (mean = 0.64 ± 0.03), and *B. pascuorum* was the least (mean = 0.51 ± 0.04).

Recorder accuracy also varied significantly between years (Table 2, model 1; Year: $F_{1,1585} = 98.8$, $p < 0.001$; Fig. 2), with the 1477 ladybird records submitted 1980-2004 being 99.8% accurate, decreasing to an all-time low in 2005 (mean proportion correctly identified = 0.85 ± 0.028), before increasing to 95.8% correctly identified in 2006 – 2015. Bumblebee recorder accuracy varied between 49% and 62% over the five years of BeeWatch. We did not find a significant difference in recorder accuracy between months (Table 2, model 1; Month: $F_{11,1585} = 1.5$, $p > 0.05$).

Species misidentified

In total, 552 of the records submitted by recorders as *H. axyridis* were found not to be that species when checked by an expert. These misidentifications were of six species: *A. bipunctata* (29.9%), *C. septempunctata* (20.8%), *A. decempunctata* (18.8%), *P. quattuordecimpunctata* (13.4%), H. *sedecimguttata* (12.1%), or *C. quattuordecimguttata* (4.9%). Recorders misidentified native species as *H. axyridis* most often in 2005, when the number of records wrongly submitted was 21% of the number of actual *H. axyridis* records (Fig. 4).

In contrast to *H. axyridis*, the proportion of records incorrectly submitted as *B. hypnorum* remained relatively stable at 2.3 to 5.5% of records annually, albeit over a shorter period (Spearman's rho: 0.4, p = 0.75; Fig. 4). Of the 54 records misidentified by recorders as *B. hypnorum*, only three species were represented: *B. pascuorum* (88.8%), *B. terrestris/lucorum* (5.6%) and *B. hortorum* (3.7%).

A much larger number of species are represented when either *H. axyridis* or *B. hypnorum* themselves were misidentified as other species by recorders. For *H. axyridis* there was a total of 1477 records originally submitted as one of 24 different species. The species that *H. axyridis* individuals were most frequently misidentified as were *A. decempunctata* (12.6%), *A. bipunctata* (11.9%), *C. undecimpunctata* (10.8%) and *S. vigintiquattuorpunctata* (9.9%). The proportion of *H. axyridis* which were mistakenly identified as native species increased over time (Spearman's rho = 0.86, p < 0.001). Therefore, misidentified records switched from being largely native species misidentified as *H. axyridis*, to *H. axyridis* misidentified as native species over the 11 years of the dataset.

For *B. hypnorum*, there were 98 records which were originally submitted as sightings of 17 different species of bumblebee. The most frequently misidentified species were *B. barbutellus* (12.2%), *B. ruderatus* (12.2%), *B. lucorum* (10.2%), *B. sylvestris* (10.2%) and *B. terrestris* (10.2%). Like the misidentifications of other species as *B. hypnorum*, the proportion of misidentified *B. hypnorum* records increased over time, though this was not a significant increase (Spearman's rho = 0.8, p = 0.3).

Discussion

In this paper we show that ladybirds are much more accurately identified than are bumblebees in these datasets. The flagship-species approach did create a dataset strongly biased towards records of the flagship species, whereas the general-species approach created a relatively even distribution of records across species within a group.

Ladybirds showed a large and significant increase in the number of records from 2005 onwards. It is impossible to attribute this to any one cause and several factors will have played roles, including the high media profile of *H. axyridis*, but it is striking that, after the adoption of the flagship-species approach, records were very heavily biased towards the flagship species, twice reaching 77% of the year's total records during 11 years. Despite the bias, the number of records submitted of ladybirds other than the flagship species also increased dramatically (a 48 – fold increase).

In comparison, the number of bumblebee records submitted per year was comparatively evenly distributed throughout the shorter duration of this survey. It should be noted that the original arrival of *B. hypnorum* in Britain did not occur during the survey period, although it did continue to colonise new areas. With around 1,500 records submitted annually from 2012 – 2015, the figure is considerably smaller than the annual 5,900 records submitted to the ladybird recording scheme during 2005 - 2015. However, this is substantially more than the 59 records submitted annually to the ladybird survey before it adopted on-line recording and the flagship species approach. This shows the advantage of easy-to-access online recording allied to promotion of the group to potential citizen scientists (and, in both these cases, helped by considerable media coverage of the species groups).

It also demonstrates one of the drawbacks, in the sheer amount of time required to verify records. In Britain, recording schemes have generally been run by a single individual or small team of 'national recorders' (verifiers) and record collation and verification has occupied spare time. Verification of 59 records at 99.8% accuracy is considerably better-suited to this approach than dealing with 5,900 records at 85% or even 95% accuracy (and it should be remembered that these figures do not include records submitted without photographs, or the less common species). It may be that the general-group approach generates fewer records, but these may be more valuable overall if there is less of a bias towards any one species, as well as reducing workload on verifiers.

When the putative flagship species within the bumblebee group (*B. hypnorum*) is examined, it is clear that the general-group approach generated a more evenly distributed dataset across species. *Bombus hypnorum* accounted for a mean 22% of the annual records, peaking at 29%, considerably less than the weighting towards *H. axyridis* with the flagship-species approach. This is important in light of the increased usage of citizen-science data for large-scale scientific analysis beyond simple distribution mapping (Agapow and Isaac 2002; Comont et al. 2012; Comont et al. 2014; Isaac et al. 2014; Powney and Isaac 2015; Purse et al. 2015; Maes et al. 2015). Although datasets are never complete or unbiased, the value of biological records is that they are perceived to produce a broadly accurate representation of the species and populations across a given area. If the collection method introduces further biases to the data, for example towards overrepresentation of a flagship species, these data become less accurate and therefore less valuable (e.g. August et al. 2015, Prendergast et al. 1993, Telfer et al. 2002). This is particularly pertinent for datasets used to prioritise conservation efforts.

Furthermore, we found that promotional approaches generated different biases in recorder accuracy for individual species. For the flagship-species approach, the promotional interest was firmly on *H. axyridis*, and recorders were initially eager to have found and recorded the species. This lead to a high rate of misidentifications of native species as *H. axyridis*, aided at first by the restricted range as the species colonised Britain. As the flagship species became more widespread and abundant, recorders instead began mistaking individuals of *H. axyridis* for native species, the two trends crossing during 2010. No such pattern was discernible for *B. hypnorum* (albeit over a much shorter time period) which was not promoted over and above the group as a whole, and for which rates of both types of misidentification increased over time. *Bombus hypnorum* varies considerably less than does *H. axyridis*, but the differing trends in rates of misidentifications between the two have implications for interpretation of data unsupported by photographs/specimens in particular from recording schemes using the two approaches.

In general, and unsurprisingly, species which varied more were correctly identified less often. The least-accurately identified bumblebee, *B. pascuorum*, varies considerably in colour between bright ginger and pale brown, and the quantity of black hairs on the abdomen fluctuates, changing the appearance considerably even between nestmates. Likewise, *A. bipunctata* and *A. decempunctata* were the 5th and 7th most accurately identified species of ladybird (of 7). Both vary considerably in the strength and colour of their markings, and have several named colour forms, including melanic forms, which are widespread in the population.

This appears to be less supported by the bumblebee data. Of the six species and aggregate species considered, three show considerable sexual dimorphism, but these were the 1st, 3rd and 4th best-identified species. Those where all three castes are similar in appearance were the 3nd, 5th and 6th best-identified. However, bumblebees generally show wear and tear more than ladybirds, losing hairs and fading quickly in the sun, which can cause considerable complexity in identification. Additionally, female bumblebees can sting, which may cause a certain understandable reluctance on the part of recorders to inspect them as closely as can be required for accurate identification!

This all highlights a need for verification, even for widespread or abundant species, as the biases in identifying a flagship species do not remain constant over time. Although these biases can be removed with record verification, the interpretation of unverified records is more difficult, and it is likely that recorders of similar identification abilities who submit records without supporting evidence (i.e. a photograph or specimen) misidentify species at similar frequencies. The wider involvement of the general public in recording ladybirds with the launch of the online recording scheme in 2005 did cause a significant decrease in the accuracy of records submitted. The rate of accurate identification dropped from 99.8% (1980-2004) to 85% during 2005. This is similar to rates reported in other studies (Crall et al. 2011; Gardiner et al. 2012), although it did climb back to 95.4% during 2006-15, indicating a possible effect of familiarity with the species, or use of new identification guides. Although bumblebees were only accurately identified to species around half the time (49-62%) in this study, it is notable how much more accurate recorders were than in some previous studies, where participants struggled to identify bumblebees to group or colour pattern (Kremen et al. 2011, Roy et. al. 2015). This is likely to be the advantage of using a self-selected group motivated to identify bumblebees and submit records for their own enjoyment, rather than running a school activity or defined experiment where participation is perhaps more forced.

Verification also provides an opportunity to increase volunteer recorder's knowledge of the group by a form of online mentoring. For example, recorders submitting records to BeeWatch receive much more assistance in identification as a matter of course than do ladybird recorders. This includes allowing recorders the option of whether they wish to suggest an identification or not and there is much more information provided post-submission to the recorder, with the aim of improving recorder identification ability. The use of verified data is key to improving the confidence of both reviewers and researchers in the quality of the data from citizen-science projects and recording schemes (Silvertown 2009; Conrad and Hilchey 2011). Even partial verification allows an estimation of error rates and power analysis (Gardiner et al. 2012). However, this does have the cost of vastly increasing verifier workload per record.

In summary, using a flagship species generates a dataset with more integral biases than does the general-group approach. However, the use of a charismatic flagship species such as *H. axyridis* can capture the imagination of the public and the media to drive recording to new heights, outweighing many of the disadvantages of the approach. It should be recognised, however, that the general-group approach many generate a dataset with fewer biases and that more records may not, in and of themselves, be better for the purposes to which the data may be put.

Paradoxically, its success as a flagship species may make the arrival of *H. axyridis* both the best and the worst of things to have happened to ladybirds in Britain. A voracious predator and competitor with significant detrimental effects on native species (Roy et al. 2012b; Comont et al. 2014), yet also the means by which we have enthused recorders and generated data which has hugely increased our understanding of the group.

References

Agapow MP, Isaac BNJ (2002) MacroCAIC: revealing correlates of species richness by comparative analysis. Div Distrib 8:41–43.

August T, Harvey M, Lightfoot P, Kilbey D, Papadopoulos T, Jepson P (2015) Emerging technology for biological recording. Biol J Linn Soc 115:731-749

Barnosky AD, Matzke N, Tomiya S, Wogan GOU, Swartz B, Quental TB, Marshall C, McGuire JL, Lindsey, LE, Maguire, CK, Mersey, B, Ferrer, AE (2011) Has the Earth's sixth mass extinction already arrived? Nature 471:51–57.

Bolker BM (2008) Ecological Models and Data in R. Princeton University Press, Princeton

Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulson JR, Stevens MHH, White, J-SS (2009) Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol Evol 24:127–135.

Burnham PK, Anderson RD (2002) Model selection and multi-model inference: a practical information-theoretic approach. Springer-Verlag, New York.

Comont RF, Roy HE, Lewis OT, Harrington R, Shortall CR, Purse BV (2012) Using biological traits to explain ladybird distribution patterns. J Biogeogr 39:1772–1781.

Comont RF, Roy HE, Harrington R, Shortall CR, Purse BV (2014) Ecological correlates of local extinction and colonisation in the British ladybird beetles (Coleoptera: Coccinellidae). Biol Invasions 16:1805–1817.

Conrad CC, Hilchey KG (2011) A review of citizen science and community-based environmental monitoring: issues and opportunities. Environ Monit Assess 176:273–291.

Conrad KF, Warren MS, Fox R, Parsons MS, Woiwod IP (2006) Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. Biol Conserv 132:279-291

Crall WA, Newman JG, Stohlgren JT, Holfelder AK, Graham J, Waller MD (2011) Assessing citizen science data quality: an invasive species case study. Conserv Lett 4:433–442.

Dunn RR (2005) Modern Insect Extinctions, the Neglected Majority. Conserv Biol 19:1030–1036.

Edwards M, Jenner M (2009) Field guide to the bumblebees of Great Britain and Ireland, 2nd edn. Ocelli, Eastbourne

Foster GN (2015) Taking the oldest insect recording scheme into the 21st Century. Biol J Linn Soc 115:494–504.

Gardiner MM, Allee LL, Brown PMJ, Losey JE, Roy HE, Smyth RR (2012) Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. Front Ecol Environ 10:471–476.

Isaac BNJ, Pocock OMJ (2015) Bias and information in biological records. Biol J Linn Soc 115:522–531.

Isaac NJB, van Strien AJ, August TA, de Zeeuw MP, Roy DB (2014) Statistics for citizen science: extracting signals of change from noisy ecological data. Methods Ecol Evol 10:1052-1060

JNCC (2014) Fifth National Report to the United Nations Convention on Biological Diversity: United Kingdom. Peterborough

Kremen C, Ullman KS, Thorp RW (2011) Evaluating the quality of citizen-science data on pollinator communities. Conserv Biol 25:607-617

Lawson Handley L (2015) How will the molecular revolution contribute to biological recording? Biol J Linn Soc 115:750–766.

Maes D, Isaac NJB, Harrower CA, Collen B, van Strien AJ, Roy DB (2015) The use of opportunistic data for IUCN Red List assessments. Biol J Linn Soc 115:690–706.

Pescott OL, Walker KJ, Pocock MJ, Jitlal M, Outhwaite CL, Cheffings CM, Harris F, Roy DB (2015) Ecological monitoring with citizen science: the design and implementation of schemes for recording plants in Britain and Ireland. Biol J Linn Soc 115:505–521.

Pocock MJO, Roy HE, Preston CD, Roy DB (2015) The Biological Records Centre: a pioneer of citizen science. Biol J Linn Soc 115:475–493.

Powney GD, Isaac NJB (2015) Beyond maps : a review of the applications of biological records. Biol J Linn Soc 115:532–542.

Prendergast JR, Wood SN, Lawton JH, Eversham BC (1993) Correcting for variation in recording effort in analyses of diversity hotspots. Biodivers Lett 1:39-53

Preston CD, Roy DB, Roy HE (2012) What have we learnt from 50 years of biological recording? Br Wildl 24:97–106.

Purse BV, Comont RF, Butler A, Brown PMJ, Kessel C, Roy HE (2015) Landscape and climate determine patterns of spread for all colour morphs of the alien ladybird *Harmonia axyridis*. J Biogeogr 42:575–588.

R Development Core Team (2015) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Ricciardi A (2004) Assessing species invasions as a cause of extinction. Trends Ecol Evol 19:619.

Roy HE, Baxter E, Saunders A, Pocock MJO (2016) Focal plant observations as a standardised method for pollinator monitoring: opportunities and limitations for mass-participation citizen science. PLoS One 11(3): e0150794.

Roy HE, Brown PMJ, Comont RF, Lawson Handley, L-J, Poland, R (2012a) UK Ladybird Survey: engaging people in recording ladybirds. Antenna 36:186–193.

Roy HE, Adriaens T, Isaac NJB, Kenis M, Onkelinx T, san Martin G, Brown PMJ, Hautier L, Poland R, Roy DB, Comont RF, Eschen R, Frost R, Zindel R, van Vlaenderen J, Nedvěd O, Ravn HP, Grégoire JC, de Biseau JC, Maes D (2012b) Invasive alien predator causes rapid declines of native European ladybirds. Div Distrib 18:717–725.

Roy HE, Brown PMJ, Frost R, Poland R (2012) Ladybirds (Coccinellidae) of Britain and Ireland. CEH, Wallingford, UK

Roy HE, Rorke SL, Beckmann B, Booy O, Botham MS, Brown PMJ, Harrower CA, Noble D, Sewell J, Walker K (2015) The contribution of volunteer recorders to our understanding of biological invasions. Biol J Linn Soc 115:678–689.

Sandhu SH, Wratten DS, Cullen R, Case B (2008) The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. Ecol Econ 64:835–848.

Silvertown J (2009) A new dawn for citizen science. Trends Ecol Evol 24:467–471.

Straub L, Williams GR, Pettis J, Fries I, Neumann P (2015) Superorganism resilience: Eusociality and susceptibility of ecosystem service providing insects to stressors. Curr Opin Insect Sci. 12:109-112

Sutherland JW, Roy BD, Amano T (2015) An agenda for the future of biological recording for ecological monitoring and citizen science. Biol J Linn Soc 115:779–784.

Telfer MG, Preston CD, Rothery P (2002) A general method for measuring relative change in range size from biological atlas data. Biol Conserv 107:99-109

Thomas JA, Telfer MG, Roy DB, Preston CD, Greenwood JJD, Asher J, Fox R, Clarke RT, Lawton JH (2004) Comparative losses of British butterflies, birds, and plants and the global extinction crisis. Science 303:1879–1881.

van Lenteren JC (2006) Ecosystem services to biological control of pests: why are they ignored? Proc. Neth. Entomol. Soc. Meet. 17:103-111

Vanbergen AJ, Heard MS, Breeze TD, Potts SG, Hanley N (2014) Status and Value of Pollinators and Pollination Services. DEFRA, London

Watson R, Albon S, Aspinall R, Austen M, Bardgett R, Bateman I, Berry P, Bird W, Bradbury R, Brown C, Bullock J, Burgess J, Church A, Christie S, Crute I, Davies L, Edwards-Jones G, Emmett B, Firbank L, Fitter A, Gibson C, Hails R, Haines-Young R, Heathwaite L, Hopkins J, Jenkins M, Jones L, Mace G, Malcolm S, Maltby E, Maskell L, Norris K, Ormerod S, Osborne J, Pretty J, Quine C, Russell S, Simpson L, Smith P, Tierney M, Turner K, van der Wal R, Vira B, Walpole M, Watkinson A, Weighell T, Winn J, Winter M (2011) UK National Ecosystem Assessment: Synthesis of the Key Findings. Unepwcmc Cambridge

Wilson RJ, Thomas CD, Fox R, Roy DB, Kunin WE (2004) Spatial patterns in species distributions reveal biodiversity change. Nature 432:393–396.

Table 1. Total number of records for seven species of bumblebee and seven species of ladybird fulfilling the requirements of being submitted either with a specimen or a photograph and thus used for analysis.

Species group	**Latin name**	**Common name**	**Number of records**
Bumblebees	*Bombus hypnorum*	Tree	1424

	Bombus pratorum	Early	809
	Bombus pascuorum	Common carder	1105
	Bombus lapidarius	Red-tailed	867
	Bombus hortorum	Garden	248
	Bombus terrestris/lucorum	Buff-/White-tailed	1849
	TOTAL		6302
Ladybirds	*Harmonia axyridis*	Harlequin	32957
	Coccinella septempunctata	7-spot	15205
	Propylea quattuordecimpunctata	14-spot	3583
	Adalia bipunctata	2-spot	5111
	Adalia decempunctata	10-spot	2472
	Halyzia sedecimguttata	Orange	1984
	Calvia quattuordecimguttata	Cream-spot	1369
Overall	**TOTAL**		62,681

Table 2. Candidate model set testing for differences in the proportion of correctly identified records across months, years, species and species groups. In each case the response variable is the proportion of correct identifications. ΔQAIC is measured from the best-fitted model.

Model no.	**Model**	**Residual deviance**	**Residual df**	**QAIC**	**ΔQAIC**
1	Species group + Species + Year	3354.1	1573	998.6	-
2	Species group + Species + Year + Month	3298.1	1562	1004.5	5.9

3	Species group + Year	3569.8	1584	1036.7	38.1
4	Species group + Species + Month	3546.6	1563	1074.1	75.5
5	Species group + Species	3628.5	1574	1075.7	77.1
6	Species + Month	3546.6	1574	1105.5	106.9

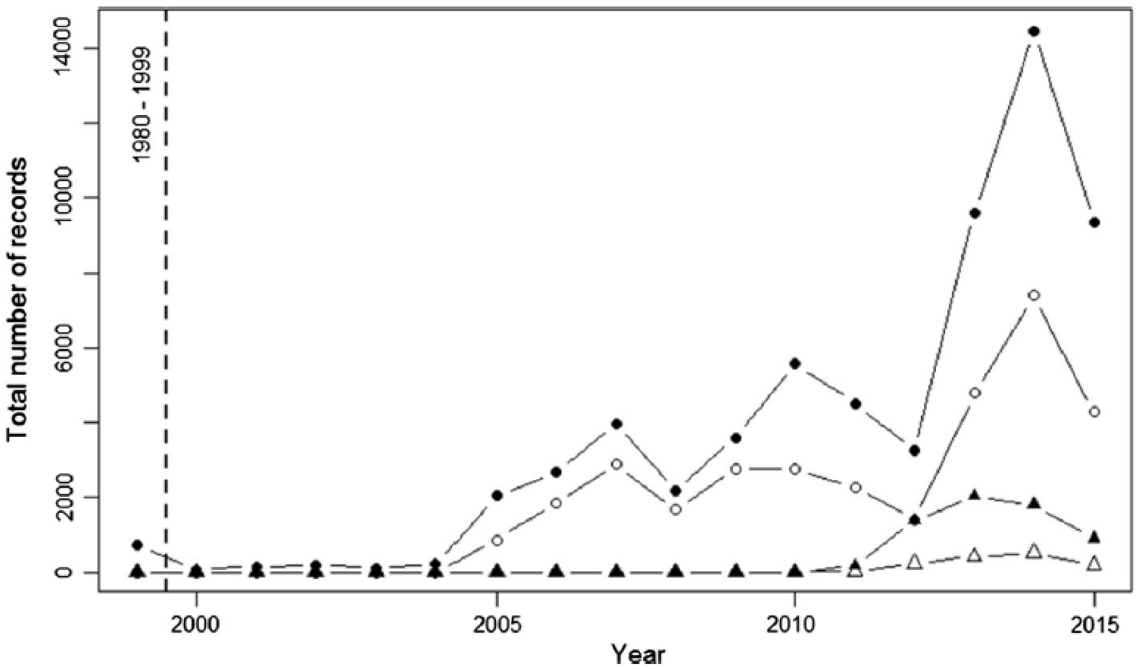

Fig. 1 Proportion of records correctly identified by recorder shown by year and species group. Mean values for 1980 – 1999 ladybird records are provided for comparison. Filled points represent ladybirds; open points, bumblebees. Error bars show ± 1 S.E.

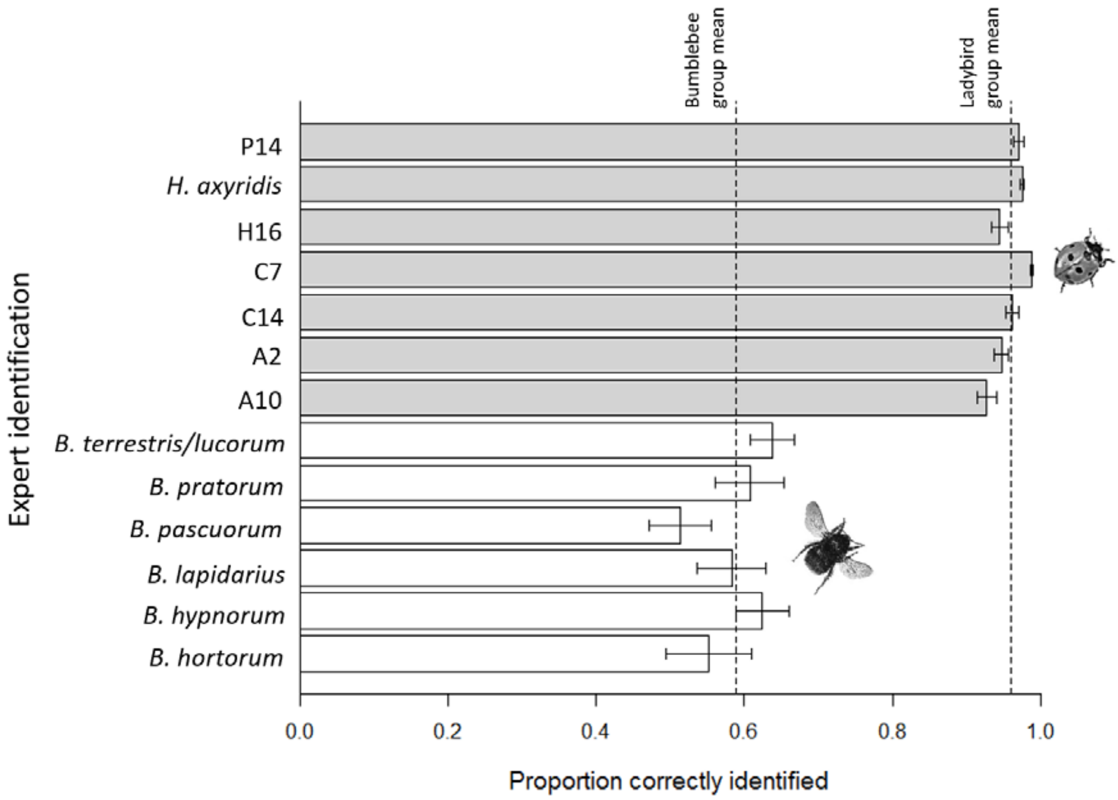

Fig. 2 Proportion of records correctly identified by recorders, per species. Ladybird species names are abbreviated: A10 = *Adalia decempunctata*; A2 = *Adalia bipunctata*; C14 = *Calvia quattuordecimguttata*; C7 = *Coccinella septempunctata*; H16 = *Halyzia sedecimguttata*; *H. axyridis* = *Harmonia axyridis*; and P14 = *Propylea quattuordecimpunctata*; all bumblebees are genus *Bombus*, only specific names are provided. The dotted lines represent the mean proportion of correctly identified records for the species group, and error bars are 1 SE.

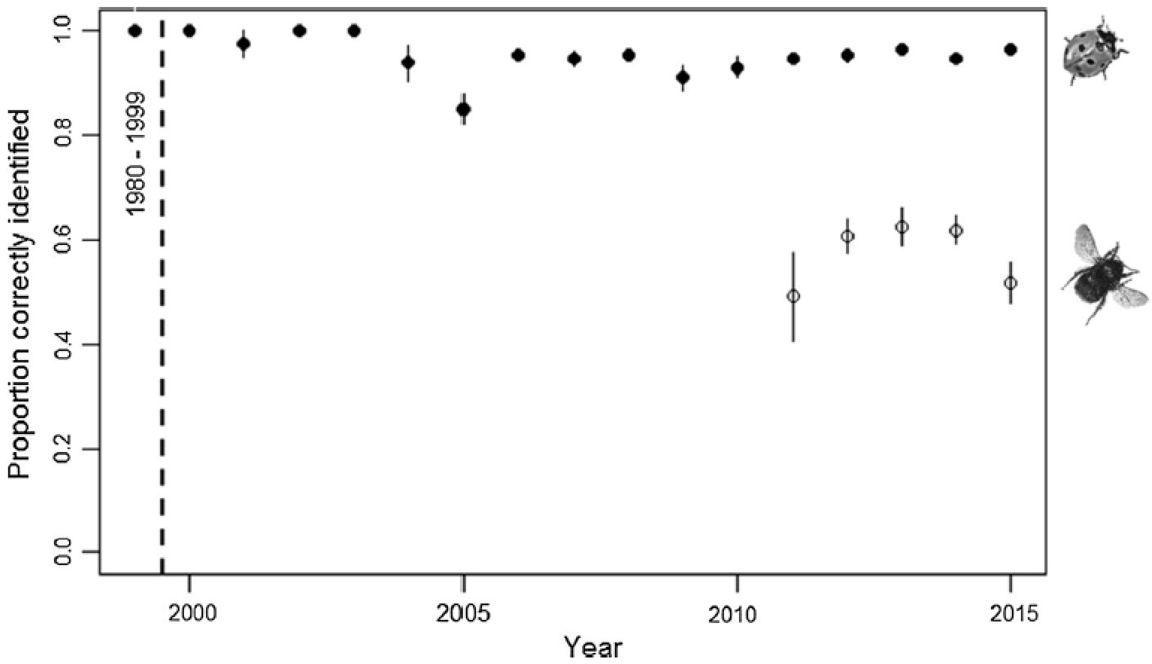

Fig 3 Proportion of records correctly identified by recorder shown by year and species group. Mean values for 1980 – 1999 ladybird records are provided for comparison. Filled points represent ladybirds; open points, bumblebees. Error bars show ± 1 S.E.

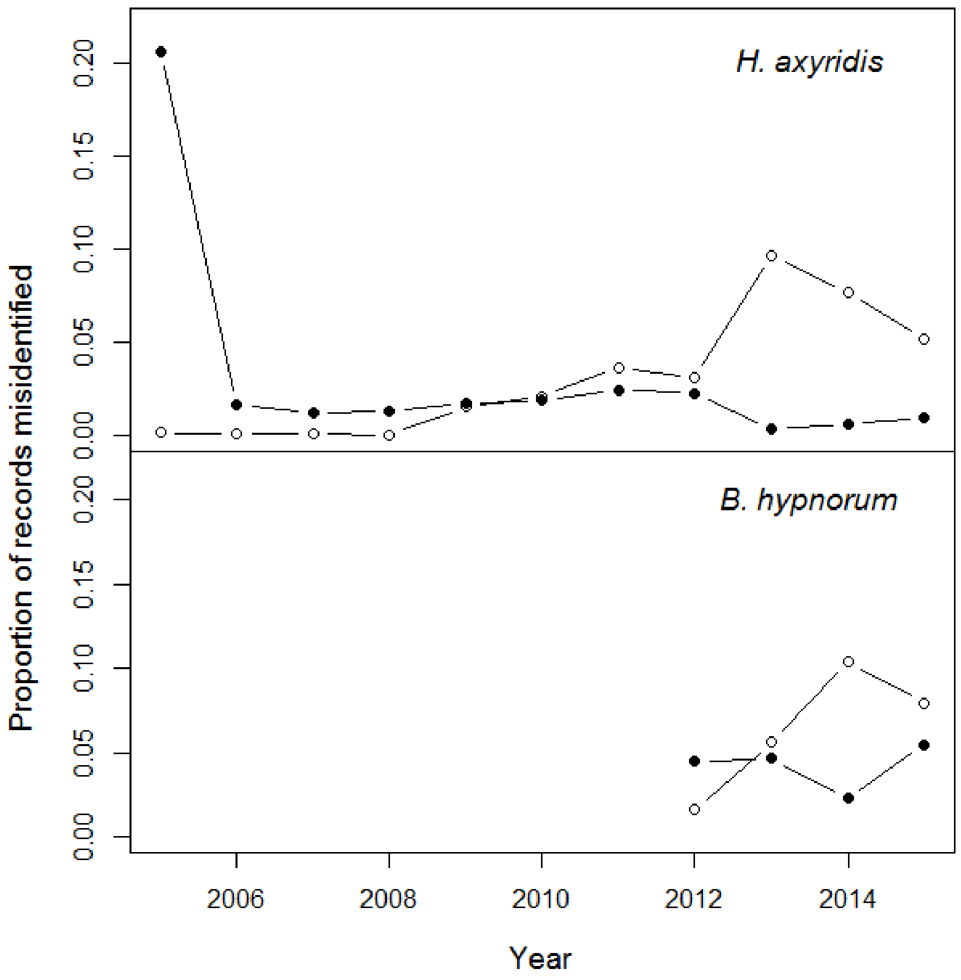

Fig. 4 Proportion of records misidentified for *H. axyridis* (top panel) and *B. hypnorum* (bottom panel). Open points represent the proportion of records which were submitted as the subject species but which experts determined were of a different species; filled points represent the proportion of records which were submitted as different species, but which were actually the subject species.