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Tracking the spread of the eastern dwarf tree frog (*Litoria fallax*) in Australia using citizen science

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ABSTRACT

An increasing number of species are establishing populations outside of their native ranges, often with negative ecological and economic impacts. The detection and surveillance of invasive species presents a huge logistical challenge, given the large spatial regions in which new populations can appear. However, data collected through citizen science projects are increasingly recognised as a valuable source for detection and monitoring of invasive species. We use data from a national citizen science project, FrogID, to quantify the spread of the eastern dwarf tree frog (*Litoria fallax*) outside its historical native range in Australia. Of 48 012 records of *L. fallax* in the FrogID database, 485 were located far outside the historical native range of the species. *L. fallax* has established geographically large populations hundreds of kilometres away from its native range, and these appear to be spreading in extent over time. These populations have resulted in novel species co-occurrences, with *L. fallax* now co-occurring with at least two frog species not present in their native range. Although the impacts of the invasive populations of *L. fallax* remain unknown, our work highlights the value in leveraging citizen science projects to detect and monitor native species that can become invasive far outside their historical range.

Keywords: amphibian, biodiversity, community science, ecology, frogs, invasive species, monitoring, range expansion, species detection, species interactions.

Introduction

The global distribution of biodiversity is being dramatically altered because of human modification of the environment, and international trade. Plant and animal species are being transported outside their native ranges and an increasing number of species are establishing populations in these new localities. The establishment of such species can have environmental impacts ranging from single species to ecosystem-level effects (Grosholz 2002). And in some instances, they can have serious economic impacts (Bradshaw *et al.* 2016). Although many invasive species are introduced from countries outside their native range, some native species also establish invasive populations outside their native range (Simberloff 2010). These invasive native species have been the subject of far less attention, but their impacts may be similarly severe (Davis 2009).

Timely data on the spatial and temporal distribution of invasive species are vital to manage existing populations (Giovos *et al.* 2019) and detect potential establishment of populations in new regions (Reaser *et al.* 2020). However, the availability of such data is hindered by enormous logistical and resource limitations in structured scientific surveys, resulting in large gaps in knowledge of invasion patterns (Crall *et al.* 2010; Giovos *et al.* 2019). Citizen science projects focused on biodiversity can provide scientifically robust and reliable data at broad spatial and temporal scales, comparable to professionally collected or expert-derived data (Lewandowski and Specht 2015; Aceves-Bueno *et al.* 2017; Callaghan *et al.* 2020). Consequently, such citizen science data are increasingly being harnessed to monitor or guide surveillance of invasive species (Giovos *et al.* 2019; Koen and Newton 2021; Dart *et al.* 2022).

Here, we use data from a national citizen science project across Australia – FrogID (Rowley *et al.* 2019) – to detect the eastern dwarf tree frog (*L. fallax*) outside its historical native range in Australia. Using approximately 57 months of data from FrogID, we report detections of the species outside its native range, including the persistence and likely spread of established populations, and document new frog co-occurrences in its range.

Materials and methods

Study species

The eastern dwarf tree frog (*Litoria fallax*) is a small (~2.5 cm body length), commonly encountered frog native to eastern Australia, from central-eastern Queensland to the border of New South Wales (NSW). *L. fallax* was not detected outside its native range until the 1990s (Supplementary Fig. S1). The first record of the species outside its native range was in a wetland in the suburb of Moorabbin, in Melbourne, Victoria, in 1999 (Gillespie and Clemann 2000), and in 2010 it was recorded for the first time in north-eastern Victoria (Michael and Johnson 2016). The persistence and expansion of *L. fallax* throughout the suburbs of Melbourne was also documented by Bevelander (2014). The species has also established an invasive population in Guam (Christy *et al.* 2007).

FrogID dataset

We used data from the national citizen science project FrogID (Rowley *et al.* 2019; Rowley and Callaghan 2020), based on a smartphone app that allows users to submit audio recordings of calling frogs with associated metadata including location, time, and date. The species calling in each submission are then identified to species-level by experts in frog call identification. FrogID submissions typically contain the advertisement calls of more than one species of frog. The average number of frog species calling in a single recording is 1.6, and for recordings with at least one species of frog present is 2.6, with a maximum of 13 species per submission. We exported data from the FrogID database on 25 July 2022 and used data from 10 November 2017 until 30 June 2022.

The presumed native range of *L. fallax* was obtained from the Australian Frog Atlas (Cutajar *et al.* 2022) with invasive range removed based upon historical (<1980) records of the species in the Atlas of Living Australia (ALA; ala.org.au). The true historical range of *L. fallax* is unknown but is likely to be relatively reliable as it is well-sampled (the fifth most well-sampled frog species in Australia: ALA), and distinctive in both appearance and advertisement call. All records of *L. fallax* outside of this range were deemed out of range.

To examine the distribution of invasive *L. fallax* in relation to population density, we used population density (per square kilometre) from the Gridded Population of the World, Ver. 4 (GPWv4), Revision 11. We extracted human population density values for each FrogID record of *L. fallax* and conducted a Wilcoxon rank sum test in R to determine if there was any difference in human population density for records inside versus outside the presumed native range of *L. fallax*. We calculated Extent of Occurrence (EOO) for *L. fallax* using FrogID data and the package ConR in R (Dauby *et al.* 2017).

Results

In total, there were 48 012 records of *L. fallax* in the FrogID database, representing 7% of all frog records in the dataset. Of these records, 495 were located outside the presumed native range of the species (Fig. 1). Most of these were in Victoria (422), with fewer records in NSW (62), and the ACT (11). Records of *L. fallax* outside of its native range have been documented every year since the project launched in 2017, and the number of records and unique users that have recorded out-of-range *L. fallax* has increased over time, as have records of *L. fallax* and all frog species (Fig. 2).

Our analysis documents the continued persistence and likely spread of populations around Melbourne ('Melbourne population'; >400 km outside native range) and northern Victoria, documenting the population in northern Victoria extending into NSW for the first time in November 2019 ('Northern Victoria/Albury population'; >220 km outside its native range: Figs 1, 3 and S2). *L. fallax* was also documented in Canberra, in the ACT, for the first time (>50 km outside its native range) – a single record in 2018 and then five additional records each in the 2020/2021 spring/summer and 2021/2022 spring/summer. In 2021, *L. fallax* records were obtained from Griffith (>300 km outside its native range) and Wagga Wagga in NSW (>200 km outside its native range), and in 2022, the first records of *L. fallax* from Mirboo North in South Gippsland, Victoria, were received (>300 km outside its native range). Out-of-range records of *L. fallax* have a higher human population density (median of 139 people per square kilometre) compared to records within the presumed native range of *L. fallax* (median of 53 people per square kilometre: $W = 11\,023\,390$, $P < 0.001$) (Figs 3 and S3).

The known geographic extent of the Melbourne and northern Victoria/Albury *L. fallax* populations have increased over the duration of the FrogID project and are now expansive: with an extent of occurrence of approximately 1751 km^2 and 789 km^2 respectively (Fig. S4). As a result of these invasive populations, *L. fallax* now co-occurs (calling in close proximity) with species not found within its native range. *L. fallax* was detected co-occurring at the same site as 84 other frog species within its native range (Table S1), and 15 species outside of its native range, two of which were novel co-occurrences: *Crinia sloanei* (four records from four

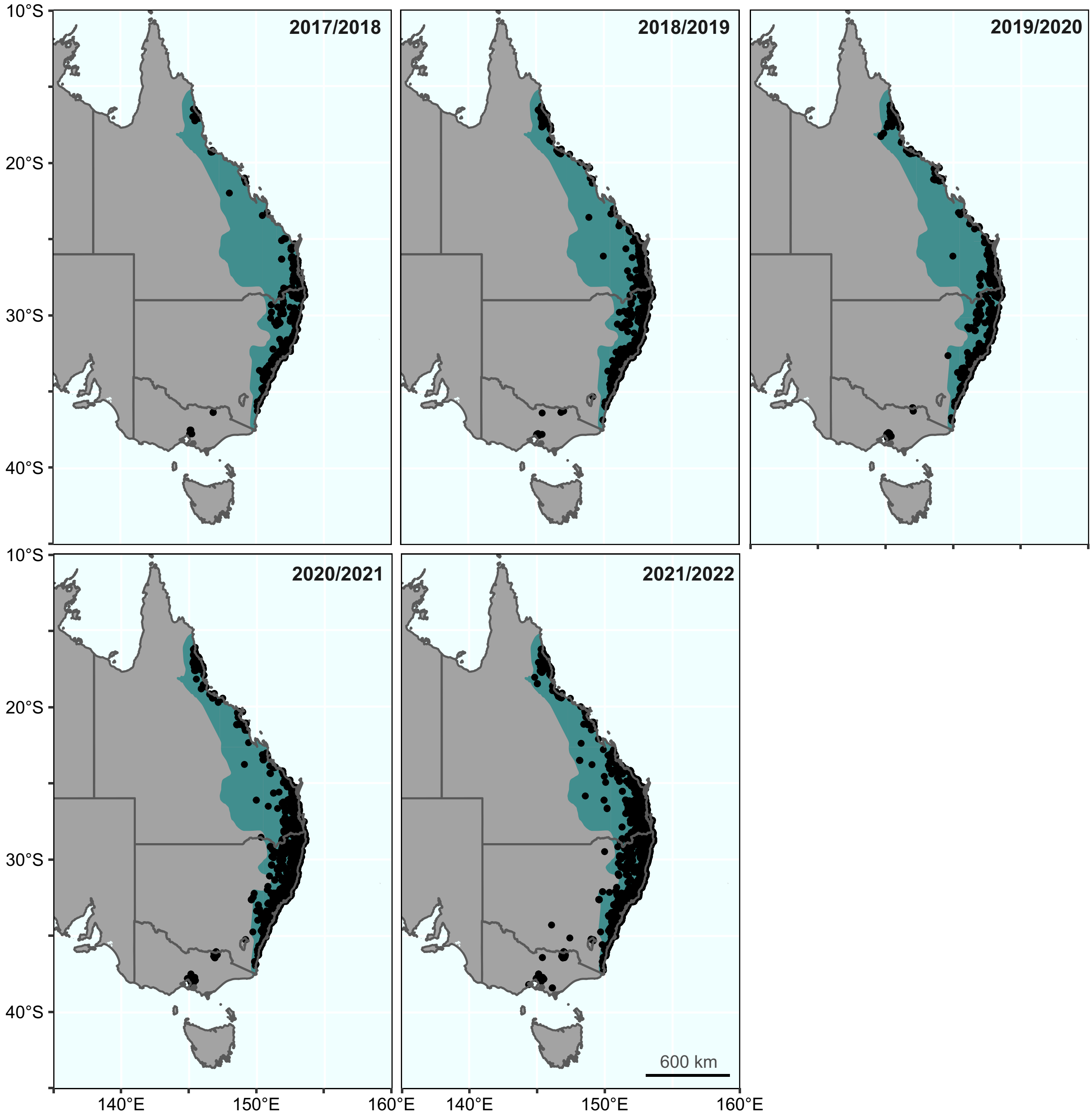

Fig. 1. Records of *Litoria fallax* (black circles) in Australia from the FrogID project over time. Each panel spans 1 July to 30 June and represents an entire breeding season for the species (except for 2017/2018, which spanned 10 November 2017 to 30 June 2018). The approximate native range of *Litoria fallax* is indicated in green.

unique users in the Albury area of NSW) and *Geocrinia victoriana* (one record from the Melbourne area of Victoria).

Discussion

L. fallax is increasingly being detected outside its presumed native range, and establishing populations that are not only self-sustaining, but appear to be spreading in geographic extent. The spread of *L. fallax* well outside its presumed native range has previously been documented (Gillespie and Clemann 2000; Bevelander 2014; Michael and Johnson 2016), but our data provide evidence of the further spread of known invasive populations and the potential establishment of previously undocumented populations as well as the

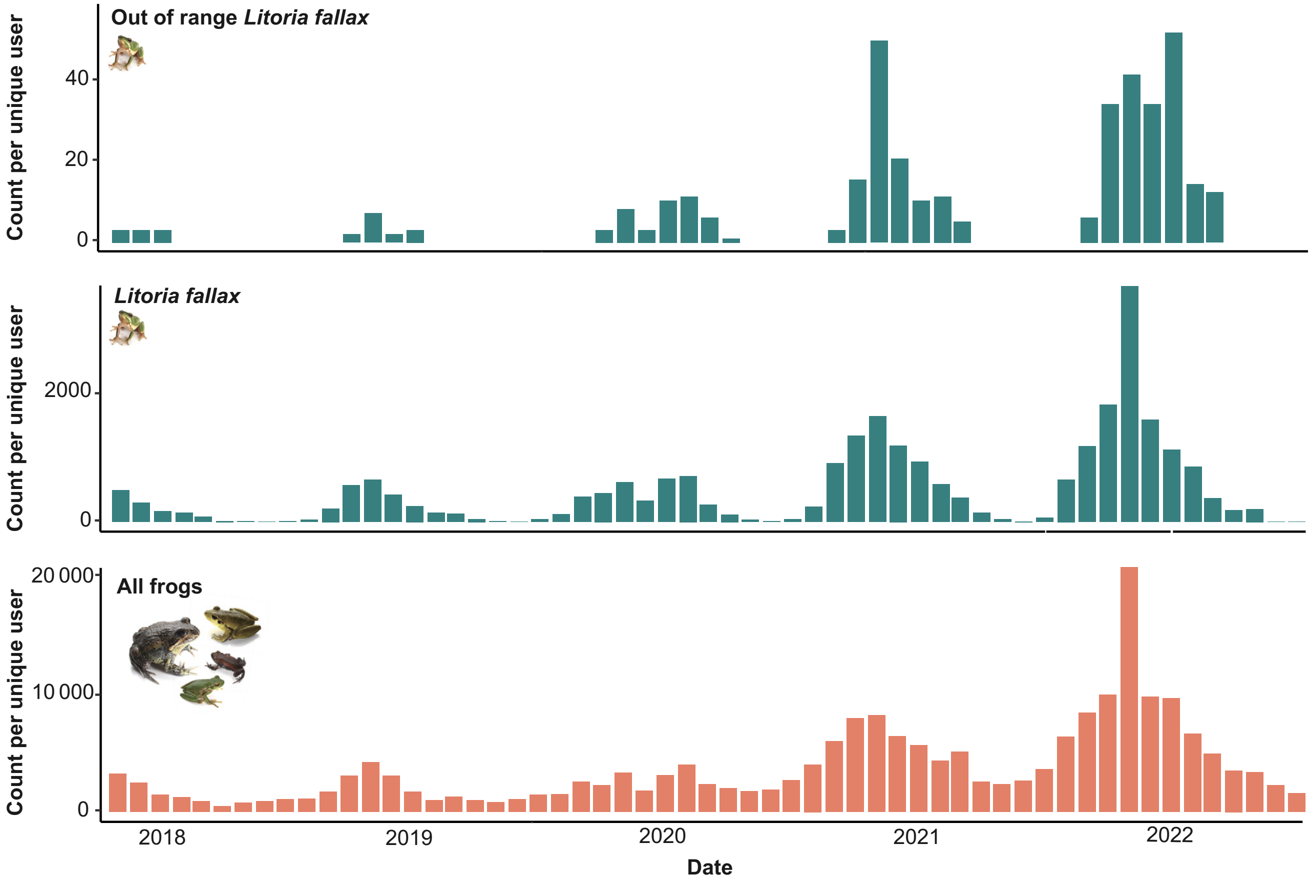

Fig. 2. Records per unique user over time from the FrogID project from 10 November 2017 to 30 June 2022 for out-of-range *Litoria fallax*, all *Litoria fallax*, and all frog species.

potential of citizen science to track this spread. However, increased sampling effort (i.e. the increased rate of FrogID submissions) and/or detectability (i.e. increased calling in wetter weather) in recent years may have contributed to the detection of these populations. It is possible that they were previously present but undetected.

Localities of *L. fallax* outside their native range were associated with areas of high human population density, which is likely the result of human-mediated transport, possibly via horticultural products and fresh fruit. Large numbers of native frogs are accidentally translocated around Australia, with over 7000 frogs per annum translocated into New South Wales alone in shipments of bananas, most of which were subsequently released into the local environment (O'Dwyer *et al.* 2000). Their small body size and habit of sheltering in vegetation, often well away from water, along with their relatively high tolerance of urbanisation (Liu *et al.* 2021) makes this species particularly susceptible to translocation outside of its native range.

The impacts of the invasive populations of *L. fallax* remain unknown. The introduction of amphibian species to novel environments can cause declines and genetic changes in native taxa (Riley *et al.* 2003), transmit disease or change disease dynamics in frog communities (Strauss *et al.* 2012), and have economic costs (impacts reviewed by Kraus 2015). Given that populations of *L. fallax* may have a high prevalence of the amphibian chytrid fungus (*Batrachochytrium dendrobatidis*) and not suffer population declines as a result (Kriger and Hero 2007), it is possible that introduced populations of *L. fallax* are acting as disease amplifiers or reservoir hosts (e.g. Rivera *et al.* 2019).

We report on potential novel species co-occurrences as a result of the invasive populations of *L. fallax*, one of which is the threatened Sloane's froglet (*Crinia sloanei*). Continued use of FrogID may allow a greater understanding of any impacts, particularly on this and other threatened native species in the new range of *L. fallax*, such as the southern bell frog (*Litoria raniformis*). Although fieldwork will be necessary to elucidate the impact of these novel co-occurrences, continued collection of FrogID data will assist in better understanding the impact of invasive frog species on local frog communities.

We demonstrate the utility of citizen science in detecting and monitoring an invasive frog species in Australia. Although we focus on a single species, the FrogID project is also detecting many other native species outside their historical

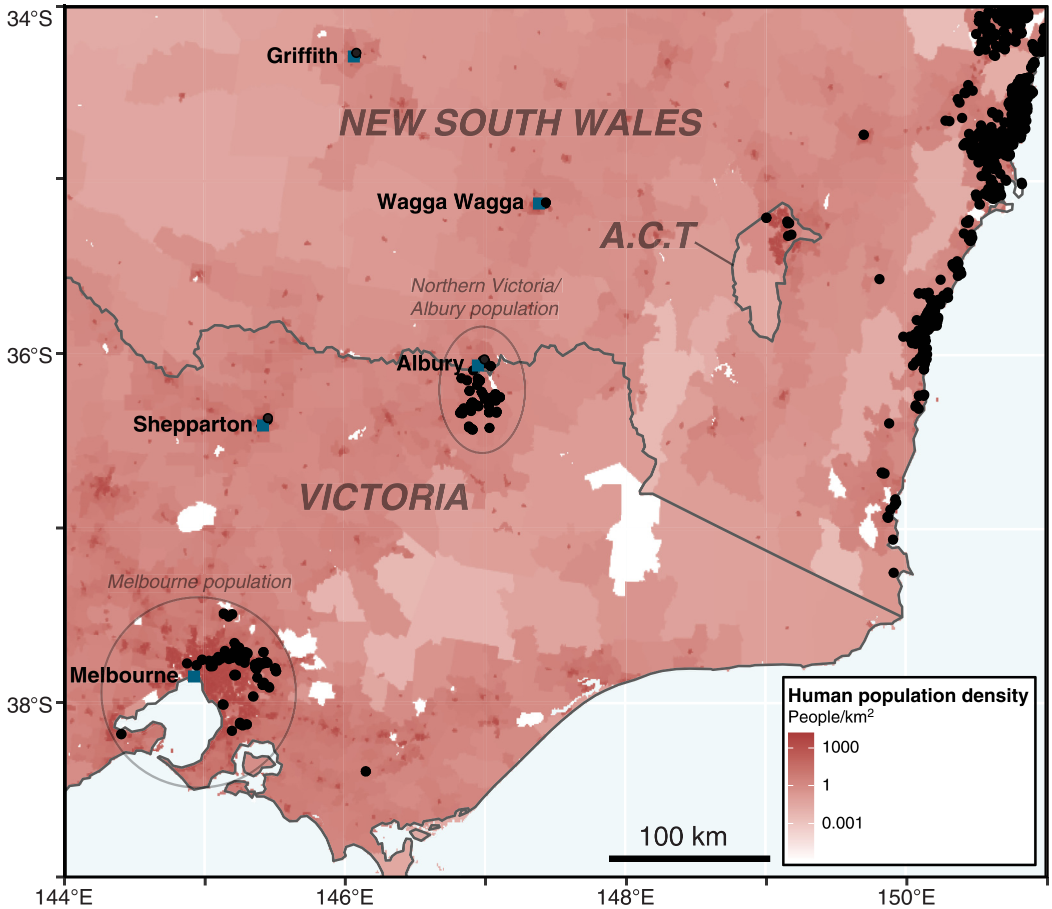

Fig. 3. Records of *Litoria fallax* (black circles) from the FrogID project in south-eastern Australia, from 10 November 2017 to 30 June 2022, and population density (number of persons per square kilometre; Gridded Population of the World v4).

ranges (Rowley *et al.* 2019). The project allows local communities to advance our understanding of invasive frog species, including the detection of calling individuals and their subsequent establishment and spread, for example for other invasive species in Australia such as the introduced cane toad (*Rhinella marina*) (Rowley *et al.* 2019). Community groups are already actively using FrogID to monitor sites and species over time (i.e. *Crinia sloanei* in the Albury area of NSW by the Sloane's Champions: Rowley *et al.* 2019) and communicating spatial and temporal priorities to participants could be used to further optimise data collection (Callaghan *et al.* 2023; Thompson *et al.* 2023), including for invasive species monitoring.

This study adds to the growing body of research confirming the ability of citizen science projects in collecting biodiversity records, including invasive species records, across large spatial scales (Giovos *et al.* 2019; Koen and Newton 2021). In addition, using citizen science to detect invasive species has benefits outside of the data themselves – citizen science has been demonstrated to engage people with science, increasing their awareness of environmental issues (Weber 2000; Jordan *et al.* 2011; Bonney *et al.* 2016).

Supplementary material

Supplementary material is available online.

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Data availability. The complete raw dataset is not fully available due to sensitivities in relation to locations of rare or threatened species and citizen scientist information (Rowley and Callaghan 2020). However, the data, with sensitive species' localities removed or buffered, are made available annually (Rowley and Callaghan 2020; data available through GBIF: https://doi.org/10.15468/wazqft and FrogID: https://www.frogid.net.au/explore). Maps of the current range of *L. fallax* in Australia are available as part of the Australian Frog Atlas (https://zenodo.org/record/6544829). A shapefile of the presumed historical (<1980) range of *L. fallax* is also available (https://zenodo.org/record/7933987).

Conflicts of interest. The authors declare no conflicts of interest.

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