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The Utility of Acoustic Citizen Science Data in Understanding Geographic Distributions of Morphologically Conserved Species: Frogs in the *Litoria phyllochroa* Species Group

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Abstract.—**Understanding species' geographic distributions is important for informing their conservation; however, an accurate understanding of where species occur is often precluded by a paucity of species records. For taxa that are difficult to visually distinguish at the species level, this problem can be compounded by misidentification of existing records. Citizen science has emerged as a potentially powerful tool to increase species observation data, but whether it can meaningfully add to our understanding of the distributions of species that are typically difficult to identify is contentious. We evaluated the volume, spread, and species identification accuracy of 3 yr of data from an acoustics-based citizen science dataset with a national aggregate of species observations collected over more than 140 yr (i.e., unvouchered human observations, photo-vouchered citizen science observations, and preserved specimens) to demonstrate the boundaries of five small, morphologically conserved frog species in eastern Australia. The national aggregate contained the most species records; however, the annual rate of record collection was much greater in the acoustic citizen science dataset. A high proportion of likely misidentified records were detected in the national aggregate dataset. Spatial bias differed between datasets, with acoustic citizen science data more biased toward highly populated areas. We demonstrate that citizen science can collect large volumes of spatially and taxonomically valid data which, especially when used in combination with more traditionally collected species records, can inform the detailed delineation of ranges in historically confusing groups of frog species.**

Our ability to understand and preserve biodiversity increases with both the quantity and quality of species presence data (Michelmore, 1994; Pergams and Nyberg, 2001; Peterson et al., 2002; Chapman, 2005). However, both are limited by the availability of resources to detect organisms and our ability to identify them, one or both of which can be difficult for many species (Gharrett et al., 2001; Goldberg et al., 2011; Gebhardt and Knebelsberger, 2015). In cases where species have low detectability, they can be missed during surveys, which can affect conservation planning (Gu and Swihart, 2004; Mazerolle et al., 2007; Cutajar and Rowley, 2020). In addition, many species are difficult to visually distinguish, making species identification problematic, even for well-surveyed areas or species with high detectability (Gharrett et al., 2001). This, too, can skew our understanding of where and how well species persist (Beerkircher et al., 2009; Shea et al., 2011; Costa et al., 2015) and therefore limit our ability to conserve them.

Citizen science has emerged as a promising new way to increase our understanding of patterns of biodiversity over space and time (Silvertown, 2009; McKinley et al., 2017; Callaghan et al., 2019), overcoming some of the logistical challenges (e.g., funding and scale) encountered with traditional surveys. The unprecedented volume of data produced by citizen scientists has the potential to revolutionize how we understand biodiversity (Spear et al. 2017); however, because of errors in species identification, its scientific utility for some taxa, particularly morphologically cryptic species, has been questioned (Stafford et al., 2010; Vantieghem et al., 2017; Abra et al., 2018). Thus, it is important to understand the taxonomic and spatial validity of citizen science–generated species observations relative to that of more-traditionally collected data, particularly for species that are difficult to distinguish from each other.

Frogs are amongst the most threatened groups of animals on the planet, and datasets can lack reliable frog species presence data because they are often difficult to detect (Goldberg et al., 2011; Renan et al., 2017; Cutajar and Rowley, 2020). In addition, once detected, many frog species are morphologically similar and can be very difficult to identify visually (Donnellan et al., 1999; Bickford et al., 2007; Rowley et al., 2015, 2019). As a result, this taxon is in urgent need of accurate, spatially comprehensive distribution data. Acoustic, rather than visual, identifications can be much more reliable for frogs (Rowley et al., 2019), but the majority of vouchered observations in frog datasets globally tend to have photographic rather than acoustic vouchers (but see Rowley et al., 2020). An added benefit of acoustic data is that it is typically less invasive to collect than photographing frogs (Rowley et al., 2019).

We used data obtained from the citizen science project FrogID (Rowley et al., 2019) to examine whether acoustic citizen science data could be useful in determining the distributions of a poorly known group of frogs. We chose the *Litoria phyllochroa* species group (and follow its nomenclature in AmphibiaWeb [2022]). This group consists of six small (<5 cm body length), green tree frogs distributed in southeastern Australia that are highly morphologically similar: *L. barringtonensis*, *L. kroombitensis*, *L. nudidigitus*, *L. pearsoniana*, *L. phyllochroa*, and *L. piperata* (Donnellan et al., 1999; Hoskin et al., 2013). Morphological conservatism in the group has led to a history of misidentifications, resulting in difficulties determining the actual boundaries of each species' range using existing datasets (McDonald and Davies, 1990; Donnellan et al., 1999; Hoskin et al., 2013). This is particularly problematic, as several species within the group are of high conservation concern. *Litoria piperata* is missing, feared extinct (Hero et al., 2004), *L. kroombitensis* is Critically Endangered (Australian Government, 2020), and other species in the group have experienced marked declines (Gillespie and Hines, 1999; Parris, 2001). Augmenting existing datasets of species in groups like this with high quality citizen

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science observations could make the historically difficult task of delineating their distributions more feasible.

In this study we evaluated the volume, spread, and accuracy of identifications of existing survey data and acoustically vouchered observations from citizen science for the *L. phyllochroa* group. We also vetted data from both sources to produce a combined dataset of spatially and taxonomically valid observations of the group, which we used to inform and map the ranges of each species in detail to assist in conservation planning.

Materials and Methods

Citizen Science.—To obtain citizen science data, we retrieved records of *Litoria barringtonensis*, *L. kroombitensis*, *L. nudidigitus*, *L. pearsoniana*, and *L. phyllochroa* from the FrogID project. FrogID, led by the Australian Museum, is based upon a smartphone application that allows users to record calling frogs in Australia and submit the recordings for identification (Rowley et al., 2019). The time, date, and geographic location (latitude, longitude, and an estimate of precision of geographic location) are automatically added by the app at the time of recording (Rowley et al., 2019), reducing the opportunity for errors in the dataset. All recordings submitted are verified by one or more experts (Rowley et al., 2019), which can greatly reduce the rate of taxonomic error (ElQadi et al., 2017). Information on temperature and the frog's body size are not included with submissions. Although capable of influencing some (particularly temporal) call parameters, these variables are not known to affect frogs' call structure or characteristics to the extent that they would be confused with another species (Koehler et al. 2017). For full details on acoustic identification see Rowley et al. (2019). Acoustic identification is ideal for many frog groups that may be difficult to identify from photographs (Rowley et al., 2019). Species in the *L. phyllochroa* group and known to be sympatric have distinct calls (Anstis, 2017). We downloaded FrogID records on 20 November 2020, including all records of the study species submitted to the project and verified since its launch on 10 November 2017. We excluded all submissions that had a geolocation accuracy value >3 km because these represent instances in which the app was unsure of the location (Rowley et al., 2019).

National Aggregate Data.—To obtain existing data, we downloaded all records of *Litoria barringtonensis*, *L. kroombitensis*, *L. nudidigitus*, *L. pearsoniana*, and *L. phyllochroa* labeled as spatially valid from the Atlas of Living Australia (ALA), also on 20 November 2020. The ALA (2020) is a national aggregate of biodiversity data collected by universities, museums, government institutions, and other sources and contains records of these species dating back to 1877. We did not include records of *Litoria piperata* because it is only known from the type series and is possibly extinct (Hero et al., 2004), preventing comparisons between datasets for that species. As with the FrogID dataset, we removed all records with a value for spatial precision uncertainty >3 km. We retained records that did not have a spatial precision value, although we acknowledge that many of these are likely to have a low degree of spatial accuracy or precision. We also removed FrogID records from the ALA dataset to avoid duplicate data, but retained all (82) records from the citizen science projects QuestaGame (QuestaGame, 2020), Flickr (Flickr, 2022), NatureMapr (NatureMapr, 2022), ALA's species sightings function, and BowerBird (Walker, 2014)—all observations based on photographic, rather than acoustic, identification by users. While the ALA includes records from the large, global citizen project iNaturalist (iNaturalist, 2022), there were no iNaturalist records of these species in the dataset.

Comparisons.—We compared the total volume of records in the FrogID and ALA datasets. We also compared their average annual rate of record collection, both for the full datasets and subsets from 2018–2019—the only full calendar years in which both projects collected data. To identify any biases in each dataset, we plotted them separately on maps and visually assessed patterns in the spread of records, both geographic and taxonomic. We also used these plotted data to determine the validity of identifications, checking for species records that, based on their locality, are likely to have been misidentified.

To produce a combined dataset of taxonomically and geographically reliable data, we projected and visualized locality data from both FrogID and the national aggregate against Environmental Systems Research Institute (ESRI; Redlands, California) World Topographic and World Imagery basemaps. We kept all FrogID records because they have been expert-validated, could be reverified, and have a known and consistent measure of geographic certainty. We removed ALA records that were within areas where more than one species in the *Litoria phyllochroa* group likely occur or outside the general range of the species to which they were assigned (and are therefore likely to have been misidentified). While some of these records have associated museum voucher specimens, time-consuming morphometric and/or molecular analyses would be required to validated their identifications. Other records had only associated photographs (from which it is difficult to identify species in this group) or no voucher at all. While the removal of these records precludes their contributing to species' range extensions, we consider this a benefit; taxonomic assignment of observations that constitute range extensions should be verified before maps are updated. We also removed ALA records deemed spatially or taxonomically suspect because they were considerably isolated from other records and either pre-1990 or $\geq$3 km from suitable breeding habitat for the species.

Species' Ranges and Conservation.—To improve our understanding of the *Litoria phyllochroa* species group's distribution and inform its conservation, we used the combined dataset to produce detailed range maps of each of the study species for which there were data from both the national aggregate and FrogID. We carried out all spatial analyses and mapping in ArcMap 10.2.2 (ESRI, 2014) and mapped species' ranges using the International Union for Conservation of Nature (IUCN) empty species polygon shapefile template (IUCN Red List, 2020) for easy assimilation of spatial data into an updated Red List of Threatened Species assessment.

We estimated the elevation parameters of species' ranges by using the Raster Calculator tool in ArcMap with the IUCN elevation raster (IUCN Red List, 2020) as input. We selected elevation ranges that encompass all records in the combined dataset for the species being mapped. We estimated species' boundaries by eye using the upper and lower limits of the selected elevation range and the presence vs. absence of species records in relation to vegetation cover (using satellite imagery) and potential biogeographic barriers (large rivers and steep escarpments).

We hand-drew rough polygons along the estimated boundaries and then used the Clip Raster tool to reduce the global IUCN elevation raster to a smaller rectangle around the polygons. We then ran the Select by Attributes tool on the new raster output to select those areas within the desired

TABLE 1. Types of occurrence data contained in the national aggregate (Atlas of Living Australia, 2020) dataset used in this study for each extant species in the *Litoria phyllochroa* species group.

Species	Human observation	Human observation and specimens	Photo-based citizen science	Museum collections	All data types
L. barringtonensis	0	0	5	115	120
L. kroombitensis	0	0	1	38	39
L. nudidigitus	612	331	29	228	1,200
L. pearsoniana	2,237	109	9	475	2,830
L. phyllochroa	2,970	0	38	448	3,456
All species	5,819	440	82	1,304	7,645

elevation range and subsequently used the Raster to Polygon tool to convert that selection into an editable polygon. We clipped the output polygon to the hand-drawn polygons using the Clip tool, used the Dissolve tool to transform the output from a grid to a solid polygon, and used the Smooth Polygon tool to remove gridded edges. Smoothing tolerance was 2 km. The resulting polygons contained many isolated sections that were considered too small to support populations of the study species as well as holes likely too small to realistically exclude them. These were artifacts of converting a raster with specified elevation parameters to a polygon over a topographically complex landscape. We "cleaned up" the polygons, removing all holes and noncontiguous parts with an area <640 m^2 using the Eliminate Polygon Part tool, leaving a still highly detailed approximation of the species' ranges. We then copied the output polygon to the IUCN shapefile.

We added an additional clipping step to polygons for *Litoria barringtonensis* and *L. pearsoniana* prior to adding to the IUCN shapefile. All records of these species projected within closed forest according to satellite imagery. For this reason, we downloaded the 2018 Forests of Australia GeoTIFF map (Australian Government, 2018), ran it through the Raster to Polygon tool, and used the Select by Attributes tool to select and remove ground cover categories unlikely to support populations of either species. Forest types that we removed were *Acacia*, *Callitris*, *Casuarina*, mangrove, *Melaleuca*, commercial forest, and nonforest, with which these species are not associated (Anstis 2017). Forest types that we kept were all eucalypt types, rainforest, other native forest, and other forest. We then clipped the outputs from the Eliminate Polygon Part tool to the amended Forests of Australia polygon. We acknowledge that this process does not take into account past land cover; however, the purpose of these maps is to demonstrate the species' contemporary distributions, and thus historically populated areas that no longer support the species are intentionally omitted.

Once each species' range was mapped, we calculated their extent of occurrence (EOO) using the IUCN EOO calculator tool (IUCN Red List, 2020) with species map shapefiles as input. The EOO is defined as a minimum convex polygon that encompasses the entire distribution of the species and is important for assessing species' conservation status according to IUCN Red List categories and criteria.

RESULTS

The national aggregate dataset contained 7,645 records of the target species: *Litoria barringtonensis* (120), *L. kroombitensis* (39), *L. nudidigitus* (1,200), *L. pearsoniana* (2,830), and *L. phyllochroa* (3,456) after the removal of 2,119 records with spatial precision uncertainty >3 km. Data sources in the national aggregate varied, as did the type of data they contained (Table 1). Most records were human observations without associated photo, call, or specimen vouchers. The next largest contributing data sources were museum collections, then scientific studies that used both human observations and vouchered specimens, with photograph-based citizen science projects contributing just 82 records. The FrogID dataset contained 2,919 validated records of the target species (all with acoustic vouchers) after the removal of 352 records with spatial precision uncertainty >3 km: *Litoria barringtonensis* (310), *L. nudidigitus* (669), *L. pearsoniana* (89), and *L. phyllochroa* (1,851). There were no FrogID records for *L. kroombitensis*.

The total accumulation rates of *Litoria phyllochroa* group records were 55.1/yr for the national aggregate and 966.6/yr for FrogID. When we considered only records from 2018–2019, annual accumulation rates were 92.5 for the national aggregate and 586 for FrogID. In contrast to FrogID data, the national aggregate dataset included a high percentage (31.0%) of records that fell considerably outside of the general known range of each species and are likely to be erroneous, which we omitted from the combined dataset used to inform mapping the species' distributions (Fig. 1A). The majority of these likely spatially inaccurate records occurred in or near the range of other species in the group and are likely because of misidentifications within the species group, or, with 68% of these records predating the current taxonomy, identifications being made prior to taxonomic splits and not being reassigned (e.g., frogs identified as *Litoria phyllochroa* prior to the formal recognition of other species in the group).

In terms of spread and bias, national aggregate records of the species group were relatively evenly abundant along the entire band that forms the ranges of *Litoria barringtonensis*, *L. nudidigitus*, *L. pearsoniana*, and *L. phyllochroa* (Fig. 1A). Among FrogID records; however, there was a marked south-central bias, with a relatively high density of records along an approximately 315-km band centered on the more populated Sydney and Illawarra Regions of New South Wales (Fig. 1B). This geographic bias also leads to a taxonomic bias, with many more records of *L. nudidigitus* and *L. phyllochroa* than the more northern *L. barringtonensis* and *L. pearsoniana* in the FrogID dataset (Fig. 1B). *Litoria kroombitensis*, which occurs in a small, remote area, was not represented in the FrogID dataset.

The estimated EOO for *Litoria barringtonensis* was 51,934 km^2, 44,743 km^2 for *L. pearsoniana*, 82,336 km^2 for *L. phyllochroa*, and 119,233 km^2 for *L. nudidigitus*. The mapped ranges of each species are presented in Figure 2, and a detailed description of their distributions can be found in the Supplementary Data online. We did not create a map or calculate the EOO for *L. kroombitensis* because it is a range-restricted species that has a well-defined distribution, and there were no FrogID data to further inform its boundaries.

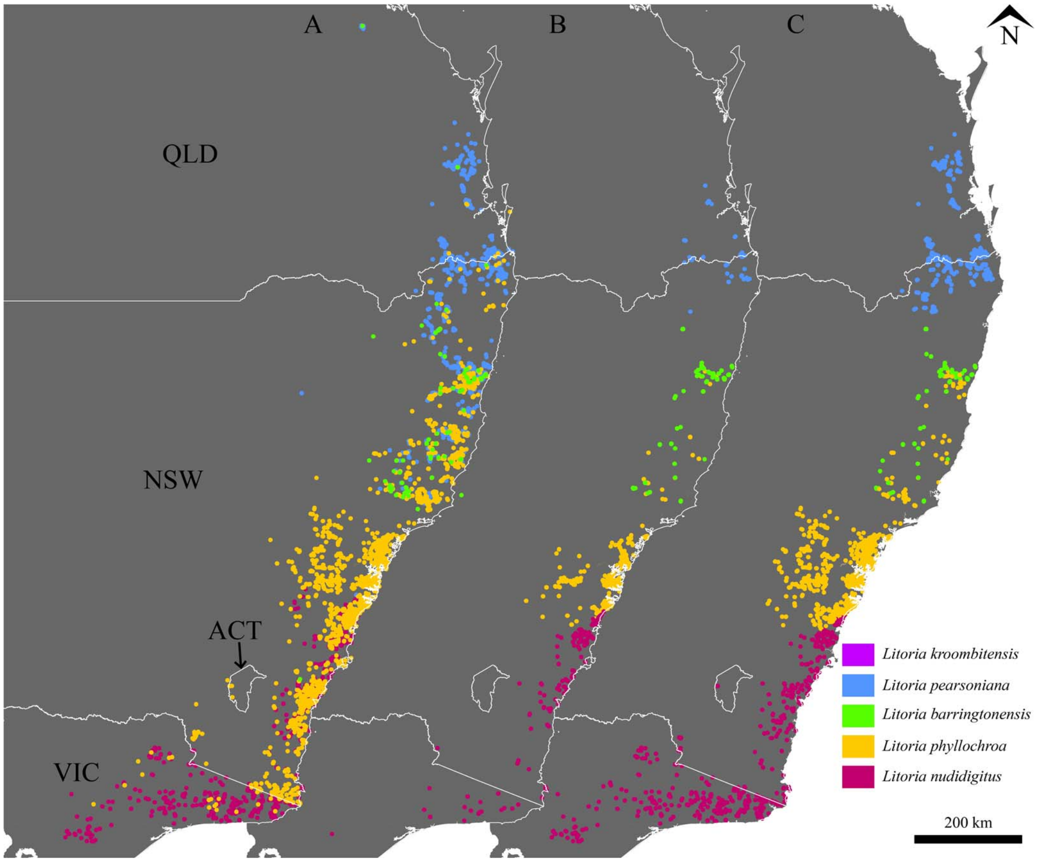

FIG. 1. Map of eastern Australia including the states of Queensland (QLD), New South Wales (NSW), Australian Capital Territory (ACT), and Victoria (VIC) showing records of known extant species of the *Litoria phyllochroa* group from the Atlas of Living Australia (ALA; A), FrogID (B), and a combined dataset containing both FrogID records and those deemed spatially and taxonomically reliable from ALA (C).

DISCUSSION

In a relatively short time, citizen scientists have contributed a great volume of spatially and taxonomically accurate records of a morphologically conserved group of frogs to the FrogID project. The ability of citizen science projects to rapidly collect biodiversity data is well known, particularly for conspicuous groups such as birds (Sullivan et al., 2009) and even medium to large herpetofauna (Spear et al., 2017). However, we found that citizen science was also capable of rapidly collecting records of a small-bodied, morphologically conserved frog group. Indeed, the FrogID project collected records of the *Litoria phyllochroa* species group at an annual rate over 17 times higher than the national aggregate. If this rate continues, the number of existing records of the group—a dataset of over 143 yr—will be doubled by FrogID data in approximately 5 yr. However, given the increasing rate of FrogID records overall, with >18% more submissions to FrogID in its second full year than in its first, and >97% more in its third full year than its second, and similarly exponential growth seen in other citizen science projects (Sullivan et al., 2014), this is likely a vast underestimate.

In addition to the sheer volume of species observations submitted yearly, FrogID data are useful in informing frog species' distributions because of the particular data the project was designed to include with each observation. Most observations in the national aggregate are based only on the observer's initial identification in situ and cannot be verified by associated vouchers of any kind. A smaller proportion (less than a quarter) have associated voucher specimens or photographs. However, verifying identifications of specimens of sympatric, morphologically cryptic species can require time-consuming morphometric and/or molecular analyses and can be impossible for photographic vouchers. Thus, data collected prior to taxonomic revision, or near the ranges of morphologically similar species, may be very difficult to accurately identify to species. On the other hand, all FrogID records have an associated acoustic voucher, which can be more useful than photographs for identifying species in morphologically conserved species groups and can be easily reidentified (Rowley et al., 2019). These records also have geographic coordinates with an estimate of precision generated in a consistent way, are expert-validated (Rowley et al., 2019), and the dataset is rechecked for anomalies prior to release.

While citizen science is capable of producing an unprecedented volume of spatially and taxonomically valid species observations, it complements rather than replaces traditional scientific surveys. The combined, cleaned dataset of 7,011 records and range maps resulted in a more accurate understanding of the distributions of species in the *Litoria phyllochroa* group. As with scientific surveys, there are spatial, temporal, and taxonomic biases in citizen science data (Rowley and Callaghan, 2020; Rowley et al., 2019). Not surprisingly, we found a strong bias in the location of FrogID data toward populated sites, resulting in a bias toward south-central locations near the Sydney and Illawarra Regions of New South Wales as well as a relative lack of records in the northern portion of the species group's range. The northernmost species of the group, *Litoria kroombitensis*, is known only from a small, remote area and was absent from the FrogID dataset.

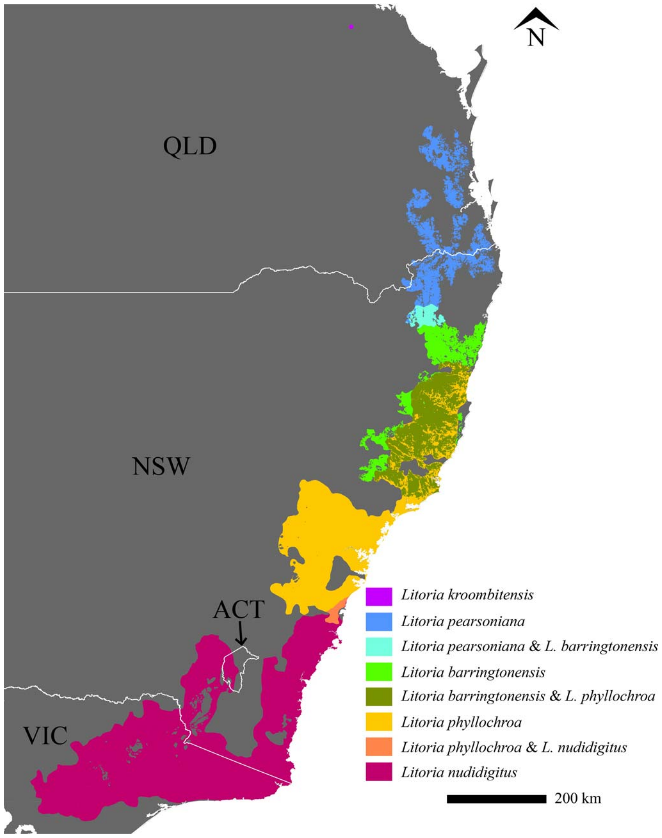

FIG. 2. Map of eastern Australia including the states of Queensland (QLD), New South Wales (NSW), Australian Capital Territory (ACT), and Victoria (VIC) showing the mapped ranges of known extant species in the *Litoria phyllochroa* group as informed by data from FrogID and the Atlas of Living Australia, including areas where species' ranges may overlap.

This study provides a considerably greater understanding of the likely distributions of frogs in the *Litoria phyllochroa* group. FrogID records from Budderoo National Park and Barren Grounds Nature Reserve provided an approximately 50-km extension in the previously reported southern range of *Litoria phyllochroa*, which was thought to stop within the Sydney Region (Gillespie and Hines, 1999; Anstis, 2017) and upper reaches of the Wollondilly River (Donnellan et al.,1999). We also increase the known areas of sympatry between species, previously identified as a priority for this group (Hoskin et al., 2013).

Previously, *Litoria phyllochroa* and *L. nudidigitus* were thought to be allopatric (Anstis, 2017). However, data from FrogID reveal a surprisingly large area of sympatry between the two species in the approximately 60 km between Stanwell Tops and northern Budderoo National Park. Similarly, *Litoria pearsoniana* and *L. barringtonensis* are thought allopatric (Anstis, 2017), but high-altitude mesic forest is contiguous between the two species' border area of Gibraltar Range and Washpool National Parks, and the northernmost records of *L. barringtonensis* are only approximately 30 km from the southernmost *L. pearsoniana* records in our cleaned dataset. With this proximity and similarities in their habitat (see Methods and Supplementary Data online), we highlight an area of potential sympatry that serves as a guide for future data collection in this sparsely surveyed area.

Our study highlights the value of citizen science data, particularly when combined with more-traditional scientific data, in rapidly collecting spatially and taxonomically accurate biodiversity data across a range of taxa—even species that are small-bodied, morphologically conserved, and behaviorally cryptic. This is the first study to provide a detailed analysis of the distributions of the *Litoria phyllochroa* group. Shapefiles of each species range map from this study are being made freely available in the Australian Frog Atlas (Cutajar et al., 2022). We hope that this information will be used to inform research, conservation, and land use–management at all levels.

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Supplementary Data

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