The arrival and spread of the European firebug *Pyrrhocoris apterus* in Australia as documented by citizen scientists

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Abstract

We present evidence of the recent introduction and quick spread of the European firebug *Pyrrhocoris apterus* in Australia, as documented on the citizen science platform iNaturalist. The first public record of the species was reported in December 2018 in the City of Brimbank (Melbourne, Victoria). Since then, the species distribution has quickly expanded into 15 local government areas surrounding this first observation, including areas in both Metropolitan Melbourne and regional Victoria. The number of records of the European firebug in Victoria has also seen a substantial increase, with a current tally of almost 100 observations in iNaturalist as of July 31st, 2021.

The case of the European firebug in Australia adds to the list of examples of citizen scientists playing a key role in not only early detection of newly introduced species but in documenting their expansion across their non-native range. Citizen science presents an exciting opportunity to complement biosecurity efforts carried out by government agencies, which often lack resources to sufficiently fund detection and monitoring programs given the overwhelming number of current and potential invasive species. Recognising and supporting the invaluable contribution of citizen scientists to science and society can help reduce this gap by: (1) increasing the number of introduced species that are quickly detected; (2) gathering evidence of the species' early expansion stage; and (3) prompting adequate monitoring and rapid management plans for potentially harmful species.

Given the range expansion patterns of the European firebug worldwide, their adaptation ability, and future climate scenarios, we suspect this species will continue expanding beyond Victoria, including other parts of Australia, New Zealand, and the South Pacific. We firmly believe that most of the knowledge about how this expansion process continues to happen will be provided by citizen scientists.

Keywords: Biosecurity, Citizen science, Heteropteran bugs, iNaturalist, Introduced species, Invasion Ecology, Invasive species, Pyrrhocoridae, Urban Ecology, Urban environments

On 10 March 2019, the first authors were guiding a group of citizen scientists in an outdoor activity targeted at documenting ecological interactions between indigenous plants and insect pollinators. The activity was part of a research and community engagement project entitled 'Pollinator Observatories', which took place in Westgate Park (Melbourne, Victoria, Australia) between April 2017 and March 2019 (Vogel, 2019; Mata, Vogel and Bolitho, 2020). During the activity, one of the citizen scientists asked for assistance to identify an insect they had spotted crawling on the ground. To our immense surprise, the insect in question was the European firebug *Pyrrhocoris apterus* (Fig. 1), a species that, serendipitously, we had researched in its native range and had experience surveying and identifying (Mata, Silva and Goula, 2013). We therefore had no difficulties in recognising the species as non-native to Australia.

We shared with the citizen scientists that we may be observing the first record of the European firebug in Australia. In the next few days, we set to substantiate or rebut this conjecture. We began by searching the literature for potential evidence of the European firebug occurring in Australia but could not find any references documenting this. We then searched the Atlas of Living Australia for European firebug records but found none. Next, we asked colleagues across our networks whether they had any relevant information on the European firebug and used this as an opportunity to communicate the discovery to the relevant biosecurity authorities. We learned that the European firebug had indeed been previously recorded in Melbourne's western suburbs as early as April 2018 by the Border Surveillance Group of the Australia Government's Department of Agriculture and Water Resources (Adam Broadley pers. comm., later published in

Figure 1. The European firebug *Pyrrhocoris apterus*, as discovered by a citizen scientist crawling through the mulch in Westgate Park (Melbourne, Victoria, Australia). Photo by Luis Mata.

DAWE, 2019). So not the first record after all. Yet – having experienced first-hand how straightforward it had been for a citizen scientist to find the European firebug – we drew our attention to the online biodiversity citizen science platform iNaturalist (https://www.inaturalist.org/), hoping to find further evidence of the arrival and potential spread of the species in Australia. We were not disappointed.

As it turns out, at the time of our inquiry (April 2019), four citizen scientists had already contributed six iNaturalist observations of the European firebug in Australia. The earliest was from 21 December 2018, the latest from 9 March 2019; all from Sunshine in the City of Brimbank (Melbourne, Victoria). We decided to monitor future iNaturalist observations to track the potential spread of the species throughout Melbourne, regional Victoria, and generally across Australia.

As we write, over 30 citizen scientists have contributed approximately 100 observations of the European firebug in Australia (Fig. 2f). These reveal that the species has been expanding its range, spreading from its original introduction enclave in the City of Brimbank (Fig. 2a) to 15 municipalities and shires in the Melbourne Metropolitan Area and regional Victoria (Fig. 2d) in less than three years. Taken together, these insights highlight the key role that citizen scientists are playing in detecting newly introduced species and documenting their establishment and expansion in their non-native ranges. We argue that this contribution is highly valuable, as it complements efforts by biosecurity agencies in charge of detecting and monitoring introduced species during their early invasion stages. This is particularly relevant for species with documented detrimental impacts in their non-native regions, if left unmanaged.

Often, unfortunately, government-funded biosecurity agencies lack resources to sufficiently fund detection and monitoring programs. The engagement of citizen scientists can effectively fill this gap and ensure invasive species do not remain undetected (Ricciardi et al., 2017; Turrini et al., 2018). With careful project design, volunteer training, and professional validation, citizen science observations can be as reliable as those undertaken by professional scientists (Kosmala et al., 2016). Citizen scientists around the world have successfully detected invasive species early, significantly contributing to the rapid management of potential pest species. For example, in Alaska, United States, citizen scientists discovered the colonial tunicate Didemnum vexillum 1000 km north of its known range during a bioblitz (Cohen et al., 2011). Similarly, citizen scientists detected the arrival of the Sergeant major fish *Abudefduf saxatilis* in the Mediterranean Sea (Azzurro et al., 2013) and the red lionfish *Pterois volitans* in the northern Gulf of Mexico (Scyphers et al., 2015). Citizen scientists are also credited by discovering the arrival of invasive mosquito species – including the Asian tiger mosquito *Aedes albopictus* and the Asian bush mosquito *Aedes japonicus* – in Germany (Walther and Kampen, 2017) and Spain (Eritja et al., 2019). These early detections contributed by citizen scientists proved integral to the management of these invasive species, in all cases prompting extensive monitoring programs, often led by further citizen scientist groups.

Citizen scientists have also made critical contributions in the ongoing monitoring of invasive species following their detection, in documenting their long-term spread and impacts on native species and ecosystems, while informing management plans and actions (Ricciardi et al., 2017; Pyšek et al., 2020). For example, a citizen science program

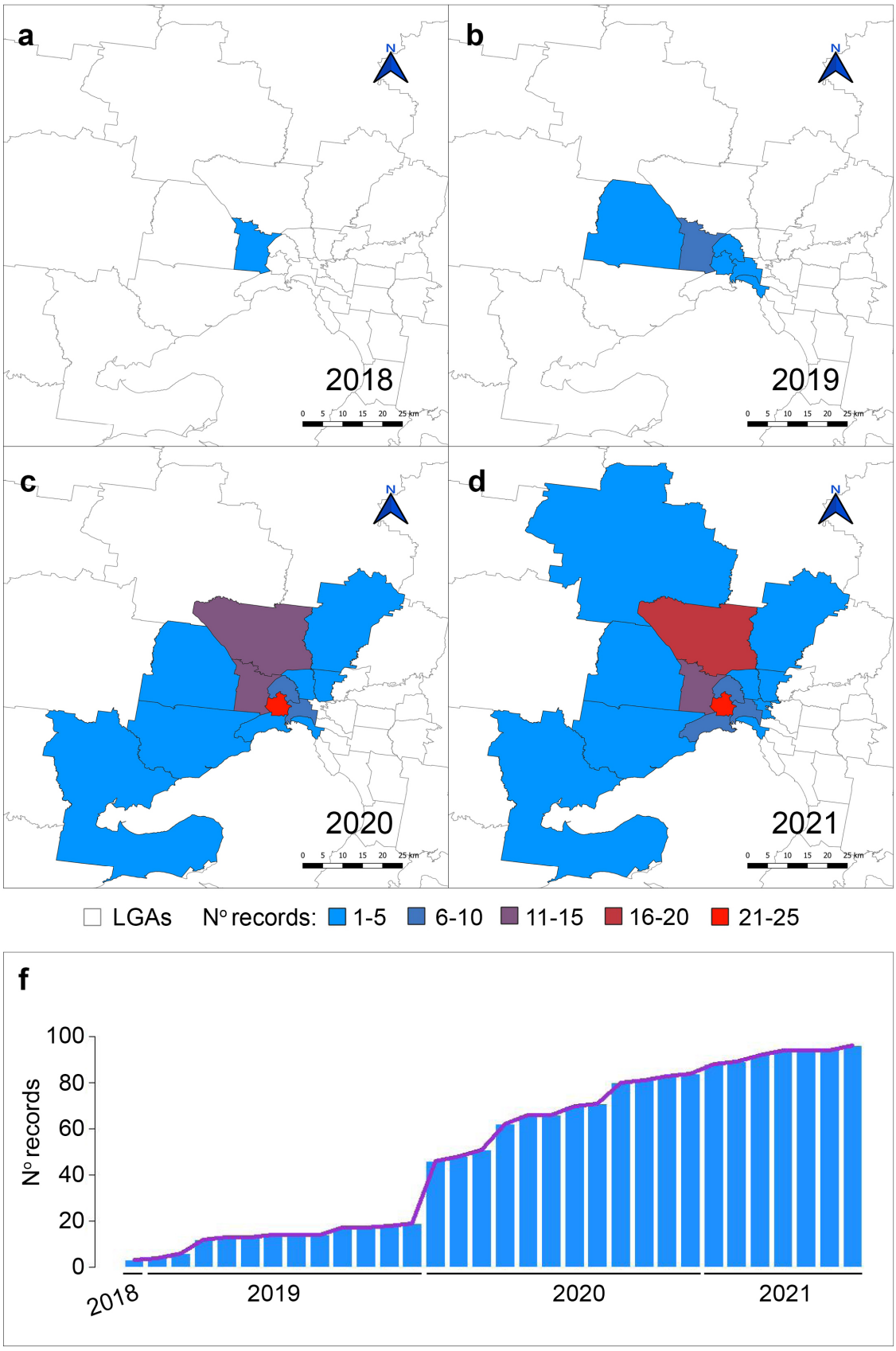

Figure 2. (**a-d**) Past and current distribution of the European firebug *Pyrrhocoris apterus* in Australia. The heat maps highlight the Local Government Areas (i.e. municipalities and shires) across the Melbourne Metropolitan Area and regional Victoria in which the species has been documented by citizen scientists through iNaturalist as of 31 July 2021. (**f**) Number of accumulated observations by month of the European firebug in Australia from December 2018 to July 2021.

in the United States monitored the effects of the stem-mining weevil *Mecinus janthiniformis* on the invasive weed Dalmatian toadflax *Linaria dalmatica* to inform the use of biological control in invasive weed management (Weed and Schwarzländer, 2014). Similarly, citizen scientists in Italy and Switzerland have been monitoring the invasion of the brown marmorated stink bug *Halyomorpha halys*, which informed management actions and clarified key aspects of the species' biology (Maistrello et al., 2016). These and other citizen science programs have proven crucial in monitoring the presence and spread of invasive species in their new non-native ranges, particularly as citizen scientists can cover much larger spatial areas and temporal periods than experts alone can (Turrini et al., 2018). Furthermore, when well designed, these programs can collect robust presence and absence data than can inform advanced statistical (Coxen et al., 2017) and DNA analysis (Ryan, 2018) approaches aimed at predicting the detrimental impacts of invasive species on native species and ecosystems, which may not be possible without the valued contribution of citizen scientists.

Citizen scientists participating in national, continental, and global projects (e.g. eButterfly, eBird, iNaturalist) often excel at detecting range expansions or shifts of both native and introduced species much earlier than professional scientists do (Crall et al., 2015; Chandler et al., 2017). Citizen scientists contributing to the butterfly conservation project eButterfly (https://www.e-butterfly.org/) have been recording the range expansion of the monarch *Danaus plexippus* in the United States since 2012, including novel observations of their rare east to west dispersal (Prudic et al., 2017). Citizen scientists have also succeeded in documenting (1) the invasion front of the grey squirrel *Sciurus carolinensis* in the northern regions of the Republic of Ireland more efficiently and cost-effectively than traditional professional field techniques (Goldstein et al., 2014); and (2) a significant range increase of the invasive European crab *Carcinus maenas* in inland waters in the United States, leading to a quick response to attempt to control the species (Grason et al., 2018). These and other examples emphasise the ability for citizen scientists to reliably study species of interest – including actual or potential threats – across wide geographical ranges.

Let's draw our attention back to the European firebug and have a closer look at its current biogeographical distribution. The European firebug has been traditionally known as a Palearctic species, ranging from central and southern Europe to western China (Kerzhner, 2001). Ample evidence, however, shows that it has been rapidly spreading outside its traditional native range (Fig 3.) While in some instances it might be difficult to disentangle natural from anthropogenic expansion – for example, in the Azores (Cardoso et al., 2011), Malta (Cassar, 2019), and northern Europe (Endrestøl and Roth, 2020) – it is evident that the European firebug has reached the American (Hodgson, 2008; Rojas and Jackson, 2018) and Australian continents assisted by humans. Given these range expansion patterns, the reported feeding and thermal adaptations of the species (Socha, 1993), and future climate scenarios, we would like to put forward the following two ideas about the future spread of the European firebug across Australia and beyond. The first is that we believe the species will likely continue to spread across metropolitan Melbourne and regional Victoria, not only eventually reaching other urban and rural areas across continental Australia, but also Tasmania, New Zealand and other South Pacific islands, and, in the not too distant future, the Antarctic continent. The second is that we are convinced that the

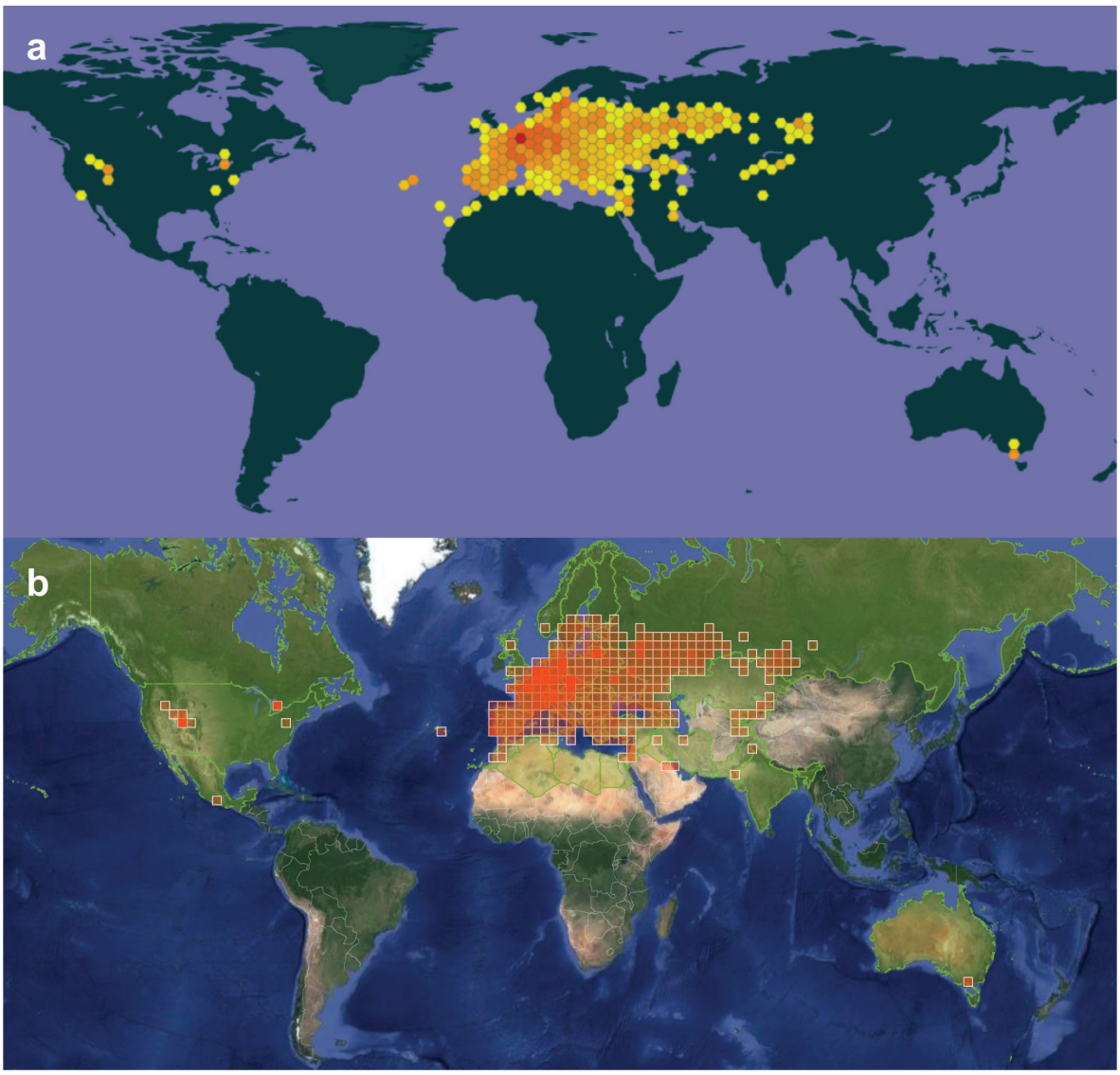

Figure 3. Current biogeographical distribution of the European firebug Pyrrhocoris apterus based on data provided by (**a**) the Global Biodiversity Information Facility (https://www.gbif.org/) and (**b**) iNaturalist (https://www.inaturalist.org/). The species was until recently restricted to the Palearctic but has now expanded its range to the African, Australian, and American continents.

large majority of the future range expansion of the European firebug across Australia and elsewhere will be first documented by citizen scientists. As such, we would like to thank them in advance for their efforts and call for biosecurity and other related agencies to recognise and support their invaluable contributions to science and society.

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discovered the European firebug in Westgate Park, all of those that have contributed observations of the European firebug and other species to iNaturalist, and last but not least, the iNaturalist team for developing and maintaining such a powerful scientific and engagement resource.

Open Research Statement

The data and codes to reproduce the analysis shown in Fig. 2 are already published and publicly available in Zenodo: https://doi.org/10.5281/zenodo.5355347

Conflict of interest statement

We have no conflict of interest to declare.

Author contribution

Luis Mata: Conceptualization (co-lead); Investigation (equal); Writing-original draft (co-lead); Writing-review & editing (equal). **Blythe Vogel:** Conceptualization (co-lead); Investigation (equal); Writing-original draft (co-lead); Writing-review & editing (equal). **Estibaliz Palma:** Data curation (lead); Formal analysis (lead); Investigation (equal); Writing-review & editing (equal). **Mallik Malipatil:** Investigation (equal); Writing-review & editing (equal).

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