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Review

Butterflies Australia: a national citizen science database for monitoring changes in the distribution and abundance of Australian butterflies

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Abstract Conservation biology is a field of science that is heavily biased against insects and allied invertebrates, largely due to a data deficiency feedback loop that maintains a cycle of ignorance and inaction. Because many invertebrate groups are, and remain, extremely data poor, it is frequently difficult to conduct even the most basic conservation actions, such as status evaluation, listing, recovery and monitoring of threatened species. Thus, declines and extinctions of invertebrates are frequently undetected and poorly documented. To address this data deficiency, we have developed a new national database – Butterflies Australia – for one insect taxon that integrates citizen science (data collectors) with global, standardised monitoring protocols and emerging tools in technology and biodiversity informatics. The database is created from a platform, which consists of a phone app and website, that offers the potential to rapidly increase data availability on the occurrence of Australian butterflies at a far greater scale than was previously possible, as well as to monitor trends in their distribution and abundance over time. We discuss the attributes and importance of successful citizen science projects and quantitative methods for monitoring butterflies, both from an Australian perspective and in an international context, and then outline the operational aspects of the Butterflies Australia platform. A review of survey methods that have been used for monitoring or inventorying butterflies in Australia over the past 50 years revealed a diverse array of sampling techniques, with little standardisation between studies and wide variation in space (sampling unit) and time (sampling effort). Transect counts, in particular, have rarely followed the international guidelines recommended for standardised global butterfly monitoring. Finally, we discuss the benefits of our new citizen science tool for butterflies and potentially other invertebrates. We envisage that our platform will engender increased community awareness, improved quantity and quality of data collection, better conservation policy and planning, as well as enhanced resourcing and research for the conservation management of butterflies.

Key words Atlas of Living Australia, BioBlitz, biodiversity informatics, butterfly conservation, eButterfly, invertebrate conservation, Lepidoptera, phone app.

INTRODUCTION

Conservation biology is a field of science that is heavily biased towards vertebrates, both in terms of total funding allocation and average expenditure invested per species. Whereas birds and mammals receive the major share of resources, insects and allied invertebrates receive comparatively little conservation attention (Cardoso *et al*. 2011b; Braby 2018). This taxonomic bias in attention is clearly apparent when one compares the proportions of species evaluated for their conservation status, with only 0.5% of the worlds described arthropod species evaluated (Cardoso *et al*. 2011a; Cardoso *et al*. 2011b). In Australia, 12–24% of all species of mammals, birds and amphibians have been listed as threatened (i.e. critically endangered (CR), endangered (EN) or vulnerable (VU)) under the national *Environment Protection and Biodiversity Act* (*EPBC Act*), but only 0.04% (40 species) of invertebrates are listed as threatened under the same conservation schedule (Walsh *et al*. 2013; Taylor *et al*. 2018). Assuming that the proportion of threatened species is roughly equal across taxonomic groups (at 16.6% – Walsh *et al*. 2013), then invertebrates are under-represented by several orders of magnitude. Similar taxonomic bias exists in species with national recovery plans, with only 22% of threatened invertebrates with a recovery plan compared with 58–65% for listed species of birds and amphibians and 42% for mammals and fish (Walsh *et al*. 2013). Even butterflies, which are the best studied invertebrate group in Australia, are under-represented in international and national threatened species lists. For example, the *Action Plan for Australian Butterflies* (Sands & New 2002) identified only six species as threatened nationally, but a further

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56 taxa were classified as data deficient at various spatial scales. Currently, only 10 species or subspecies of Australian butterflies (1.6% of the total 614 taxa) are listed as threatened (3 CR, 7 EN and 0 VU) under the IUCN Red List or *EPBC Act* (Taylor *et al*. 2018). A further 20 taxa have been assessed as threatened but only at smaller, regional scales under various state-based legislation. Thus, declines and extinctions of insects and other invertebrates are frequently unknown, poorly documented and grossly underestimated (Woinarski *et al*. 2019).

This general lack of knowledge or impediment in invertebrate conservation (Cardoso *et al*. 2011b) creates a negative feedback loop (Oberprieler *et al*. 2019), which we refer to as the 'data deficiency feedback loop' (Fig. 1). Essentially, a lack of understanding of the importance of invertebrates among the general public and policymakers, together with limited knowledge about their taxonomy and patterns of diversity, distribution and abundance, means that invertebrates are typically excluded from faunal inventory and monitoring surveys (the data collection phase). Consequently, invertebrates are rarely considered in conservation policy and planning because they are poorly known or data deficient. However, because they are excluded from such surveys and subsequent conservation programmes, invertebrates are unlikely to attract funding, resources or scientific research, consigning them to remain poorly known and data deficient, thus completing the negative feedback loop (Fig. 1). Consequently, many invertebrates are, and remain, extremely data poor, making it impossible to conduct even basic conservation actions of threatened species, such as conservation status evaluation, listing, recovery or management actions and monitoring (Braby 2018). Additionally, this may lead to the loss of available expertise in the impacted taxonomic groups as opportunities to work as a professional taxonomist disappear due to lack of funding, which may have flow on effects to other policy areas such as biosecurity (Taxonomy Decadal Plan Working Group 2018).

There is a pressing need to break this data deficiency feedback loop so that conservation policy and planning can be appropriately informed by robust data on invertebrates. One approach

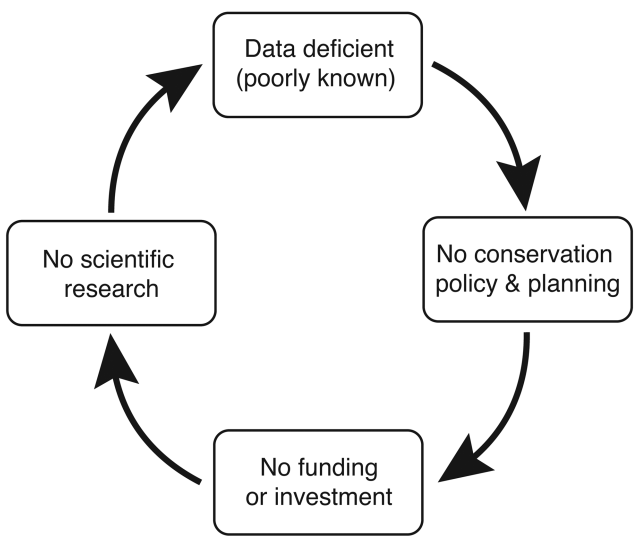

Fig. 1. The data deficiency feedback loop in invertebrate conservation.

is to enlist and foster citizen science and biodiversity informatics programs (Cardoso *et al*. 2011b; Harvey *et al*. 2020). Here, we have borrowed ideas from the taxonomic group that receives much of the conservation attention globally – birds – in an attempt to address the significant shortfall in data availability for use in conservation for butterflies. eBird, for example, is a global data gathering initiative that has grown to collect more than a hundred million observations of bird records each year by a vast network of citizen scientists (Sullivan *et al*. 2014; eBird 2020). Butterflies, like birds, have wide appeal to the general public (the 'charisma' effect) and thus are readily accepted as subjects worthy of conservation attention.

In this overview, we highlight the importance of citizen science as a collaborative mechanism for data collection on a scale that was previously not possible and then review and discuss the quantitative field survey methods and sampling protocols by which that data have so far been collected for monitoring or inventorying Australian butterflies in an international context. We then introduce a new tool – Butterflies Australia – for citizen scientists to collect, submit and verify data records via means of a phone app and web-based platforms. Finally, we discuss the benefits of the Butterflies Australia platform and how we envisage it will break the data deficiency feedback loop.

CITIZEN SCIENCE

Citizen science involves public participation and collaboration in scientific research with the aim to increase scientific knowledge (ACSA 2020). It includes the engagement of volunteers in professional research so that there is a partnership between the public and the professional scientific community (Walker 2013, 2015). Essentially, citizen scientists are the volunteers who collect and/or process data as part of a broader scientific enquiry (Silvertown 2009). Any member of the public, from children to senior citizens, can take part in citizen science, and during the past two decades, there has been an unprecedented explosion of activity, especially in the biological sciences, including conservation biology. Silvertown (2009) attributes this rapid growth of citizen science to three factors: (1) the development of the internet, together with the rise of new software tools and technology (laptop computers, mobile devices, etc.); (2) recognition by professional scientists that volunteers represent a free source of labour capable of collecting large volumes of unbiased data; and (3) funding providers increasingly imposing upon grant holders to undertake public outreach as a form of 'public accountability' of their science. Another factor may be the steady decline of employed professionals to collect basic data and the concomitant loss of support services in recent decades, resulting in increased administrative burden placed on scientists.

Throughout history, citizen scientists have always made important contributions to science, but citizen science has now moved to the point that it is part of mainstream science and culture, such as in parts of the Northern Hemisphere (Europe and North America) where it is the primary form of observational science (Walker 2015). The success of citizen science rests on several key principles (Silvertown 2009; New 2010; Tulloch

Table 1 The 10 key principles for successful citizen science adopted by the Australian Citizen Science Association (ACSA 2020)

1. Citizen science projects actively involve citizens in scientific endeavour that generates new knowledge or understanding.
2. Citizen science projects have a genuine science outcome.
3. Citizen science provides benefits to both science and society.
4. Citizen scientists may participate in various stages of the scientific process.
5. Citizen scientists receive feedback from the project.
6. Citizen science, as with all forms of scientific inquiry, has limitations and biases that should be considered and controlled for.
7. Where possible and suitable, project data and metadata from citizen science projects are made publicly available, and results are published in an open access format.
8. Citizen scientists are suitably acknowledged by projects.
9. Citizen science programmes offer a range of benefits and outcomes, which should be acknowledged and considered in project evaluation.
10. The leaders of citizen science projects take into consideration legal and ethical considerations of the project.

et al. 2013). The Australian Citizen Science Association (ACSA 2020) in conjunction with the European Citizen Science Association has adopted 10 of these principles that they consider underpin good practice in citizen science (Table 1). In addition to these principles, it is critical that the data are validated and that the methods of data collection be standardised and well designed without bias. Also, the platform should be relatively easy and fun to use to encourage continual usage. Importantly, citizen scientists need to understand the underlying reason or question behind the scientific inquiry (i.e. the bigger picture), and they must receive feedback on their contribution as a reward for participation.

The importance of data quality through a moderation or vetting process is outlined below (see Butterflies Australia). Moderation of records ensures not only high data quality but also confidence in the database in which the data are curated. Training and skill development of volunteers may be required for some projects with regard to data collection. The importance of volunteer training is exemplified by the Small Ant-blue *Acrodipsas myrmecophila* in the Australian Capital Territory (ACT). *Acrodipsas myrmecophila* is a rare, myrmecophagous lycaenid butterfly that is obligatorily associated with a specific ant, *Papyrius* sp. (Britton 1997). In the ACT, *A. myrmecophila* was previously known only from a single record (a male collected from near Uriarra Hill in November 1991 by R. A. Eggleton) (Braby 2000), but it was not known from Canberra until 2018 when a breeding site was discovered serendipitously by a citizen scientist. Subsequently, citizen scientists underwent a day of training on how to identify the butterfly, as well as how to find and identify its immature stages (eggs and pupal cases). The citizen scientists were also trained on how to search for and identify nests of the attendant ant. The outcome of this programme was that six new butterfly breeding sites (and over 500 ant nests!) were discovered by volunteers and mapped across the remnant grassy woodlands in Canberra Nature Park reserves and adjacent areas in New South Wales. This survey work led to a substantially improved understanding of the spatial distribution and conservation management requirements of *A. myrmecophila*, as well as greater appreciation by the local community about the complex ecological requirements of the species (Bond 2019).

Communication and feedback between professional scientists or volunteer experts (moderators) and their citizen scientists are a key component in the success of any citizen science project. Congenial conversations between data collectors and data users are hugely important and vital in the interactive learning experience. Some citizen science platforms have a deliberate emphasis on the creation of an ‘online community’, which can foster a friendly space for participants to chat, interact and learn. Volunteers willing to contribute their skills, time and money towards a project will only do so if they see benefits – that it is scientifically worthwhile, rewarding and a healthy/social experience and that it provides a sense of purpose. They may also wish to become involved in citizen science programmes simply from a desire to achieve direct action where they can see none being taken by local authorities. For others, the greatest reward comes in the form of scientific discovery – the thrill of finding something new, unusual or rare and to share that experience. A successful citizen science project will cater for these different motivations while still adhering to the 10 key principles (Table 1), as well as ensuring high data quality and good communication.

The field of biodiversity informatics has seen a dramatic increase in data collection and analysis in recent decades, particularly with regard to mapping the spatial distribution of species (Jetz *et al*. 2012). Central among these is the Global Biodiversity Information Facility (GBIF 2020), which is an international biodiversity aggregator into which many data sets feed. Currently, GBIF holds around 1.6 billion occurrence records. Two other globally important citizen science platforms are eBird (2020) and iNaturalist (2020). eBird is an international platform developed by Cornell University for submitting records on birds (Sullivan *et al*. 2014); it sets the gold standard for engaging citizen scientists on a global scale, with over 140 million records submitted during the first decade (Fig. 2). Currently, more than 100 million bird observations are contributed annually to eBird by citizen scientists around the world, and this exponential growth in data accumulation is typical of projects that adhere to the key guiding principles noted above. iNaturalist is another international citizen science platform for submitting biodiversity records; currently, it has collected 47 million records for 292 000 species in the 12 years since its inception in 2008.

Nationally, the most important citizen science bioinformatics platform in Australia is the Atlas of Living Australia (ALA 2020), with currently around 90 million occurrence records. It aggregates data sets from regional databases (>8000); however, individual citizens can no longer upload data directly to ALA – instead, they are directed to a link to iNaturalist on the ALA website to submit observations. Significant regional citizen science bioinformatics platforms in Australia are Canberra

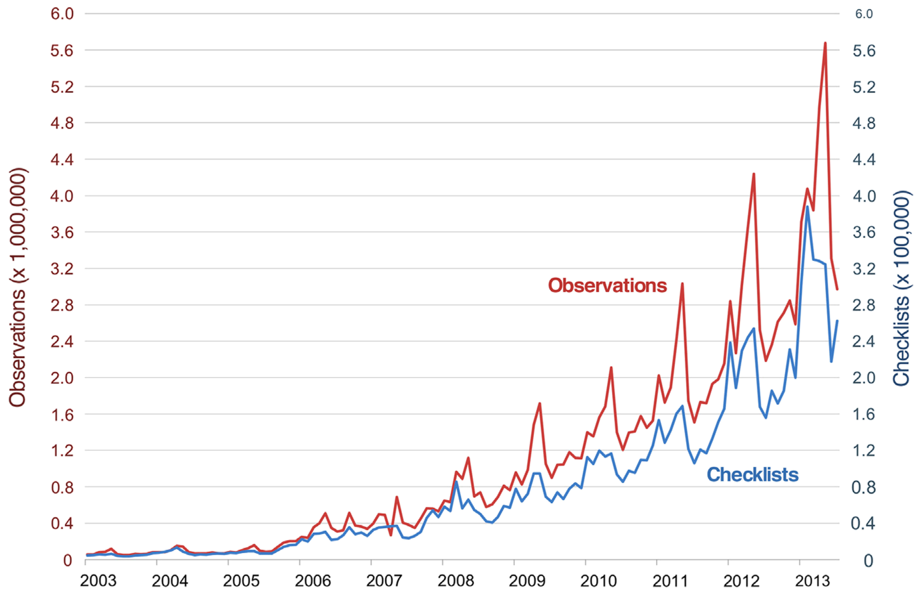

Fig. 2. The exponential growth of citizen science data collected by eBird during the first decade since its inception in 2003 (source: Sullivan *et al*. 2014). The graph shows the number of observations and checklists (species lists) submitted monthly from 2003 to 2013. The amount of data increased annually by 30–40%, with a cumulative total of over 140 million observations submitted by mid-2013. Currently, eBird (2020) is generating around 140 million observations per year.

Nature Map (2020) and BioBlitz (2020), among others. Canberra Nature Map started in 2014 as a website to map rare plants in the Australian Capital Territory, but it quickly expanded to cover all flora and fauna in the ACT and adjacent areas. It now belongs to the NatureMapr platform, which covers several regions outside Canberra. Local experts moderate data records, which are then migrated to ALA. BioBlitz manages snapshot biodiversity surveys undertaken by professional scientists in conjunction with citizen scientists that target a specific area during a fixed time period. BowerBird was a natural history website dedicated to citizen science, and it was released and launched in 2013 with the intention of being an online version of a traditional field naturalist club, with mentoring of newer members by more experienced members (Walker 2013, 2015). It has now closed, with its content moved to iNaturalist and ALA.

Butterflies have had a long history of citizen science participation, particularly in the Northern Hemisphere, but this uptake has yet to be fully realised in countries like Australia (New 2010). The UK Butterfly Monitoring Scheme (UKBMS 2020) is perhaps the best known long-term citizen science monitoring project for butterflies, which has been running since 1976 (Asher *et al*. 2001; Thomas 2005). In North America (Canada and USA), eButterfly (2020) is a relatively new initiative modelled on eBird, and it has been a highly successful citizen science platform for submitting butterfly data since its inception in 2012 (McFarland *et al*. 2015; Prudic *et al*. 2017). In Australia, participation of citizen scientists in butterfly natural history and conservation has, up until now, been on a much smaller scale and mostly centred around migration (Smithers 1972, 1977, 1978, 1983a, 1983b, 1985) and recovery teams for threatened species under various state-based conservation schedules (New & Yen 1995, 2013; Williams 1996). Notable examples of citizen science activities include Courtenay Smithers' pioneering efforts on butterfly migration and mark–release–recapture (MRR) studies on *Danaus plexippus* in the 1960s–1970s (Peters 2012). Monitoring, ecological restoration and conservation management of three flagship butterfly species over the past three decades have been largely undertaken by citizen science groups: the Friends of the Eltham Copper Butterfly for *Paralucia pyrodiscus* (New 2011), the Richmond Birdwing Conservation Network for *Ornithoptera richmondia* (Sands & New 2013) and an informal group for the Purple Copper *Paralucia spinifera* (Baker *et al*. 1993; Nally 2003; Mjadwesch & Nally 2008; New 2010).

BUTTERFLY MONITORING

Monitoring is the systematic collection of data in a standardised manner at regular intervals over time (Spellerberg 2005). Lovett *et al*. (2007) define environmental monitoring as a time series of measurements (of physical, chemical and/or biological variables) designed to answer questions about environmental change. Monitoring, in a biodiversity context, is the tool by which one can determine if the natural assets of a site or location are changing over time from a predetermined standard (baseline), typically in relation to key threatening processes (habitat loss or deterioration, invasive species, pollution, climate change, etc.), habitat restoration or natural ecological succession (Stork *et al*. 1996; Samways 2005). Moreover, monitoring provides the early warning signal of detrimental change, and thus, it provides the hard evidence for intervention and other informed management decisions (Lindenmayer & Gibbons 2012).

In conservation biology, the two variables that are most frequently monitored are: (1) the spatial distribution of species, to assess changes in occupancy, geographic range size or geographic range boundaries (usually inferred from atlas mapping or recording schemes), and (2) the abundance of species, to assess changes in relative abundance or absolute population size (usually derived from population monitoring schemes) (Thomas 2005; van Swaay *et al*. 2008; Jetz *et al*. 2012). However, other components of biodiversity may be monitored, such as species richness and composition. In some cases, it may be important to monitor certain biological attributes of species, such as their phenology, sex ratio, movement patterns and migration or aggregation behaviour.

Among insects, butterflies have been widely used in monitoring programmes, particularly in the Northern Hemisphere (Europe, North America and parts of Asia), to assess long-term changes in occupancy or distribution and abundance (Thomas 2005; van Swaay *et al*. 2008; van Swaay *et al*. 2015). Butterflies have many desirable attributes that are useful for monitoring such biological variables: their taxonomy is relatively well-understood, most species are relatively easy to identify, they are day flying and relatively conspicuous, the life history and general biology are well-documented, and information is available on the ecology for most species (Thomas 2005; McGeoch 2007; Gerlach *et al*. 2013).

In Australia, butterfly monitoring is still in its infancy, and the science has not reached the level of maturity seen in countries like the UK or USA (Braby & Williams 2016). Although there has been progress towards compiling atlases based on point data for some regions (Crosby 1986; Virtue & McQuillan 1994; Gullan *et al*. 1996; Braby *et al*. 2018), fine-scale distributional mapping schemes designed to record spatial changes over broad geographical scales are yet to be realised (Dunn & Dunn 1991). At one level, the geographical range of Australian butterflies is reasonably well known (e.g. see expert range maps in Braby 2016); however, the vast majority of spatial data about species distributions is not readily available in an electronic format or has not been integrated, being scattered in specimens in museum and private collections, field notebooks of collectors and private databases, as well as the scientific and grey literature. Similarly, monitoring of populations in Australia to assess temporal trends in relative abundance typically has been short term (≤3 years) and usually not designed to determine if there are temporal trends against a standard baseline, either locally, regionally or nationally (Table 2). Exceptions to this are perhaps the pioneering study by Smithers (1972) (4.5 years) and two studies (Newland 2006; Bell 2014) that conducted replicated, snapshot surveys 12 years apart specifically to examine the impact of key threatening processes. There are, however, several long-term studies (7–30 years) of individual species or assemblages currently in progress that have not yet been formally published. These population monitoring studies include the butterfly fauna of the ACT (7 years: S. Bond unpubl. data), the butterfly assemblage at Penambol Conservation Park, South Australia (15 years: B. T. Haywood pers. comm. 2020), the threatened Ptunarra Xenica *Oreixenica ptunarra* in Tasmania (22 years: Bell 1999, 2014, & pers. comm. 2020) and the threatened Eltham Copper *P. pyrodiscus* near Melbourne, Victoria (ca. 30 years: A. Canzano & J. Harris pers. comm. 2020).

van Swaay *et al*. (2015) published an international set of guidelines for standardised monitoring of butterflies. They recommended two primary methods for monitoring adult butterflies: (1) transect counts, and (2) fruit baiting (for tropical forest species). However, other (supplementary) methods, such as point counts, area counts, MRR and counting other life stages (e.g. larvae), can be used depending on the habitat or target species (see van Swaay *et al*. 2015). The methods are standardised and quantitative, based on specific dimensions in space (the sampling unit) and time (the sampling effort) and repeated at various time intervals (the survey effort), so that the data collected are robust for statistical analysis in order to detect changes over time.

In Australia, various quantitative sampling methods have been used for monitoring or inventorying butterflies to estimate abundance and/or species richness over the past 50 years (Table 2). Of the 48 studies reviewed, transect counts have been most popular (42%), but MRR and point counts or area counts have frequently been used (Table 2). Novel methods, such as the use of malaise traps (Ginn *et al*. 2007), and capture rates based on sweep netting have also been deployed. Fruit baiting has rarely been used (Braby 1995b; Sambhu *et al*. 2018), mainly because few butterflies in Australia specialise on fermented fruits (Braby 2000). Three studies dealing with threatened species (Braby 2010; Andren & Cameron 2012, 2014; Taylor 2014) mainly focused on mapping the spatial distribution based on occupancy surveys (presence/absence data) and then estimating the occupancy rate, as well as the extent of occurrence and/or area of occupancy. Several studies (Hill 1992, 1995; Haywood & Wilson 2002; Collier *et al*. 2006; Franklin 2011; Kennedy 2020) claim to have used the Pollard walk, which follows standardised criteria in terms of dimensions of the sampling unit and sampling effort, time of day and prevailing weather conditions, but closer examination of these papers revealed widespread misunderstanding of the criteria, particularly those for the sampling unit. The Pollard walk (Pollard *et al*. 1975; Pollard 1977; Pollard & Yates 1993) is a specific type of transect counting method and the one recommended as the international standard for monitoring butterflies (van Swaay *et al*. 2015). It involves walking along a fixed route or transect (typically 300–1000 m in length) at a slow, constant pace (~1 km/45–60 min or 100 m/5–6 min or 17–22 m/min) and counting all the butterflies in an imaginary cube of 125 m^3 (i.e. 2.5 m either side, 5 m above ground and 5 m in front of the observer). Butterflies observed outside the imaginary cube are recorded as incidentals. Binoculars, camera or sweep net (to catch and release specimens) can be used to assist with identification, but counting should cease when the observer is stationary as this will affect the sampling effort.

Weather conditions and temporal factors are important criteria for successful butterfly monitoring, and the variables of temperature, cloud cover, wind, time of day and time of year all need to be considered. Pollard (1977) recommended that surveys be undertaken only in suitable weather conditions, specifically between temperatures of 13–17 °C during sunny weather (≥60% sunshine) or above 17 °C regardless of cloud cover. van Swaay *et al*. (2015) incorporated these criteria into their set of global monitoring guidelines, noting a minimum temperature of 13 °C and a maximum temperature of 33–35 °C for butterfly

Table 2 Summary of quantitative survey methods used for monitoring or inventorying butterflies (adult stage) in Australia

Method	Sampling unit/sampling effort	Survey effort	Purpose	Target species	Reference
Point count	46 m line/30 min	96 samples over 4.5 years (1 count approx. per fortnight × 96 sampling occasions × 1 site)	To assess seasonal and annual changes in abundance	*Danaus plexippus*	Smithers (1972)
Point count	10 m radius of circle/20 min	108 samples over 17 months (2 sampling units × 3 counts per day × 6 sampling occasions × 3 sites)	To determine species richness and composition among rainforest microhabitats	Assemblage (110 species)	Hill *et al.* (1992)
Point count	~6 m radius of circle/1–2 observers/12–20 min	45 samples over 1 week (3 counts per day × 3 sampling occasions × 5 sites)	To assess and compare abundance among sites	*Paralucia pyrodiscus*	van Praagh (1996)
Point count	3 m radius of circle/2 min	96 samples over 2 years (12 counts per day × 4 sampling occasions × 1 site, plus 12 counts per day × 2 sampling occasions × 2 sites)	To assess diurnal changes in abundance in relation to adult food sources	*Croitana aestiva*	Palmer and Braby (2012)
Area count	30 m × 10 m quadrat/20 min	54 samples over 17 months (3 counts per day × 6 sampling occasions × 3 sites)	To determine species richness and composition among rainforest microhabitats	Assemblage (110 species)	Hill *et al.* (1992)
Area count	200 m^2 quadrat/20 min	90 samples over 6 months (10 sampling units × 1 count × 3 sampling occasions × 3 sites)	To compare abundance among rainforest microhabitats in relation to corridors	Assemblage (61 species)	Hill (1995)
Area count	50 m × 50 m quadrat/30 min	72 samples over 1 year (1 count per month × 12 sampling occasions × 6 sites)	To compare species richness and composition in relation to habitat restoration	Assemblage (18 species)	Lomov *et al.* (2006)
Area count	200 m × 50 m quadrat/50 min	96 samples over 8 months (8 counts per day × 2 days × 2 sampling occasions × 3 sites)	To assess diurnal and seasonal changes in species richness, composition and abundance	Assemblage (43 species)	M. F. Braby (unpubl. data)
Transect count	1870 m × 10 m × 5 m transect/time not given	84 samples over 3 years (1 count per week × 28 sampling occasions per year × 3 years × 1 site)	To assess seasonal changes in abundance	*Heteronympha merope*	Pearse (1978)
Transect count	2100–3825 m × 10 m × 5 m transect/86–120 min	48 samples over 1 year (1 count per month × 12 sampling occasions × 4 sites)	To determine temporal distribution of species richness	Assemblage (>60 species)	Hill (1987, 1988)
Transect count (Pollard walk)	1500 m × 5 m transect/30–45 min	22 samples over 5 months (1 count per week × 22 sampling occasions × 1 site)	To assess seasonal changes in abundance	*Geitoneura klugii*, *Geitoneura acantha*	Braby and New (1989)
Transect count	2100 m × 10 m × 5 m transect/95 min	45 samples over 2.5 years (1–2 counts per month × 30 sampling occasions × 1 site)	To assess temporal changes in abundance in relation to adult food resources	*Hypochrysops apelles*, *Hypochrysops epicurus*	Hill (1992)
Transect count	500 m/20 min	60 samples over 1 week (1 count per hour × 10 h × 6 sampling occasions × 1 site)	To assess mate location behaviour of males	*Hypolimnas bolina*	Rutowski (1992)
Transect count	2000 m × 8 m transect/40 min	12 samples over 12 h (1 count per hour × 12 h × 1 site)	To assess diurnal changes in abundance	*Tisiphone helena*	Braby (1993)

(*Continues*)

Table 2 (Continued)

Method	Sampling unit/sampling effort	Survey effort	Purpose	Target species	Reference
Transect count (Pollard walk)	1000 m × 5 m transect/ 40 min	390 samples over 22 months (1 count × 2–3 sampling occasions × 170 sites)	To assess patterns of spatial distribution and temporal abundance	Assemblage (16 species)	Braby (1995a)
Transect count (Pollard walk)	1000 m × 5 m transect/ 40 min	360 samples over 1 year (10 counts per day × 3 days × 4 sampling occasions × 3 sites)	To assess diurnal and temporal changes in abundance in relation to habitats	Assemblage (7 species)	Braby (1995b)
Transect count	100–150 m × 20 m transect/ ~7 min	216 samples over 6 weeks (3 sampling units × 3 counts per day × 8 sampling occasions × 3 sites, at Eltham)	To assess activity and compare abundance among sites	*Paralucia pyrodiscus*	van Praagh (1996) and Braby *et al*. (1999)
Transect count	Space and time not given	13 samples over 13 months (1 sample per month × 13 sampling occasions × 1 site)	To assess seasonal changes in abundance	*Cephrenes augiades*, *Cephrenes trichopepla*	Lyonns (1999)
Transect count	1020 m/time not given	96 samples over 1 year (1 count per hour × 7 h × 12 sampling occasions × 1 site)	To assess handling effects of mark–recapture on catchability of territorial males	*Hypolimnas bolina*	Kemp and Zalucki (1999)
Transect count	1050 m × 10 m transect/ 25 min	23 samples over 6 months (1 count per week × 23 sampling occasions × 1 site)	To determine species richness, composition and abundance in relation to habitat condition	Assemblage (10 species)	Haywood and Wilson (2002, and pers. comm. 2020)
Transect count (Pollard walk)	Space and time not given, except width of transect (5 m)	32 samples over 12 years (2 counts per month × 4 sampling occasions in 1991–1992 × 1 site, plus 2 counts per day × 12 sampling occasions in 2003–2004 × 1 site)	To determine changes in species richness, composition and abundance in relation to habitat disturbance	Assemblage (74 species)	Newland (2006)
Transect count	1490–2450 m × 10 m transect/37–70 min	53 samples over 15 months (17–19 counts × 3 sites)	To assess and compare diversity, species richness and abundance in relation to urban habitats	Assemblage (21 species)	Collier *et al*. (2006)
Transect count	155–5100 m × 10 m transect, at 50–60 m/min	552 samples over 20 months (1 count per fortnight × ~8 sampling occasions × 34 sites, plus 2 sampling units × 1 count per fortnight × ~8 sampling occasions × 12 sites)	To compare species richness and abundance in relation to fragmentation of urban habitats	Assemblage (35 species)	Williams (2008, 2009, 2011, and pers. comm. 2020)
Transect count	2900 m × 10 m × 5 m transect/90–120 min	23 samples over 14 months (2–3 counts × 8 sampling occasions × 1 site)	To determine temporal distribution of species richness and abundance	Assemblage (29 species)	Franklin (2011)
Transect count	210–1120 m × 10 m × 2 m transect, at 50 m/min	>180 samples over 16 years (1 count × 2–5 sampling occasions per year × 6 years (1998–2002, 2014) × 15 sites)	To assess changes in abundance (population density) in relation to threats	*Oreixenica ptunarra*	Bell (1999, 2014, and pers. comm. 2020)
Transect count	Space and time not given, except width of transect (10 m)	135 samples over 3 years (1 count per week × 5 sampling occasions per year × 3 years × 9 sites)	To assess seasonal changes in abundance (population density) in relation to impacts of threats (introduced wasps)	*Oreixenica ptunarra*	Potter-Craven *et al*. (2018)

(*Continues*)

Table 2 (Continued)

Method	Sampling unit/sampling effort	Survey effort	Purpose	Target species	Reference
Transect count (Pollard walk)	1000 m × 5 m × 5 m transect/ 20 min	200 samples over 5 months (1 count × 2 sampling occasions × 100 sites)	To compare species richness and abundance in relation to intensification of urbanisation	Assemblage (14 species)	Kurylo *et al.* (2020)
Transect count	2000 m × 6 m × 3 m transect/ time not given	30 samples over 3 years (1 count per month × 10 sampling occasions × 3 years × 1 site)	To assess seasonal changes in abundance	*Dispar compacta, Taractrocera papyria, Ocybadistes walkeri*	Kennedy (2020)
Occupancy survey	Area variable, number captured or observed/2 observers/1.5 h	46 samples over 3 years (1 sample × 46 sites)	To determine occupancy and abundance	*Euploea alcathoe*	Braby (2010)
Occupancy survey	Area variable (1–41 800 m^2 patch size)/time not given	293 samples over 2.5 years (1 sample × 293 patches)	To determine occupancy	*Ocybadistes knightorum*	Andren and Cameron (2012)
Occupancy survey	Area variable, number observed/1–2 observers/15–160 min ($\bar{x}$ = 60 min)	37 samples over 2 weeks (1 sample × 37 sites)	To determine occupancy	*Jalmenus eubulus*	Taylor (2014)
MRR	Not given	4 samples over 4 months (4 sampling occasions × 1 site)	To determine seasonal changes in population size and sex ratio	*Heteronympha merope*	Edwards (1973)
MRR	~200 m × 100 m quadrat/2 observers/15–20 min	9 samples over 4 months (9 sampling occasions × 1 site)	To determine population size, sex ratio and longevity	*Euploea corinna*	Kitching and Zalucki (1981)
MRR	30 m × 30 m quadrat/30 min	9 samples over 5 months (1 sample per fortnight × 9 sampling occasions × 1 site)	To assess seasonal changes in population size	*Danaus plexippus*	James (1981)
MRR	30 m × 10 m quadrat/3 h	6 samples over 3 months (1 sample per fortnight × 6 sampling occasions × 1 site)	To determine population size and sex ratio	*Danaus plexippus*	James (1982)
MRR	110 m × 35 m quadrat/5 h	32 samples over 3 years (1 sample per fortnight × 8 sampling occasions per year × 2 years × 1 site, plus 1 sample per week × 16 sampling occasions × 1 site)	To determine population size, sex ratio, migration and other population parameters	*Danaus plexippus*	James (1984a, 1984b)
MRR	Area not given/30–40 min	112 samples over 10 months (1 sample per week × 19 sampling occasions × 4 sites, plus 1 sample per week × 18 sampling occasions × 2 sites)	To determine seasonal changes in population size and sex ratio and estimate longevity and movement patterns	*Danaus plexippus*	Zalucki and Kitching (1984)
MRR	100 m × 50 m quadrat/5–6 h	60 samples over 5 months (1 sample per week × 20 sampling occasions × 3 sites)	To determine and compare seasonal changes in population size and estimate longevity and movement patterns	*Geitoneura klugii*, *Geitoneura acantha*	Braby and New (1989)
MRR	~3 km^2/6 days	64 samples over 2 years (1 sample per fortnight × 16 sampling occasions per year × 2 years × 2 sites)	To determine age structure and sex ratio and estimate longevity and movement patterns	*Tirumala hamata*, *Euploea corinna*, *Euploea tulliolus*	Scheermeyer (1993)
MRR and fruit baiting	5 traps/1000 m transect/ 3 days	4 samples over 1 year (4 sampling occasions × 1 site)	To assess seasonal changes in population size	*Mydosama terminus*	Braby (1995b)

(*Continues*)

Table 2 (Continued)

Method	Sampling unit/sampling effort	Survey effort	Purpose	Target species	Reference
MRR	120 m × 70 m quadrat/2 h	27 samples over 4 weeks (1 sample per day × 17 sampling occasions × 1 site, plus 10 supplementary samples × 1 site)	To determine population size and estimate longevity and movement patterns	*Hypochrysops halyaetus*	Dover and Rowlingson (2005)
Fruit baiting	11 traps/1000 m transect/ 3 days	108 samples over 1 year (3 sampling units × 12 sampling occasions × 3 sites)	To compare species richness and abundance in relation to modified landscapes	Assemblage (49 species)	Sambhu *et al*. (2018)
Malaise trapping	1 trap/5 days	96 samples over 2 years (12 sampling occasions × 8 sites)	To determine efficacy of malaise traps as a sampling tool for monitoring diversity	Assemblage (17 species)	Ginn *et al*. (2007)
Other (sweep netting)	25 m radius of circle/number captured/2–4 collectors/1 h/ 15 days	16 samples over 3 months (4 sampling occasions × 4 sites)	To determine abundance (population density) and sex ratio	*Danaus plexippus*	Bull *et al*. (1985)
Other (sweep netting)	Area and time not given, number captured/h	24 samples over 2 years	To assess seasonal changes in abundance	*Eurema* (5 species)	Jones and Rienks (1987)
Other (sweep netting)	100 m × 50 m quadrat, number captured/5–6 h	60 samples over 5 months (1 capture sample per week × 20 sampling occasions × 3 sites)	To assess seasonal changes in abundance	*Geitoneura klugii*, *Geitoneura acantha*	Braby and New (1989)
Other (sweep netting)	Area not given, number captured/5–12 h	29 samples over 2 years (1 capture sample per 2–6 weeks × 29 sampling occasions)	To assess seasonal changes in abundance	*Mycalesis perseus*, *Mydosama terminus*, *Mydosama sirius*	Braby (1995b)
Other (sweep netting)	Area not given, number captured/1 h	70 samples over 20 months (1 capture sample per week × 35 sampling occasions per year × 2 years × 1 site)	To assess seasonal changes in abundance	*Cressida cressida*	Orr (1999)

Dimensions for transect sampling units are length by width and, when given, by vertical height above ground. Note transect width refers to the combined distance on each side of the observer; for example, if the observer recorded butterflies up to 5 m on either side of the transect, then the width is 10 m.

MRR, Mark–release–recapture.

activity. However, these guidelines require flexibility for implementation according to latitude and altitude. For example, in the temperate areas of mainland southern Australia, temperatures below 21 °C are generally too cold for butterfly activity, while those above 35 °C are too hot for most species, whereas in the tropical region of northern Australia, optimal activity occurs when temperatures are >25 °C, and cloud cover is less of an issue. Surveys should not be undertaken during rain, strong wind, smoke or fog because butterflies are less likely to be active and thus less likely to be detected. Time of day affects activity and thus detectability (e.g. Frazer 1973; Rutowski 1992; Braby 1995b; Wittman *et al.* 2017), and time of year needs to be considered for seasonal species with short flight periods. Pollard (1977) recommended an optimal time of day between 1045 and 1545 h. However, these times need to be flexible due to species having different diurnal activity periods. Some species in Australia are most active at dawn and/or dusk (e.g. *Chaetocneme* and *Melanitis*) or early morning and late afternoon (e.g. *Euschemon rafflesia*, *Mycalesis perseus* and *Mydosama sirius*), whereas others fly predominantly in the morning (e.g. *Netrocoryne repanda* and *Lucia limbaria*), early to mid-afternoon (e.g. *Mesodina* and *Ogyris*) or late afternoon (e.g. *Hypochrysops* and *Arhopala*) (Braby 2000).

It is clear from the quantitative surveys carried out in Australia to date that there has been little standardisation of the various methods used (Table 2), with wide variation in sampling units and sampling efforts, as well as in overall survey effort, adopted for some methods. For example, for transect counts, the length of the line transect varies from as little as 100 m to as much as 5.1 km, and the width varies from 5 to 20 m. Moreover, protocols adopted by several studies (e.g. van Praagh 1996) fall well outside the thresholds recommended by the international guidelines (van Swaay *et al.* 2015). This lack of standardisation is not surprising because the studies usually had different objectives or purposes.

For transect counts, we recommend a route of up to 1 km over 50 min following criteria of the Pollard walk (i.e. counts in a spatial volume of 5 m × 5 m × 5 m). Ideally, the transect should be located in a single habitat or, if in a heterogeneous habitat, stratified into sections or sectors (e.g. 100 m in length) to take into account habitat variability and potentially different management requirements. The counts ought to be repeated on regular intervals during the flight season (typically once every 1–2 weeks depending on the phenology of the species), and at the end of the year, the counts are summed for each species for each site to provide an index of abundance for that year. Obviously, a 1 km transect may not be practical for small areas; however, if a minimum length of 300 m cannot be achieved, we suggest using alternative sampling methods (e.g. point counts or area counts). For point counts, we recommend that this method be used for surveying dense habitats in which there are no tracks (e.g. clearings or light gaps in rainforest), forest canopies, hilltops and residential gardens – in our experience, a circle with a radius of 10 m surveyed for 30 min (i.e. similar to the sampling unit and effort used by Hill *et al.* 1992) has proven to be suitable for point counts. For area counts, an area of 1 ha of a circle (56 m radius) or quadrat (100 m × 100 m or 200 m × 50 m) surveyed for 50 min has been reliable in estimating patterns of species richness and abundance (M. F. Braby unpubl. data). Clearly, flexibility in choice of sampling method is needed, and the method adopted must be adaptable to site conditions. However, regardless of the method used, the sampling unit must be standardised in space (i.e. dimensions of transect, point or area count), and the sampling effort must be standardised in time (i.e. time taken to complete the survey). These two components need to remain consistent when samples are repeated to ensure high-quality data (van Swaay *et al.* 2015). In other words, robust monitoring must be standardised and consistent.

BUTTERFLIES AUSTRALIA

The Butterflies Australia platform (Fig. 3) (Butterflies Australia 2020) is a national citizen science initiative that provides tools for butterfly enthusiasts of all levels of experience, engaging both amateur and expert butterfly watchers, to contribute their observational data in a format that is useful for scientific analysis (Sanderson 2019). Butterflies Australia was developed as a national database of butterfly records, specifically to remove the impediment of data deficiency for butterflies in Australian conservation policy and scientific research, with the overarching goal of breaking the data deficiency feedback loop for at least one group of invertebrates (Fig. 1). Essentially, Butterflies Australia combines new technology platforms (phone app and website) with citizen scientists who will be encouraged to follow the international butterfly monitoring protocols described above.

The project has the following general aims: (1) to raise community awareness of butterflies, and invertebrates in general, specifically the need for more research and conservation efforts; (2) to encourage community participation through good user interface design in the app and website, including provision of a free field guide in the app; (3) to increase availability of scientifically robust observational data on butterflies; and (4) to influence policymakers to provide more attention to butterflies and potentially other invertebrates in their available funding and policy design. The long-term objective is to improve understanding of the distribution and abundance of native and introduced Australian butterfly species and how their ranges and populations are changing over time. Ultimately, these data should inform policy by providing more accurate and up-to-date data contributing to the conservation status of each species, as well as identifying and prioritising areas for biodiversity conservation.

The collection of observation data is done through either the phone app or website. While the interfaces for the two platforms differ slightly, they collect the same information. The requirement for each observation follows the three minimum Darwin Core metadata standards, namely: (1) species scientific name, (2) date and time (temporal data) and (3) location, latitude and longitude, together with spatial accuracy or precision of the record (spatial data). Observer name is not mandatory, but the account name used to sign into the system is recorded as a unique observer ID. Observations can be recorded as either incidental records, which are ad hoc, serendipitous species records that

(a)

(b)

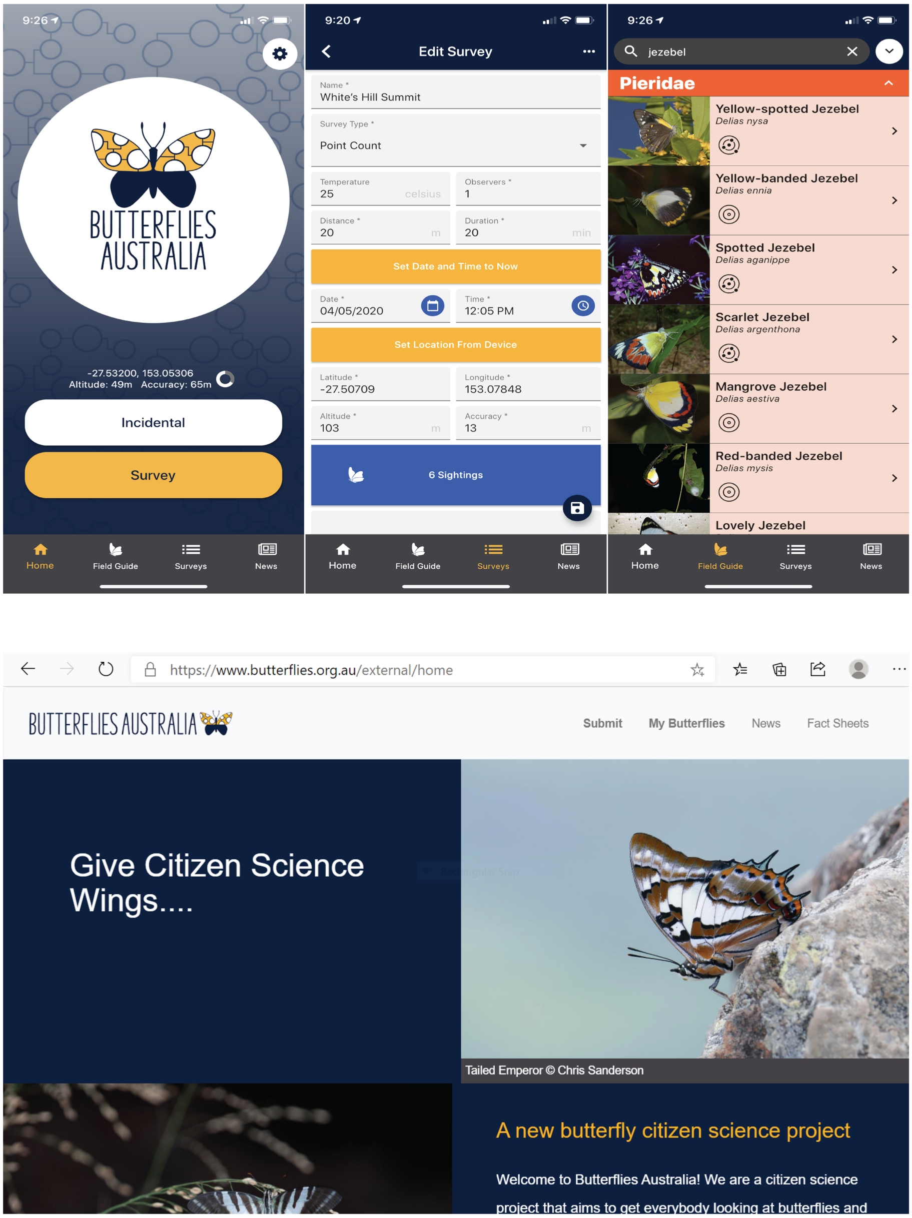

Fig. 3. Interface of the new Butterflies Australia platforms: (a) phone app, and (b) website.

include the above information, or as surveys. Both incidental and survey observations have the capacity to include information about all life history stages of each species; however, the default for observations is the adult stage unless otherwise specified. The terms and conditions of the platform make it clear that citizen scientists must not send data for which they do not have ownership, including data collected illegally (e.g. trespass or lack of collecting permits for protected areas). Nomenclature for species and higher classification of butterflies follows the names adopted by the Australian Faunal Directory (AFD 2020), which is managed by one of us (M. F. B.).

The survey methods included in the platform are designed to be flexible. There are three broad types of survey methods: (1) point counts, (2) area counts, and (3) line transects (transect counts). For point and area counts, citizen scientists can freely set the diameter of the area (i.e. sampling unit) and the duration of the count (i.e. sampling effort). Similarly, for line transects, citizen scientists set the length of the transect and the duration of the count. It is possible to record other important information, such as altitude and temperature, and any other key information (in the comments field for the survey). This interface design allows a high degree of flexibility with survey methods when using the app and website while allowing a high level of repeatability of surveys over time.

Phone app

The mobile phone app (Fig. 3a) comprises a free iOS and Android app available for download. It has a number of features that are not currently available on the website interface. Survey location can be set via the GPS chip in the phone. This feature works offline, so even if the citizen scientist is not in range of a mobile tower or Wi-Fi hotspot, they will be able to record data in the remotest parts of the country. To allow for this, surveys are not automatically uploaded to the server but must be authorised by the citizen scientist once they are in range of a mobile tower or have Wi-Fi connection. This feature also allows citizen scientists to review their sightings before they are sent to the database for moderation.

The phone app includes a photographic field guide. The text provided for each species is minimal to aid in successful identification and is not intended to replace the role of a book for field identification. The app field guide has a photo gallery, which depicts many life histories, as well as differences in sex, subspecies, seasonal forms, colour morphs and other variations. Moreover, the app field guide format can provide many images per species and in this regard is more advantageous than a hard copy book because we expect the number of images to substantially increase over time.

Website

The online website (Fig. 3b) is where the citizen scientist can search through the validated records. Within the species search facility, citizen scientists can choose to search on a date range, by state, on species scientific or common name, or a combination of these elements. For example, a very specific search could be conducted for all records of the migratory Caper White *Belenois java* in Queensland for the month of October for the years 2019–2020. Results of this search are displayed in a table or can be displayed on an interactive map, where each record can be clicked to display the original observation in the database, including any images attached or comments from moderators.

The data verification facility is a feature of the website. This feature is only accessible to volunteer experts (see Acknowledgements) who verify data stored in the database. Local experts were recruited to participate as moderators based on established connections with the database managers (C. S. and M. F. B.) and to ensure adequate coverage of all states and territories. Thus, moderators are typically recruited to examine data from a particular state or territory, but they can verify data from anywhere in the country. The platform accepts all types of records of butterflies, including voucher specimens, photographs, those based on captured and released specimens and those based on observational sightings. The level of evidence provided by the citizen scientist assists the moderator in reviewing the species identifications, so, for example, a sighting-only record of a rare species would be subjected to more scrutiny than one backed by a photograph or voucher specimen. All observations are first passed through a series of automated filters to check if the species was recorded within certain criteria, such as its known range (spatial distribution), an appropriate altitudinal range, known time of year (temporal occurrence) and in plausible numbers. Another criterion is whether the citizen scientist is a verified user or not. Initially, all new citizen scientists have their records scrutinised by the moderators. Once new citizen scientists have demonstrated their reliability in identifying butterflies, the moderator can then verify the citizen scientist. From that point, all observations that pass the automated filter criteria will be automatically marked as valid without relying on verification by the moderators.

Records that are invalidated due to insufficient information are stored in the database and can be revisited in the future when more evidence becomes available. For example, worn specimens and the females of several hesperiids and lycaenids can be very difficult to identify without a vouchered specimen that may also require dissection and examination of the genitalia. If a citizen scientist edits a record by adding more information, the record is then automatically passed back through the moderator filters. Moderators and citizen scientists that submit invalidated records will retain access to those records, but other citizen scientists will not have access to these records. Where citizen scientists are unsure of the species identification based on a photograph, they can still submit the record as an ‘unknown species’, which will then be assessed by the moderators for identification. This feature has the potential to be very useful for biosecurity in cases where a citizen scientist finds an introduced species for the first time. In future, we plan to add an additional filter for species we consider challenging to identify so that those records will always be scrutinised by an expert before being verified.

Once verified, data are then made available for download via the Butterflies Australia website. The data are interoperable and available via application programming interface (API) for institutions that manage national data aggregations, such as the ALA. This ensures the data remain freely available to the public. The exception is for ‘sensitive data’, which is data that remain protected because, for example, a species may be threatened, or a site is likely to be significantly impacted by visitation or over-collection. Sensitive species data are displayed only in a generalised format, with the observation point obfuscated by a 50 km buffer. Sensitive species data, however, can be made available on request for research purposes provided the project meets certain criteria (e.g. raw data points are not to be released). At this stage, we plan to designate data as sensitive on a species-by-species basis rather than allowing users to designate specific records as sensitive.

DISCUSSION

The Butterflies Australia platform was officially launched in Canberra in late October 2019. Within the first 12 months of operation, over 4 000 people downloaded the app, and over 8100 validated butterfly observations representing 256 species were submitted (by 297 citizen scientists) (Fig. 4). Two-thirds of the records comprise Nymphalidae and Pieridae (65%), whereas the Hesperiidae are poorly represented (5%), which no doubt reflects the difficulty of identifying members of this speciose family. Not surprisingly, records to date are spatially biased towards the higher population centres along the eastern seaboard, but as more data accrue, citizen scientists will be encouraged to target gaps in overall coverage of geographical regions, as well as particular species. Our data will be publicly available through the ALA, Australia’s national biodiversity aggregator, which also makes that data available globally

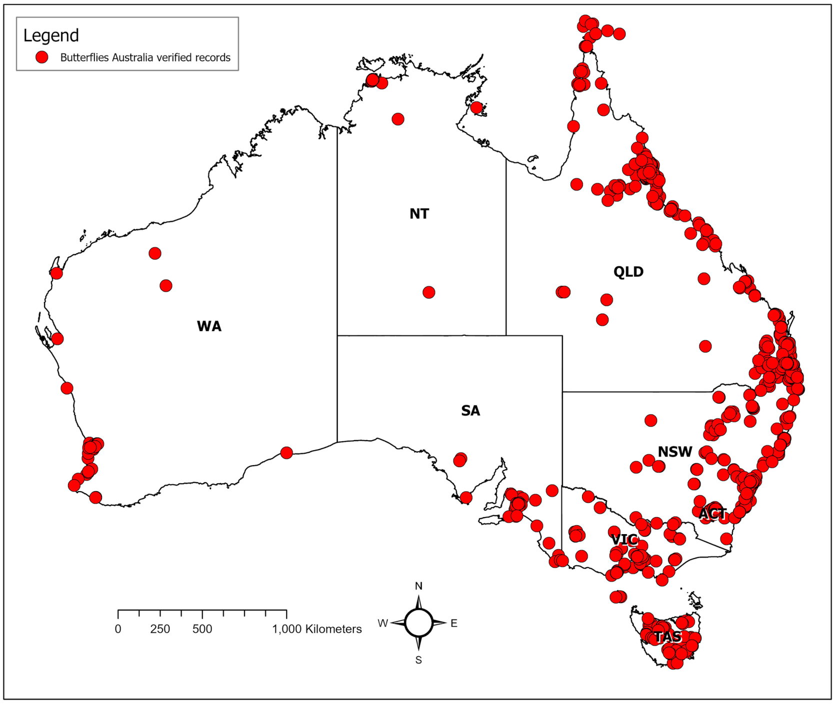

Fig. 4. Map of Australia showing spatial coverage of verified data collection points (8177 records) accumulated during the first 12 months of the Butterflies Australia platform (1 November 2019–31 October 2020). The composition of data records is Nymphalidae (39%), Pieridae (26%), Papilioniidae (16%), Lycaenidae (13%), Hesperiidae (5%) and unresolved (1%).

through GBIF. However, unlike the vast majority of records uploaded to the ALA (e.g. via iNaturalist or from museum repositories), the data quality is very high because of the stringent moderation process. Although the ALA has substantially more data at present (~250 000 occurrence records for butterflies), the data quality is lower because of lack of moderation; thus, errors due to misidentification, transcription and spatial imprecision need to be carefully taken into account when using ALA data.

The new app and website platforms for Butterflies Australia add to the growing body of citizen science platforms, both nationally and globally (e.g. Silvertown 2009; Jetz *et al.* 2012; Walker 2015; Prudic *et al.* 2017). Creating a new citizen science platform capable of recording butterfly observations from anew requires careful consideration and planning, and the design for our app and website was largely inspired by three highly successful international citizen science platforms: eBird (Sullivan *et al.* 2014), eButterfly (Prudic *et al.* 2017) and iNaturalist (2020). Several novel design features in our app include the interface for recording juvenile stages (eggs, larvae and pupae) and the ability to function offline in remote parts of Australia that may not have internet access.

By capturing both high-quality and high-quantity data, our ultimate goal is to break the data deficiency feedback loop that pervades the listing and conservation management of all invertebrates (Cardoso *et al.* 2011b), including butterflies, which are undoubtedly the most popular and 'charismatic' group of insects. By drawing on citizen scientists to participate in biodiversity informatics and to assist with mapping and/or monitoring butterflies, we feel confident that this goal can be achieved. To date, promotion of Butterflies Australia via traditional and social media outlets has reached over a million Australians (ANU media unit, pers. comm. 2020), and as noted above, the app has already been downloaded on thousands of devices, and observations have been contributed by several hundred citizen scientists. However, it may take 5–10 years before we can replicate the success of eButterfly, which amassed over 230 000 records of butterflies by more than 5500 contributors in the first five years of operation in North America (Prudic *et al.* 2017; eButterfly 2020). Currently, eButterfly has over 410 000 occurrence records (eButterfly 2020). Only by substantially increasing the amount of data available will it be possible to have a clearer picture of the distribution, abundance and critical habitat requirements of the Australian butterfly fauna, data which will assist in the status evaluation of threatened species more accurately (Geyle *et al.* 2021). We also aim to expand the database in the future so that historic data (e.g. from museum collections, private collections, field notebooks of naturalists and entomologists, photographs and scientific and grey literature) can be captured, providing greater resolution to assess temporal changes in geographical range and occupancy.

Besides the obvious benefits to the conservation of threatened species, there are potential benefits for biosecurity. The recent arrival of the Tawny Coster *Acraea terpsicore* in northern Australia (Sanderson *et al.* 2012; Braby *et al.* 2014a; Chowdhury *et al.* 2021) is a good example of the benefits of citizen scientists working with government agencies. This range-shifting species, detected through a serendipitous discovery by C. S. (then an ornithologist and amateur entomologist on vacation), had the potential to become a serious pest for the vegetable and horticultural sectors in the Top End and Ord River Irrigation Area (Braby *et al*. 2014b). The early detection allowed government scientists a small window to properly identify the species and assess its potential impacts and risks, but this process could have been greatly accelerated via a citizen science platform that was unavailable at the time. However, the potential for the arrival of other (less desirable) butterfly species from mainland New Guinea or elsewhere, such as the Banana Skipper *Erionota thrax* (Sands *et al*. 1991; Sands & New 2008) and Cycad Blue *Chilades pandava* (Wu *et al*. 2010; Tennent 2014), remains high. To mitigate these incursion risks to agriculture and biodiversity, two steps are required in the reporting process: (1) a network of people (citizens) who can detect species and, (2) a means whereby these observations can be uploaded rapidly (Walker 2013, 2015). Once the observations are reported on a citizen science platform, experts can then confirm the identification and quickly pass that information on to the relevant authorities, similar to the process adopted by MyPestGuide (2020).

In conclusion, we are encouraged by the massive growth of citizen science and the willingness of the general public to use the tools technology has to offer to contribute to bioinformatics and conservation biology. In our view, citizen science is probably the best mechanism we have at present for solving the problem of data deficiency with respect to butterfly conservation and status evaluation of threatened species. In addition to obtaining better mapping (spatial data) of species distributions, there is enormous scope for developing species distribution models and analysing ecological patterns at fine scales of resolution with access to big data sets encompassing broad spatial and temporal scales, which ultimately assists in prioritising areas for biodiversity conservation. There is huge potential for citizen scientists to contribute to a deeper understanding of trends in abundance through long-term observations over time (temporal data) by adopting the international, standardised protocols for butterfly monitoring. In addition to field observations and photographs, Butterflies Australia in the future will provide a way of integrating spatial data from other sources – specimens in collections, field notebooks, personal data sets and scientific papers – and to make that data accessible. We envisage that the new butterfly app and website will be expanded to include day-flying moths and eventually most Australian Lepidoptera. Moreover, there is potential to replicate this platform for other popular taxonomic groups, such as Odonata, some families of Coleoptera, certain Hymenoptera, Orthoptera, spiders and land snails, among others (Braby & Williams 2016). Ultimately, the new citizen science platform (app and website) should lead to increased community awareness, greater data collection and better conservation policy and planning and hence more resources (funding and research) for conservation work on invertebrates.

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