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The Biological Records Centre: a pioneer of citizen science

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People have been recording wildlife for centuries and the resulting datasets lead to important scientific research. The Biological Records Centre (BRC), established in 1964, is a national focus for terrestrial and freshwater species recording in the United Kingdom (UK). BRC works with the voluntary recording community (i.e. a mutualistic symbiosis) through support of national recording schemes (i.e. 'citizen science', but unlike most citizen science it is volunteer led) and adds value to the data through analysis and reporting. Biological recording represents a diverse range of activities, involving an estimated 70 000 people annually in the UK, from expert volunteers undertaking systematic monitoring to mass participation recording. It is an invaluable monitoring tool because the datasets are long term, have large geographic extent and are taxonomically diverse (85 taxonomic groups). It supports a diverse range of outputs, e.g. atlases showing national distributions (12 127 species from over 40 taxonomic groups) and quantified trends (1636 species). BRC pioneers the use of technology for data capture (online portals and smartphone apps) and verification (including automated verification) through customisable, inter-operable database systems to facilitate efficient data flow. We are confident that biological recording has a bright future with benefits for people, science, and nature. © 2015 The Authors. Biological Journal of the Linnean Society published by John Wiley & Sons Ltd on behalf of Linnean Society of London, *Biological Journal of the Linnean Society*, 2015, **115**, 475–493.

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INTRODUCTION

For centuries, people have been interested in identifying and documenting the occurrence of animals and plants: making biological records (Allen, 1976). A biological record is, at its simplest, a record of a species in a particular place at a particular time by a named person. Yet, despite this simplicity, biological recording is an incredibly diverse activity that engages many thousands of people across Britain and beyond (Harding, 1992; Roy *et al.*, 2014a). These people, recording as volunteers in their leisure time, have contributed tens of millions of records for tens of thousands of species in Britain (Burns *et al.*, 2013; Gurney *et al.*, 2015).

The reliance of biological recording on volunteer contributions means that is it an excellent example of volunteer involvement in science; activity known as 'citizen science'. Citizen science is rising in prominence globally as a tool for scientific research and engagement (Silvertown, 2009; Dickinson, Zuckerberg & Bonter, 2010; Dickinson *et al.*, 2012). Although the long history of volunteer involvement in biological recording is widely recognised as having played a critical role in science and decision-making, much consideration of citizen science has a US-focus (Miller-Rushing, Primack & Bonney, 2012), so the story of biological recording, its distinctive attributes, and successes, has been largely untold outside the UK, until recently.

Within the UK, the national focus for terrestrial and freshwater biological recording is the Biological Records Centre (BRC). It was established in 1964 and works closely with the voluntary recording community, principally through providing support, as appropriate, to the national recording schemes and societies (hereafter 'national recording schemes'),

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each of which have their own taxonomic focus and most of which are volunteer-led. The relationship between the national recording schemes and the BRC provides mutual benefit (Fig. 1). Here, we discuss the role of the BRC as a pioneer of citizen science in its support for biological recording in the UK for over 5 decades.

Biological recording in Britain and the biological records centre

Perhaps the most-celebrated early example of a biological recorder is the so-called 'father of natural history', John Ray (1627–1705), who in his travels around Britain catalogued and noted the species that he and others observed, corresponded with other enthusiasts and collated records in published books (Raven, 1942; Oswald & Preston, 2012). More formal collaborative arrangements for collecting distributional data were put into place in the 19th century, and records of several taxonomic groups began to be catalogued systematically in 'vice-counties', areas based on administrative counties (Allen, 1976; Preston, 1991; Foster, 2015). By 1900 there were about 500 local natural history societies (or 'field clubs') with nearly 100 000 members (McIntosh, 1986), drawing together a wide membership of women and men, and people from working class backgrounds as well as the more affluent (Secord, 1994a, b). The accounts of natural history collated and written by naturalists in this era are remarkably thorough and serve as the earliest baselines from which Britain's changing biodiversity can be assessed, e.g. regional floras (Walker, 2003).

In the early 20th century, ecology as a scientific discipline was becoming established, developing as an empirical science from the study of natural history. One of the pioneers, A.G. Tansley (1871–1955), was especially interested in understanding patterns of vegetation communities in relation to topography and habitat. He explicitly recognised the value of records from 'amateurs': 'Scattered up and down the country are scores of men... whose acquaintance with their local floras is absolutely unequalled... they would do [mapping local floras] a hundred times better than a visiting botanist, with no knowledge of the locality' (Tansley, 1904). Later, in 1954, the Maps Scheme of the Botanical Society of the British Isles proposed to map records of all species in all $10 \times 10\ km^2$ across Britain and Ireland (Preston, 2013). They explicitly recognised this would only be possible 'by enlisting the support of as many volunteer recorders as possible', so not just recruiting from local natural history societies, but also via articles and letters in national and local newspapers and through schools (Perring, 1992; Preston, 2013). It was pioneering in its ambition, and today would be regarded as a form of 'mass participation' citizen science. The *Atlas of the British Flora* (Perring & Walters, 1962) demonstrated the success of drawing on a wide range of recorders, from experts to less experienced, to gain national-scale knowledge of plant distributions. One result which came as a surprise to contemporary botanists was the striking evidence for change in the flora during the historical period (Fig. 2A).

Following the success of the BSBI's plant atlas project, it was recognised that a national focus for

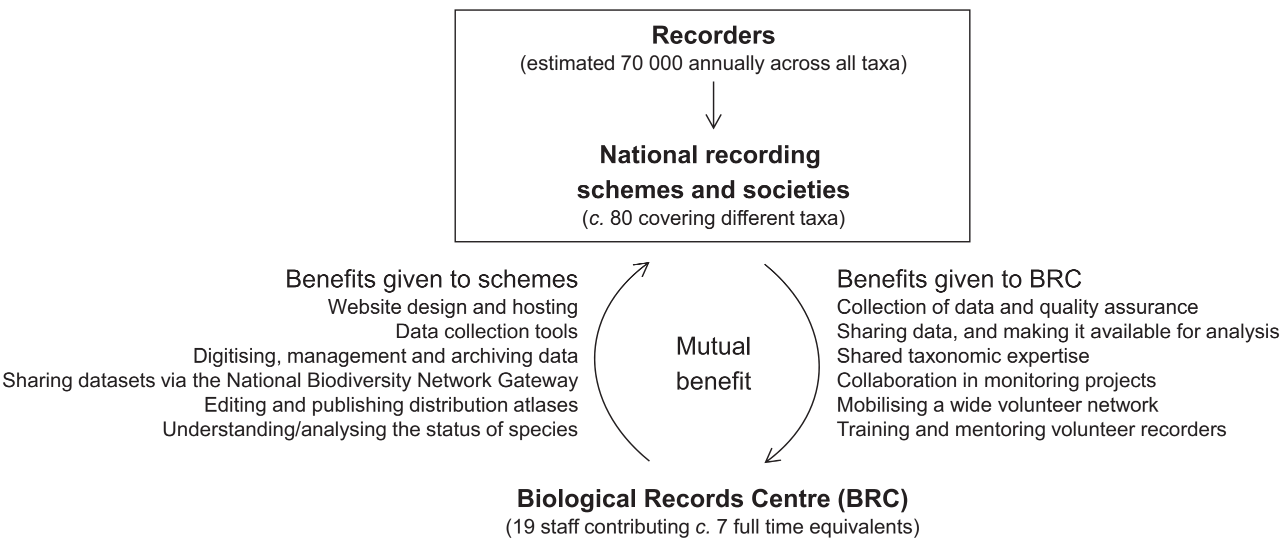

Figure 1. The relationship between 'professionals' in the Biological Records Centre (BRC), national recording schemes (mostly volunteer led) and volunteer recorders showing some of the mutual benefits gained by each.

biological recording was valuable, and so the BRC was formed in 1964 with support from government funding. The BRC initially had a broad remit to promote the study of the distribution of plants and animals (Preston, 2013). By 1968, a total of 18 national recording schemes were associated with the BRC (listed in Preston, 2013), growing to 69 in 1990 (Harding & Sheail, 1992) and 85 currently (Roy *et al.*, 2014a). These schemes cover a great taxonomic breadth, from plants through many invertebrate taxa, to mammals (Fig. 3). Although individual schemes vary in their style, they share many attributes (James, 2011a; Foster, 2015; Pescott, 2015b). In addition to these schemes, the BRC was influential in the establishment of Local Record Centres (Harding & Sheail, 1992) and the National Biodiversity Network (NBN). Occurrence data from national recording schemes are made publically accessible through the NBN Gateway, and from there uploaded to the Global Biodiversity Information Facility (GBIF).

Ultimately, though, the story of the BRC is one of synergistic partnerships with the volunteer-recording community rather than as an organisation mandating requirements for biological recording, i.e. it is neither 'top-down' nor 'bottom-up'. The relationships between BRC, the national recording schemes, and the volunteer recorders build on decades of working in partnership with a shared goal of documenting wildlife across the UK. National recording schemes are independent of the BRC, but are offered support appropriate to their needs and requests, while value is added by the BRC to the contribution of volunteers and their data by applying scientific expertise and a cross-taxa perspective (Fig. 1). The BRC is able to act as a conduit between the communities of recorders and potential users of the data, especially government agencies and academic researchers. There is certainly no requirement for any national recording scheme to receive support from or share data with the BRC, but the vast majority willingly do so and over the 50 years of this partnership the benefits to all have been demonstrated through many diverse publications and outputs (Fig. 1).

Biological recording as a tool for biodiversity science

During the past few decades, understanding of the threat that environmental change poses to biodiversity has increased. It has become clear that engaging volunteer recorders is an effective, cost-efficient way of monitoring species and environmental change over long time periods and/or large spatial extents. These records therefore have direct practical application, e.g. in assessing the status of species (Burns *et al.*, 2013; Maes *et al.*, 2015; Powney & Isaac, 2015) and habitats (Gillingham *et al.*, 2015a; Thomas & Gillingham, 2015b), and contributing to UK government biodiversity indicators (Department for Environment Food and Rural Affairs, 2014).

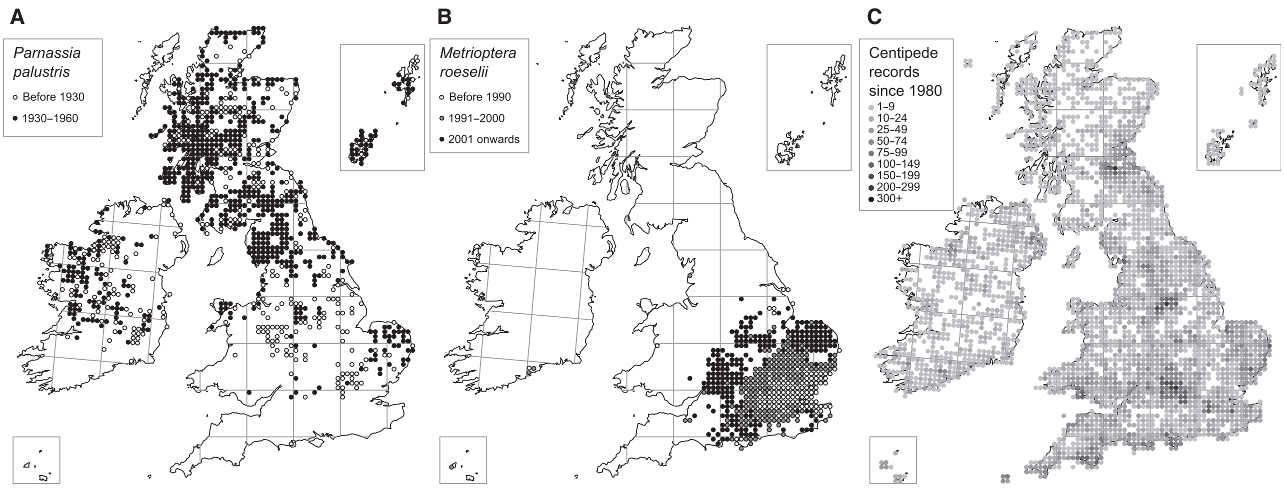

Figure 2. The power of biological recording (A) was first demonstrated by maps in the *Atlas of the British Flora* (Perring & Walters, 1962), as exemplified by the recorded decline of the plant Grass-of-Parnassus *Parnassia palustris*, and (B) also demonstrates range expansion by species such as the Roesel's bush cricket *Metrioptera roeselii* (Orthoptera: Tettigoniidae). C, These maps are so valuable because recording occurs across the whole region (albeit with variation in intensity), even for groups considered to be less charismatic such as centipedes (Chilopoda), as shown here. A record in (C) is a unique combination of species, 10 km^2 and year.

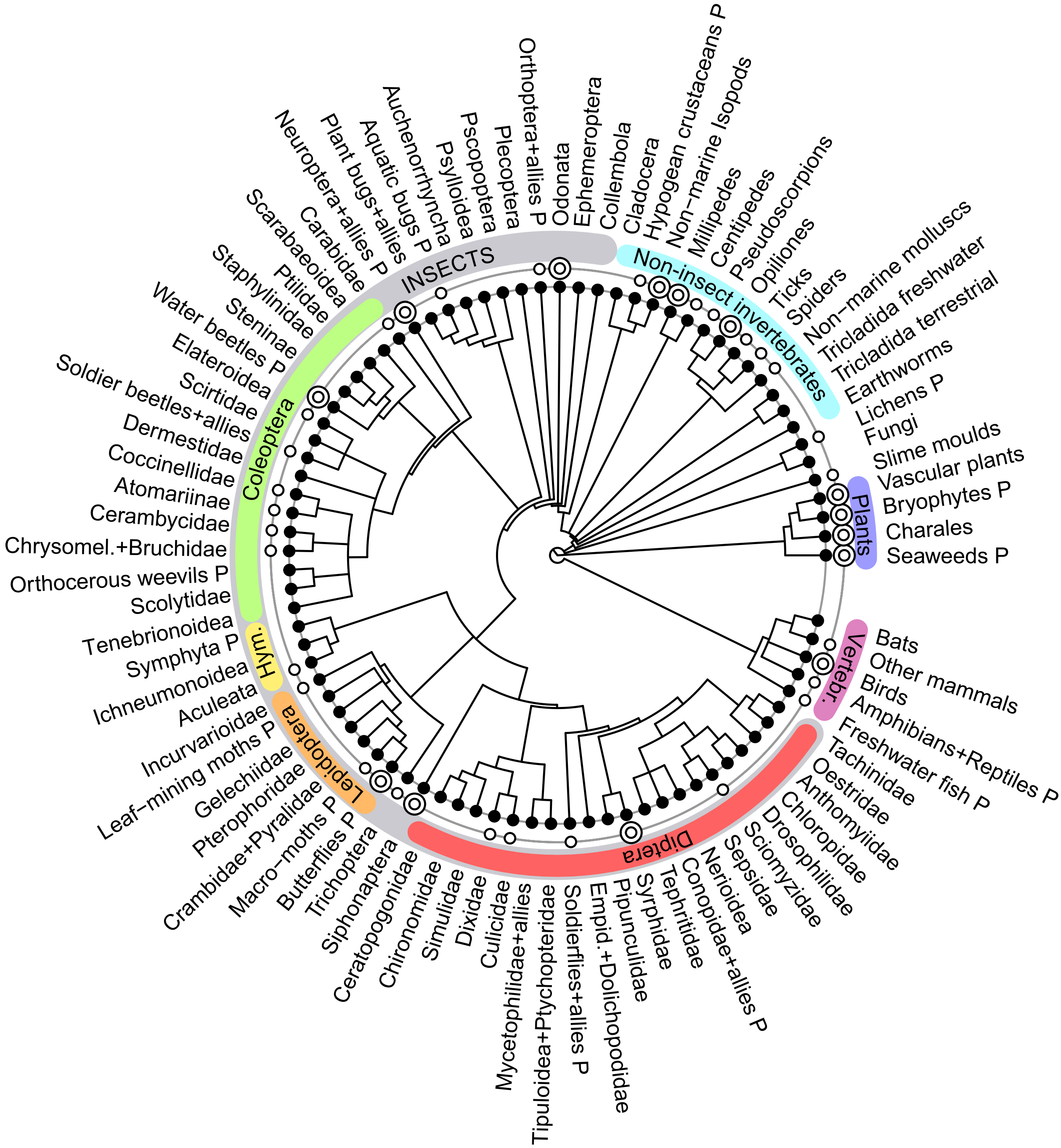

Figure 3. Phylogenetic tree showing the diversity of taxa recorded through national recording schemes in the UK. Open circles indicate the taxonomic groups for which a single (single circles) or repeat (double circles) distribution atlases have been published. The phylogeny is adapted from Maddison & Schulz (2007); some national recording schemes cover polyphyletic groups, indicated by 'P' and are situated in the position of the most speciose taxa. Coloured arcs indicate the major taxonomic groupings. Branch lengths are illustrative only.

However, biological records are also an important resource for scientific research in understanding the impacts of environmental change at large spatial extents over long time periods, including internationally (Hochachka *et al.*, 2012; Theobald *et al.*, 2015; Gurney, 2015). During the period 2004–2014 alone there were over 200 peer-reviewed journal papers using volunteer-collected biological recording data from the UK (Roy *et al.*, 2014a), and published distribution atlases have had substantial scientific impact (Table 1). In particular these data are valuable because they cover wide geographic range, long time scales, and wide taxonomic breadth. Firstly, the wide geographic spread of recorders leads to wide spatial coverage, increasing its representativeness. Coverage is patchy for some of the less well recorded taxa (Fig 1C; Isaac & Pocock, 2015; Preston & Pearman, 2015), but gaps are often explicitly targeted with additional recording. The UK is relatively small but very varied, covering a wide range of climate, geology, land use, and population density, and many national recording schemes also cover the whole of Ireland (i.e. not just Britain or the UK). This supports research on patterns of species richness and the selection of protected areas (Prendergast *et al.*, 1993; Gillingham *et al.*, 2015a; Thomas & Gillingham, 2015b). The wide coverage therefore means that the data span relatively wide environmental gradients, and so the impacts of diffuse effects can be quantified effectively (Stewart *et al.*, in press), e.g. habitat loss (Hill & Preston, 2015; Thomas *et al.*, 2015), eutrophication or changes in air quality (Pescott *et al.*, 2015a). Secondly, the long-term nature of biological recording provides a historical context against which to assess current trends (Oliver & Roy, 2015). This is especially important because many of the current uses of biological records were not anticipated when some of the recording began, e.g. range shifts in response to climate change (Hickling *et al.*, 2006; Mason *et al.*, 2015), pollinator declines (Biesmeijer *et al.*, 2006) or impacts of alien species (Roy *et al.*, 2012b, in press) and diseases (Purse & Golding, 2015). Thirdly, the diversity of taxonomic groups covered by biological recording (Fig. 3) means that records are gathered for species with a very wide range of response and functional traits. This means the wide impacts of biodiversity change can be quantified (Hickling *et al.*, 2006; Burns *et al.*, 2013; Thomas *et al.*, 2015) and mechanisms of change can be inferred (Warren *et al.*, 2001).

These attributes of large spread, long-term and wide taxonomic range also make the data valuable for fundamental ecological research, especially in large-scale and macro-ecology (Devictor, Whittaker & Beltrame, 2010), e.g. landscape and population ecology (Oliver *et al.*, 2009, 2010; Chen *et al.*, 2011), species interactions and evolutionary biology (Pateman *et al.*, 2012), patterns of rarity and spatial scaling (Hartley *et al.*, 2004; Wilson *et al.*, 2004), and in biogeography (Heikinheimo *et al.*, 2012). Analyses of species across a wide taxonomic range enable general trends to be determined (Warren *et al.*, 2001; Pocock *et al.*, 2006), and allows cascading impacts of species change to be predicted (Fox *et al.*, 2014). Finally, the challenges of these data, i.e. usually presence only, rather than presence-absence, data with unstructured and uneven recording effort, drive

Table 1. The citations and H-index of the distribution atlases with an H-index of at least 20

Publication	Taxon	Number of primary citations	Number of secondary citations	H-index
Gibbons, Reid & Chapman (1993)	Birds	585	21 919	68
Perring & Walters (1962)	Plants	311	11 643	59
Sharrock (1976)	Birds	450	14 666	57
Asher *et al.* (2001)	Butterflies	344	13 742	51
Preston, Pearman & Dines (2002)	Plants	505	10 424	48
Heath, Pollard & Thomas (1984)	Butterflies	148	9210	48
Lack (1986)	Birds	151	4399	32
Luff (1998)	Ground beetles (Carabidae)	94	1652	23
Arnold (1993)	Mammals	43	1282	21
Kerney (1999)	Land and freshwater molluscs	158	2352	20

A publication has an H-index of h when it has been cited by h papers each cited h times (Hirsch, 2005), and so its H-index is one way of quantifying its scientific impact. The cited reference search was conducted with Web of Science and so citations refer only to peer-reviewed journal articles (accessed 28 January 2015).

the development of new analytical approaches (Dennis *et al.*, 2013; Isaac *et al.*, 2014).

Citizen science and biological recording

Citizen science has been described in various ways (Dickinson *et al.*, 2010; Bonney & Dickinson, 2012; Miller-Rushing *et al.*, 2012; Roy *et al.*, 2012a); our definition is that citizen science is the 'intentional involvement, in a non-professional capacity, of people in the scientific process, e.g. the collection, interpretation and/or analysis of data, and also potential involvement in generating questions, designing studies, disseminating results, and acting upon results'. Biological recording in the UK clearly fits the definition of citizen science, but the term has been slow to be applied to this activity. There are many possible reasons for this, but the simplest possibility is that the term is superfluous; in the UK the term 'biological recording' adequately describes these volunteer-contributed, high-quality data. Another possible reason is that discussion of citizen science has tended to have a focus on the USA (Bonney *et al.*, 2009b; Bonney & Dickinson, 2012; Miller-Rushing *et al.*, 2012; Theobald *et al.*, 2015; but see Silvertown, 2009; Greenwood, 2012). Biological recording covers a diverse range of activities (as we discuss below), involving novices, volunteer experts, and professionals in various different ways (Fig. 4). There have been various studies proposing models to describe variation across different citizen science approaches (Cooper *et al.*, 2007; Bonney *et al.*, 2009a; Wiggins & Crowston, 2012; Haklay, 2013), but biological recording does not fit neatly into the current models, nor into the linear way in which citizen science project development is often presented (Bonney *et al.*, 2009b; Shirk *et al.*, 2012). In

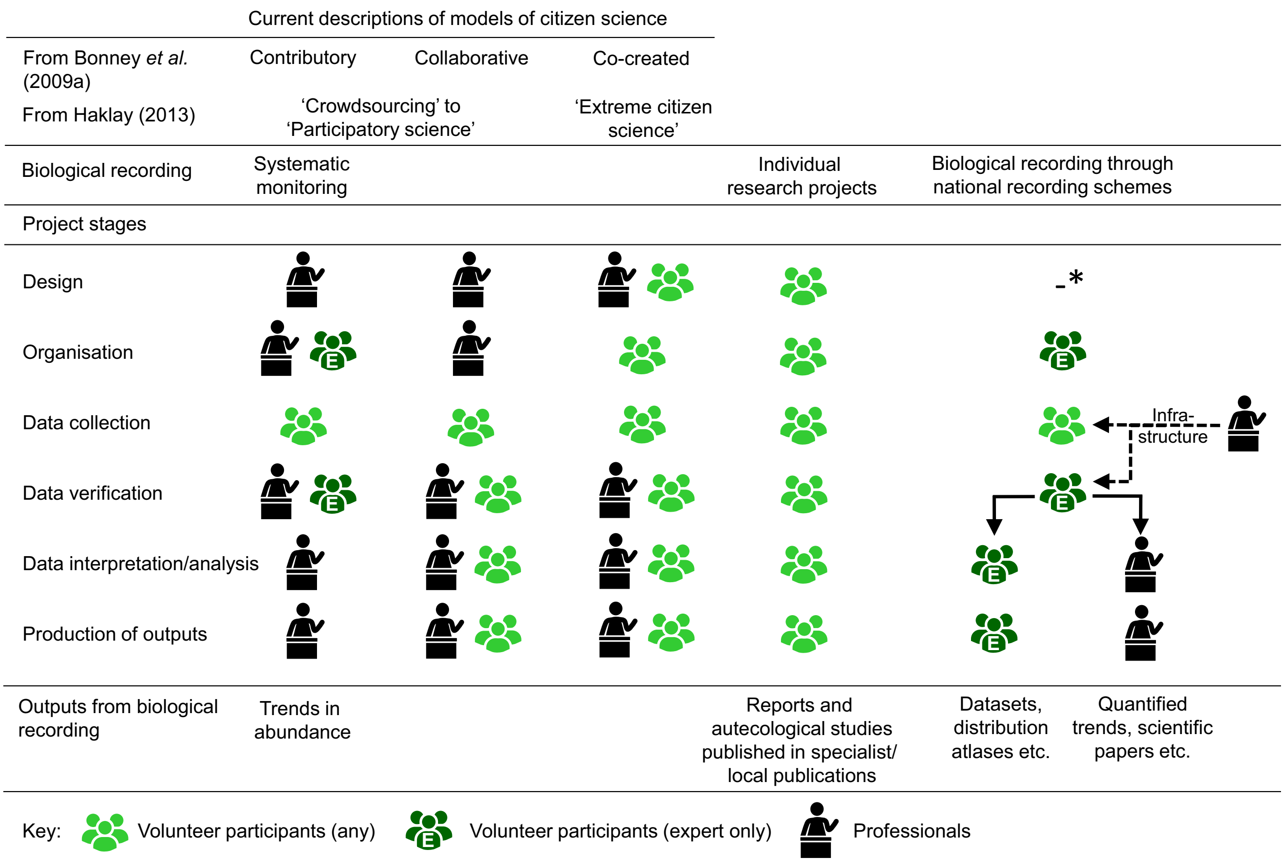

Figure 4. Models that have been used to describe variation across citizen science approaches compared to different biological recording activities, showing the distinctiveness of national recording schemes. This is illustrative and in reality there can be overlap between volunteers, expert volunteers and professionals in biological recording. The description of current models and project stages are adapted from Cooper *et al.* (2007), Bonney *et al.* (2009a), Shirk *et al.* (2012) and Haklay (2013). *Aspects of biological recording will have a degree of structure, e.g. to fulfil an organiser's ambition to obtain adequate coverage of a region by skilled recorders during a particular time period (e.g. fieldwork for an atlas). However, this 'design' cannot easily be captured as metadata, unlike formal protocols (e.g. in contributory citizen science) or site selection (as in systematic monitoring).

particular, some biological recording activities lead to high-quality data but have relatively little instructive involvement from professionals and are not formally designed, i.e. they have less involvement from professionals even than 'co-created' (Bonney *et al.*, 2009a) or 'extreme' (Haklay, 2013) citizen science. Professional input adds value to the biological recording data through its use in further research and monitoring. Activities such as biological recording (as we discuss here), participatory monitoring (Danielsen *et al.*, 2014) and 'farmer participatory research' (Chandler *et al.*, 2012) do fall within the broad definition of citizen science and so it would be valuable for further discussion on typologies of citizen science to include such activities. This would facilitate sharing of relevant expertise and experience between the diverse range of practitioners. Also, 'citizen science' has been recommended as a useful keyword to track and acknowledge the contributions of volunteer participation in scientific activities, which should lead to its increased visibility and credibility (Cooper, Shirk & Zuckerberg, 2014).

THE DIVERSITY OF BIOLOGICAL RECORDING ACTIVITIES AND OUTCOMES

Considering biological recording in the wider context of citizen science (Table 2) emphasises that although modern biological recording grew from distribution mapping projects in the early 20th century it is now much more diverse than this. Biological recording represents different activities engaging a diversity of participants in different ways and leading to a wide range of outputs, as is true for citizen science more generally (Silvertown, 2009; Tulloch *et al.*, 2013; Theobald *et al.*, 2015).

The diversity of recording activities

Unstructured recording

Recording by many of the participants involved in biological recording is described as 'opportunistic', that is recorders can make observations when and where they like, which produces an 'unstructured' dataset, i.e. there is no formal structure imposed upon the process of gathering the records, or at least none that is routinely recorded as part of the dataset (Isaac *et al.*, 2014). Therefore, nothing certain is known about the intervening gaps in space and time, or the completeness of the records, so consequently there are challenges with the interpretation and analysis of these data, including geographic or spatial bias (Hill, 2012; Van Strien, van Swaay & Termaat, 2013; Isaac *et al.*, 2014).

The technological innovations that have made it straightforward for people to submit records (August; and see below) means that these unstructured data are likely to continue to increase in quantity dramatically. Professional researchers, e.g. in BRC, continue to develop sophisticated analytical techniques that are best able to extract quantitative information (e.g. on distribution patterns and change) from these datasets (Hill, 2012; Van Strien *et al.*, 2013; Isaac *et al.*, 2014; Powney & Isaac, 2015); this is one of the ways in which professional scientists add value to biological recording data.

Focussed recording

The information content of a dataset of unstructured, incidental records can be dramatically increased if recorders make small changes to their behaviour (Tulloch *et al.*, 2013; Isaac & Pocock, 2015). Examples of these changes include recording all species seen rather than just the interesting species, recording search effort (Isaac *et al.*, 2014; Sullivan *et al.*, 2014) or conducting comprehensive surveys ('atlas projects') across a whole region (Harding & Sheail, 1992). Following the *Atlas of the British Flora* (Perring & Walters, 1962), many of the national recording schemes have conducted atlas projects (Fig. 3). They represent a concerted effort over a 'limited' period of time (which might be up to a few decades) to record the whole of the region (Britain, UK or Britain and Ireland, depending on the scheme) with 'adequate' coverage. These projects often involve a degree of organisation to ensure adequate coverage and more structured recording, e.g. 'square bashing' to attempt to conduct a complete census for the taxonomic group within a 2 × 2 km or 10 × 10 km square. However, this structure is not easy to record as metadata or a protocol, partly because often the approaches are not consistent across the whole dataset (which also includes incidental records). Repeat atlases have been published for several taxonomic groups (Fig. 3) and are especially important for quantifying change in species distributions (Telfer, Preston & Rothery, 2002) and generating new research questions.

In additional to distribution atlases, focussed recording can also be driven by a specific question of interest to the recording community. For example, the national transect of bryophytes provided a baseline against which future responses to changes in air quality could be measured (Bates *et al.*, 1997) and the Anglers Monitoring Initiative (which is a collaboration of anglers with the Riverfly Partnership: Ephemeroptera, Plecoptera, and Trichoptera recording schemes) is conducting standardised sampling to assess river water quality (http://www.riverflies.org).

Structured monitoring

For some taxa, there are sufficient dedicated participants to implement a 'systematic monitoring'

Table 2. Examples of butterfly recording projects in the UK and the diversity of activities, participants and outputs all of which contribute to knowledge about the status of UK butterflies, but are undertaken in different ways and aimed at different participants

Project	Organisation	Record type	Likely participants	Structured sampling?	Location	Outputs
Unstructured recording						
Butterflies for the New Millennium	BC (staff and expert volunteers)	Usually counts but some presence only	Anyone with the ability to identify butterflies	No	Self-selected but aims for coverage of the whole country	Distribution databases; national trends in distribution; status reports; Red Lists; scientific research publications
iRecord Butterflies smartphone application	BC/CEH	Counts (incidental records) or complete lists with counts	Anyone with the ability to identify butterflies	No	Self-selected	Distribution databases; real-time results; online results summary
County-level recording	BC (expert volunteers), Local Environmental Records Centres and natural history groups	Usually counts but some presence only	Enthusiasts, supported by volunteer regional recorders	Relatively unstructured*	Self-selected	Distribution databases; local atlases; regional annual reports
Focussed recording						
Rare species surveys	BC (staff and expert volunteers)	Counts	Enthusiasts, supported by volunteer regional recorders and national experts	Relatively unstructured*	Pre-selected (previously known locations or locations predicted by species distribution models)	Distribution databases; national trends in distribution; status reports
Individual research projects	Individuals	Local monitoring/ scientific studies established and conducted by individuals	Keen voluntary enthusiasts, and sometimes paid staff as part of their work in conservation and environmental consultancy	Yes – self imposed structure	Self-selected	Participant-published scientific articles

Table 2. *Continued*

Project	Organisation	Record type	Likely participants	Structured sampling?	Location	Outputs
Systematic monitoring						
UK Butterfly Monitoring Scheme (traditional scheme)	BC/CEH	Complete lists with counts	Enthusiasts	Yes – upto 26 weekly transect walks per year	Initially self-selected but repeatedly visited	National trends in abundance; status reports; Red Lists; scientific research publications
Wider Countryside Butterfly Survey	BC/BTO/CEH	Complete lists with counts	Enthusiasts, especially birdwatchers	Yes – 2–3 transect walks per year	Pre-selected stratified random sample (some locations shared with UK Breeding Bird Survey)	National trends in abundance; status reports; Red Lists; scientific research publications
Mass participation						
Big Butterfly Count	BC	Presence only	General public (i.e. mass participation, contributory citizen science)	No	Self-selected	Real-time results; online results summary
Migrant watch	BC	Presence of a single, easily identified species (painted lady *Vanessa cardui*)	General public (i.e. mass participation, contributory citizen science)	No	Self-selected	Real-time results; online results summary
iSpot	Open University	Presence only of any species (incidental records), including butterflies	General public collecting records, enthusiasts confirming identifications	No	Self-selected	Records and identifications online, submission of records to national recording scheme

The four categories of activity (further described in the text) are indicative, and individual activities may fall in more than one category. In most cases the recording is supported by Butterfly Conservation (BC) and the BRC through the Centre for Ecology & Hydrology (CEH).
*See footnote for Fig. 4 for an explanation of structure in these projects.

scheme. The UK Butterfly Monitoring Scheme is one such long-standing scheme established by the BRC in 1976 (Pollard & Yates, 1993). Professional scientists designed protocols, in close collaboration with volunteer recorders, and undertake analysis to produce annual national trends in butterfly abundance, which are now used in UK government biodiversity indicators (Department for Environment Food and Rural Affairs, 2014). The data have also been used extensively in scientific research (e.g. Warren *et al.*, 2001; Oliver *et al.*, 2010; Pateman *et al.*, 2012). In order to make such data fit for purpose there has been increasing emphasis placed on stratified random sampling in monitoring schemes (Brereton *et al.*, 2010; Pescott *et al.*, 2015b). Such projects require contracted staff to coordinate and support them; monitoring schemes leading to national biodiversity indicators (i.e. producing annual trends in abundance) each cost about £100 000 per year to support (Roy *et al.*, 2012a). However, the pioneering development and long-standing success of these types of monitoring schemes helps support the current acceptance and enthusiasm for citizen science as a monitoring tool (Dickinson *et al.*, 2012).

Wider participation

Finally, one of the appeals of biological recording is that it is an activity that is potentially open to anyone, so mass participation activities are an ideal way of engaging people with biological recording, with science and with nature (Cooper, Hochachka & Dhondt, 2012). While most biological recording requires some expertise in species identification, one of the growing trends in citizen science is the opportunity for participation by the general public (i.e. inexperienced or novice participants), especially focussed on recording a particular noticeable or charismatic species. When the data can be verified, e.g. through submission of photographs, then these data can be collated as part of the scheme's datasets and so the participation is a type of 'mass participation' contributory citizen science. This approach has been successfully adopted by the ladybird (Coleoptera: Coccinellidae) recording scheme (http://www.ladybird-survey.org/); following the adoption of a user-friendly website and smartphone app the number of recorders has increased rapidly (Roy & Brown, in press). Mass participation is especially valuable when the general public can act as a dispersed network for the early detection of invasive non-native species (Aitkenhead, 1981; Tree Health and Plant Biosecurity Expert Taskforce, 2012; Roy *et al.*, 2015) or the spread of colonising species (Brown *et al.*, 2008; Roy *et al.*, 2012b).

A DIVERSITY OF PARTICIPANTS: FROM EXPERT NATURALISTS TO MASS PARTICIPATION

Who are the participants?

In 1995, it was estimated that at least 40 000 volunteers were involved in recording in the UK (Burnett, Copp & Harding, 1995). This has not been quantified more recently, but based on our experience we believe that the current figure would be about 70 000, for people voluntarily participating in biological recording across all taxa (excluding mass participation projects) in various ways and varying in their level of expertise (Fig. 1). The citizen science literature typically refers to 'citizens' and 'professionals' as discrete groups of people (Cooper *et al.*, 2007; Bonney *et al.*, 2009a; Devictor *et al.*, 2010). However in biological recording the distinctions are blurred; the participants, who are involved in different ways, vary in their expertise from novices through to expert volunteers (Figs 4, 5). Indeed, with the loss of taxonomists from museums and universities, often the national taxonomic experts are non-professional. Voluntary recorders, from novices to prolific expert recorders and recording scheme organisers, may be practising scientists, ecological consultants or conservationists, or have had scientific training earlier in life. For most taxonomic groups the national recording scheme organiser is a volunteer and, supported by voluntary regional experts, acts to ensure the accuracy of the datasets. The contribution by individual recorders tends to be highly skewed, with many submitting a few records and a few submitting the majority of records (Ball *et al.*, 2011; Isaac & Pocock, 2015). Professionals, then, are often involved in activities that support (rather than lead or organise) recording, and add value to the data (Fig. 4).

Harnessing enthusiasm for sustainable citizen science

We believe that one of the key advantages of biological recording in the UK is not that it is question led or has specific aims (which are usual recommendations for successful monitoring projects; Lindenmayer & Likens, 2010), but that it is led by volunteer experts who are involved because of their enthusiasm and passion (for their taxon of interest, natural history in general and the peer community of recorders). Currently, there is a lot of interest in understanding the motivation of participants in citizen science (Rotman *et al.*, 2012; Nov, Arazy & Anderson, 2014). Enthusiasm is an intrinsic motivation (Blackmore *et al.*, 2013) and it is likely that the success of biological recording (in terms of quantity and quality of data, and retention of keen recorders and recording scheme organisers) is because it harnesses and cultivates people's enthusiasm (see also Sullivan *et al.*, 2014),

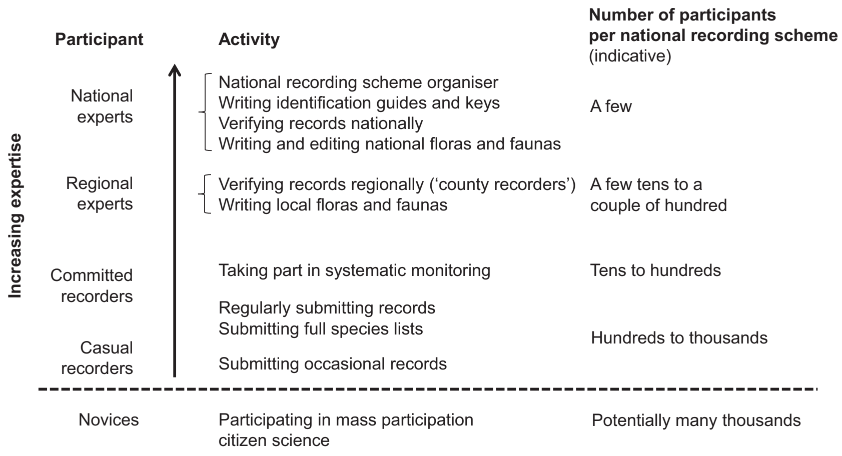

Figure 5. An illustration of the range in experience of different participants in biological recording, their activity and an indication of their number.

rather than imposing obligations on participants. This demonstrates one way of addressing the challenge of how to sustain citizen science projects and activities (Dickinson *et al.*, 2012). Relying on the enthusiasm of volunteers does mean that there is no formal control over the national recording schemes. Some schemes wane in activity, while new ones can be started relatively easily (see James, 2011a); for example the Tachinid recording scheme, begun in 2000.

Of course, relying on enthusiasm does not mean that a person's recording behaviour is unchangeable; in focussed recording and structured monitoring (see above) people participate in a more structured way. However, it does mean that those designing schemes need to be sensitive to the motivations of recorders, since imposing too rigid a structure could reduce participation. In maintaining the relationship with recorders, it has been helpful that many BRC staff are themselves voluntary recorders in their spare time, and therefore there is a shared culture and understanding with the national recording schemes.

Changes in the cultural context for biological recording

British society has changed considerably since the BRC was established in 1964 and biological recording has benefited from the cultural backdrop of increased affluence, leisure time and mobility. However, these favourable factors may have peaked: currently, leisure time and travel (assessed as number of leisure trips per year) are decreasing (OECD, 2009; Morris *et al.*, 2014), while retirement age is increasing and healthy years of retirement are increasing more slowly than life expectancy (OECD, 2011; Office for National Statistics, 2012). It remains to be seen what impact this has on biological recording in the future.

In contrast, there has been a continued growth in communications and information technology. Internet usage is almost ubiquitous and smartphone usage is rapidly increasing (Ofcom, 2014). The relatively recent availability of online forums and social media has permitted the organic growth of communities of recorders who can support each other, e.g. through sharing notes on identification and sampling approaches (August *et al.*, 2015). The iSpot project is one example of a purpose-designed platform to facilitate learning in species identification (Silvertown *et al.*, 2015). Through the use of information technology it may be relatively easy (depending on the taxon) to confirm identifications or even harvest records, e.g. from photographic observations, via online social media platforms, while personal online blogs makes it easier than ever to share interesting sightings (although if records remain only in personal blogs then this hinders the onward flow of data).

Pioneering the use of technology to support the flow of data

The effective use and re-use of biological records depends on effective data flow: from the observation through to submission of a record, data collation and onwards to data use, and re-use (Fig. 6). Efficient data flow is a challenge for citizen science in general (Newman *et al.*, 2011), but the BRC has supported technological development throughout its 50 years to facilitate effective data flow (August *et al.*, 2015).

Stage one: record

The BRC has been described as a pioneer of efficient data systems (Harding & Sheail, 1992), and this role has continued, e.g. with the development of the Indicia database toolkit (http://www.indicia.org.uk), a fully-customisable system which can be implemented in recording scheme and society websites (NBN Trust). A generic implementation of Indicia, called iRecord (http://www.brc.ac.uk/irecord), allows participants to enter casual records and computerised lists of records through a user-friendly interface. Recorders can curate and visualise their own records on this system, while records are archived securely. Records are made available to experts for review, using the results of automatic checking rules to help confirm sightings or identify outliers which may represent misidentifications. iRecord facilitates the publication of datasets via the NBN Gateway (and subsequently to GBIF), thereby giving a more rapid flow of records from the point of submission to being shared more widely. This technology, which is increasingly being adopted by individual national recording schemes, Local Environmental Records Centres and other citizen science projects, meets the desire for re-usable, inter-operable data systems to support efficient data flow (Newman *et al.*, 2011; Bonney *et al.*, 2014).

In terms of actually making the record, many field recorders still use pencil and notebook or record cards (although increasingly relying on GPS handsets for geo-location) and this may be the most efficient method for capturing data in the field for many experts. However, communications technology has facilitated the ability to make records, especially incidental records, through smartphone apps (Newman *et al.*, 2012). Currently in the UK there are apps linking directly to iRecord (for efficient data flow) for recording ladybirds, butterflies, orthopterans, mammals, and invasive non-native species (Roy *et al.*, 2014a, 2015; August *et al.*, 2015). These provide the ability to take a photograph (or potentially, for species such as orthopterans to make a sound recording), capture location via GPS and store the record for later upload to iRecord. These apps are an ideal tool for widening participation, especially when the species are relatively large or immobile, conspicuous and easy to identify. Records still need to be verified for them to become scientifically useful though, and one important advantage of inter-operable data systems is that there is the potential to bring together records from many different websites and smartphone apps to facilitate efficient verification.

Stage two: verify to ensuring data quality

Ensuring standards of data quality in citizen science is vital if the data are useful for scientific purposes (Dickinson *et al.*, 2010; James, 2011b). Accuracy of data has always been a priority within biological recording: even a single erroneous record will be conspicuous as a dot on a distribution map (Fig. 2), so there has been considerable attention on ensuring accuracy, especially for outlying records. Unusual records require a weight of evidence (e.g. reputation of the recorder, retained voucher specimens for invertebrates and plants, supporting description or photograph) for the identification to be accepted as valid.

Online systems for data capture allow rapid feedback to individuals through automated verification tools (Fig. 6). These are applied through the NBN Record Cleaner (Ball & French, 2012), embedded within data capture tools such as Indicia. The validity of formatting and spelling is automatically checked, while records falling outside of the 'verification rules' are flagged to the recorder for confirmation. Currently there are verification rules comprising expected location, date range (years of occurrence and months of activity) and ease of identification created for 14 763 species from 27 taxonomic groups. The NBN Record Cleaner has been developed since 2001, but other citizen science projects have subsequently independently developed a similar framework of automated and expert verification (Bonter & Cooper, 2012; Sullivan *et al.*, 2014). Records that pass review by an expert verifier (assisted by automated data verification) are accepted to the national recording scheme's dataset. One advantage of data systems such as Indicia is that it allows multiple people to act as verifiers and all of the verification decisions are transparently recorded.

Stage three: share and publish

Throughout the history of biological recording, there has always been an emphasis on sharing and using records; this activity continues to incentivise and motivate recorders. This pioneering attitude towards openness is slowly becoming prevalent in science (Soranno *et al.*, 2015). Ideally the results of citizen science projects should be shared in real-time to encourage participation (Tweddle *et al.*, 2012). Although this is possible with data systems such as Indicia, it does not yet regularly happen in biological recording across the UK. Partly, we believe this is because of the emphasis on presenting accurate, verified data rather than potentially misleading unverified records. One of the main ways in which verified data are shared is via the NBN Gateway; as of the start of 2015, the site delivered over 100 million records (Fig. 7A). The majority of the data (estimated 70%) come from the national recording schemes and societies, with Local Record Centres and government agencies being other submitters of data (estimated to provide 25% and 5%, respectively, of the data submitted in 2014). Through the NBN Gateway, datasets are made available for download for re-use, either freely or with permission of the data provider, depending on the particular dataset.

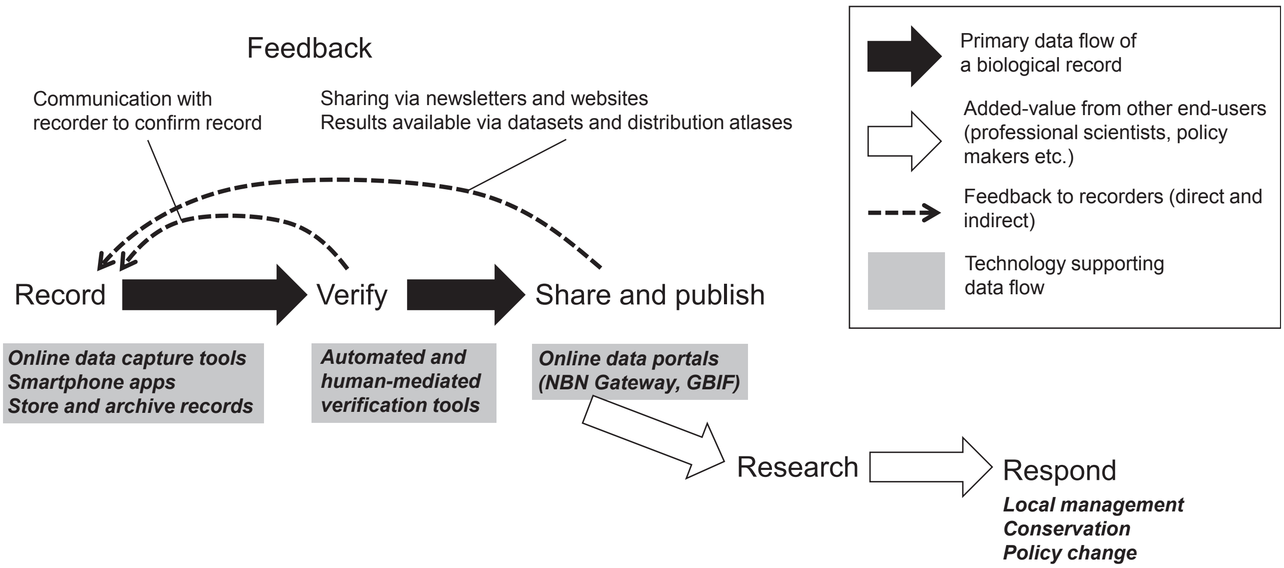

Figure 6. The flow of data from making a record to end use and how data flow and feedback to recorders is enhanced by new technologies. The contribution of the Indicia database toolkit (http://www.indicia.org.uk/), developed with the BRC, is shown in the grey boxes.

A diversity of outputs from biological records: gaining and sharing information from data

Outputs from volunteer recorders

One outcome from biological recording is that many recorders undertake 'individual research projects' on their own or with others (Fig. 4), e.g. local monitoring of a species at a particular site, or make observations on novel interactions or behaviour. People publish these in various journals and newsletters, including those produced by natural history societies and recording schemes. Such observations may throw light on observed national trends, or raise hypotheses which can then be tested by national studies. Taken together, these are valuable autecological studies that substantially contribute to our knowledge of particular species and this role continues to be important; the ecology and behaviour of many invertebrate species, for instance, remains to be documented. These studies are a natural corollary of a recorder's enthusiasm, yet they do not fit within the current literature of citizen science practice (Fig. 4). Somewhat bizarrely, they appear to fit descriptions of 'countercultural nomadic science' (McQuillan, 2014) and, in terms of the formative involvement of participants, they seem to go beyond what Haklay (2013) defined as 'extreme citizen science'. One of the forthcoming challenges for citizen science practitioners is discovering the best ways of involving participants in analysis and reporting, and giving them credit for their discoveries (Fortson & Lynn, 2014), yet the aspiration to involve volunteers in all aspects of the scientific process (from design to outputs) has actually been fulfilled in natural history in the UK for well over a century.

Outputs led by expert volunteers

Publishing distribution atlases is an integral part of the BRC's work and the production of atlases is often led by volunteer experts. The number of atlases from the national recording schemes continues to increase (Fig. 7B); now 12 127 taxa (*c.* 20% of the total number in the UK; Burns *et al.*, 2013) from 40 taxonomic groups have published distributions (Fig. 7C), with many schemes having published repeat atlases (Figs 3 and 7B). Depending on the taxon, atlases are produced as a series of annotated maps in which there is expert interpretation of the distribution pattern, e.g. taking recording bias into account, or as part of more comprehensive autecological reviews. Staff at the BRC often provide practical support for producing distribution atlases, e.g. adding value through further analysis, but the process is usually volunteer led and there is no requirement for atlas production imposed by the BRC. BRC staff also provide logistical support, e.g. editing, production, and distribution, of atlases and other outputs such as recording scheme newsletters.

Added-value from professionals

Throughout this description of BRC's work, we have emphasised the mutualism between national recording schemes and professionals. One of the important benefits of professional involvement is sophisticated analysis to quantify trends in distribution and abundance (Dennis *et al.*, 2013; Isaac *et al.*, 2014), covering hundreds of species (Fig. 7C). These trends are used as a raw product for scientific research and for applications such as red list assessments of threat (Maes *et al.*, 2015) and reporting on the state of biodiversity (Burns *et al.*, 2013), e.g. with UK government biodiversity indicators (Department for Environment Food and Rural Affairs, 2014).

One of the specific benefits of a centre, such as the BRC, to act as a focus for biological recording is the ability to provide an integrated, cross-taxon use of biological records data. Examples of the benefit of this over-arching view are: testing for congruent trends across diverse taxa (Hickling *et al.*, 2006; Gurney, in press; Hill & Preston, 2015; Pescott *et al.*, 2015a; Thomas *et al.*, 2015a), testing for parallel trends in trophically linked taxa (Biesmeijer *et al.*, 2006; Fox *et al.*, 2014; Stewart, 2015) or considering taxonomically cross-cutting issues such as the early detection of invasive species (Roy *et al.*, 2014b) or pests (Purse & Golding, 2015) and monitoring of pollinators. It also facilitates the ability of funders to work in partnership with volunteer recorders.

Outputs directly leading to action

Scientific outputs, such as those described above, can be used to inform decision-makers and are particularly useful for providing evidence to government in relation to relevant policies, but the records can also be put to direct use in conservation management and planning decisions. Recording itself may be motivated by site-based monitoring which, with expert interpretation, can inform the direction of, and assesses the success of, conservation management. Recording may also provide early detection of alien invasive species at a site, which could prompt rapid action for their extirpation. The history of biological records for a site or suite of sites is also used by ecological consultants and other stakeholders to inform planning decisions, sometimes with support from Local Environmental Records Centres and conservation non-governmental organisations. Biological records can therefore be used as a tool for advocacy, action, and protection, and this can be a strong motivator for local recorders.

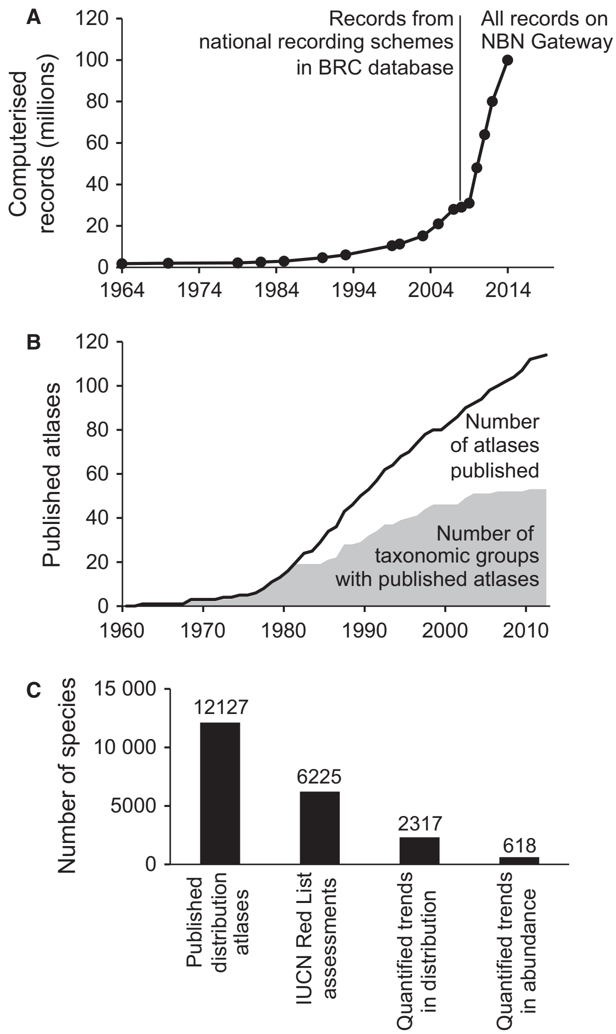

Figure 7. A, The number of computerised biological records is increasingly dramatically, and (B) outputs, such as the number of distribution atlases, are also increasing. C, These resources can be used to assess status and trends for many of the 59 000 terrestrial and freshwater species in the UK (details in Burns *et al.*, 2013). The gap between the number of atlases and the number of taxonomic groups in (B) is due to repeat atlases for some taxonomic groups (see Fig. 3) and partial coverage of taxonomic groups for some atlases.

CONCLUSION: THE CONTINUING ROLE OF THE BRC IN SUPPORTING BIOLOGICAL RECORDING AND CITIZEN SCIENCE

The long history of biological recording in the UK has provided an inspiring legacy of scientifically rigorous data, for use in scientific research, monitoring, and reporting. The BRC has had an instrumental role in supporting the practice of biological recording for over 50 years. We are confident that biological recording will continue to excel in its core activity of collecting and collating excellent quality occurrence data across a wide range of taxa (Fig. 3). The lessons learned through the coordinated and partnership approach of biological recording will continue to be shared with the wider community of citizen science practitioners (Roy *et al.*, 2012a). With the prominence of and enthusiasm for citizen science

(Bonney *et al.*, 2014), especially mass participation citizen science, we are confident that volunteers involved with biological recording will continue to innovate to reach out to a wider community of potential participants. This will bring challenges (e.g. ensuring high data quality and making best use of the time of those willing to verify records) but also opportunities (e.g. continuing to increase the volume of data for benefit for scientific research; Hochachka *et al.*, 2012), and with effective use of these data we expect even greater benefits for science, society, and the environment. Technological innovation will, no doubt, continue to facilitate biological recording, but also change what is possible (August *et al.*, 2015; Lawson Handley, 2015), although the key resource in biological recording will always be people, their commitment and their expertise. In conclusion, biological recording has a long history and scientific legacy. Given the enthusiasm for citizen science in general, we are confident that it has a bright future with benefits for people, science, and nature.

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