Biological Conservation 267 (2022) 109470

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

COVID restrictions impact wildlife monitoring in Australia

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ARTICLE INFO

Keywords:
Wildlife monitoring
COVID-19
Citizen science
Conservation
echidna
Protected area
Remoteness
ARIA+
Australia

ABSTRACT

The global COVID-19 pandemic has imposed restrictions on people's movement, work and access to places at multiple international, national and sub-national scales. We need a better understanding of how the varied restrictions have impacted wildlife monitoring as gaps in data continuity caused by these disruptions may limit future data use and analysis.

To assess the effect of different levels of COVID-19 restrictions on both citizen science and traditional wildlife monitoring, we analyse observational records of a widespread and iconic monotreme, the Australian short-beaked echidna (*Tachyglossus aculeatus*), in three states of Australia. We compare citizen science to observations from biodiversity data repositories across the three states by analysing numbers of observations, coverage in protected areas, and geographic distribution using an index of remoteness and accessibility. We analyse the effect of restriction levels by comparing these data from each restriction level in 2020 with corresponding periods in 2018–2019.

Our results indicate that stricter and longer restrictions reduced numbers of scientific observations while citizen science showed few effects, though there is much variation due to differences in restriction levels in each state. Geographic distribution and coverage of protected and non-protected areas were also reduced for scientific monitoring while citizen science observations were little affected.

This study shows that citizen science can continue to record accurate and widely distributed species observational data, despite pandemic restrictions, and thus demonstrates the potential value of citizen science to other researchers who require reliable data during periods of disruption.

1. Introduction

The World Health Organization officially declared the novel coronavirus (2019-nCoV or COVID-19) a public health emergency of international concern on 30 January 2020 (World Health Organization, 2020a) and then declared a pandemic on 11 March 2020 (World Health Organization, 2020b). The impacts of the virus on global activity over the last year have been enormous and though the rapid development of vaccines have brought significant change and hope that it can be brought under control, the outlook for the future remains somewhat uncertain. Governmental policy responses around the world have varied greatly and change over time (Hale et al., 2021a) with accompanying variations in outcomes. Typical guidance for controlling the virus spread has included actions such as increased handwashing, personal distancing, tracking locations and contacts, wearing personal protective equipment, restricting personal movements and working from home. While these policies have been aimed primarily at human health, they have also affected our environment, biodiversity and conservation actions.

In Australia, the pandemic response has involved both the federal and state governments, with the Australian government declaring a Human Biosecurity Emergency on 18 March 2020 (Commonwealth Parliament of Australia, 2020) and subsequently closing the international borders, while leaving the states responsible for most other aspects of the pandemic response. This resulted in significant variations in state actions with restrictions being applied of varying duration and severity. At state level, South Australia (SA) was the least affected, Victoria (Vic) had long periods of severe restrictions due to COVID

Abbreviations: ARIA+, Accessibility/Remoteness Index of Australia.

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https://doi.org/10.1016/j.biocon.2022.109470
Received 1 September 2021; Received in revised form 16 January 2022; Accepted 21 January 2022
Available online 4 February 2022

outbreaks, while New South Wales (NSW) was less officially restricted but dealt with some COVID spread.

The variations between states and over time resulted in varying degrees of travel and work limitations, with stay-at-home orders the highest degree of restriction. Non-essential travel and work were advised against and people were recommended to work or study from home, where possible. Many government departments, education and research organisations also restricted fieldwork and outreach activities and, as public safety could not be assured, parks and protected areas were often closed (Parliament of Australia, 2020).

These pandemic-related restrictions on people have produced the "anthropause" (Rutz et al., 2020), which has had a variety of impacts on biodiversity conservation research and practice. There have been positive impacts such as fewer disturbances to fauna and flora (Montgomery et al., 2020), reductions in wildlife roadkill (Bíl et al., 2021; Driessen, 2021; Manenti et al., 2020), improved legislation against wildlife consumption and trade (Koh et al., 2021) and changed activity patterns for some species (China et al., 2021; Manenti et al., 2020). Negative aspects include large increases in environmental pollution from personal protective equipment (PPE) such as masks and gloves (Hiemstra et al., 2021; Zhang et al., 2021), disruptions to field and lab work (Evans et al., 2020), reduced environmental monitoring and protection (Evans et al., 2020; IUCN, 2020), interruptions to some management processes such as invasive species control programs (Manenti et al., 2020; Miller-Rushing et al., 2021), changes to distribution and abundance of some species (Gilby et al., 2021), along with funding cuts curtailing existing projects (Rose et al., 2020).

Corlett et al. (2020) recently posed the question: what consequences will restrictions on field and lab work during the pandemic have for the species and ecosystems we are studying, monitoring, and protecting? Disruptions to scientific wildlife surveys and research caused by these restrictions may result in data gaps or other changes to long-term data collections which could impact later scientific analysis and affect our understanding of wildlife populations and biodiversity dynamics (Basile et al., 2021; Evans et al., 2020). As any successful conservation project requires local community cooperation and involvement (Koh and Sodhi, 2010), we extend this question by examining how pandemic restrictions on the general public disrupt biodiversity observations recorded by citizen scientists and then compare these to how observational data from scientific sources have been affected.

Citizen Science (CS) is increasingly used to augment scientific biodiversity monitoring by broadening the spatial and temporal coverage of species observations (Bonney et al., 2009; Dickinson et al., 2010) and thereby enabling research that would be very difficult using formal scientific methods. In some parts of the world, CS projects have been severely impacted by COVID restrictions. Ad-hoc list submissions to the South African Bird Atlas project showed an approximate 50% decline during a strict lockdown in April 2020 while lists following a defined protocol declined 70% (Rose et al., 2020). In Japan, the CS-based City Nature Challenge recorded a greater than 60% decrease in participants and observations, also in April 2020 (Kishimoto and Kobori, 2021). There were mixed results in other projects, with CS bird observations from iNaturalist increasing in urban areas but decreasing in rural areas in Italy and Spain (Basile et al., 2021).

Although CS is often seen as spatially biased (Mair and Ruete, 2016; Silvertown et al., 2013), with CS participants recording observations in known and local locations (Dickinson et al., 2010), could this be an advantage during periods of restricted movements, so that such monitoring can still occur while other scientific fieldwork is impossible or severely reduced? Do movement restrictions affect CS observation numbers or where they are made? For example, are there changes to monitoring in protected areas (PA), which are considered vital for biodiversity conservation (Brooks et al., 2004; Buckley et al., 2008; Worboys et al., 2015) and often dominate traditional conservation efforts (Joppa and Pfaff, 2011)? In some countries, reduced income and fluctuating visitation patterns, particularly in tourism-dependent economies, resulted in reduced management activities such as species monitoring and protection, along with a range of other impacts (Hockings et al., 2020; Miller-Rushing et al., 2021). Does reduced access to PA also affect CS observations?

In this paper, we explore the effects of pandemic-related restrictions on wildlife monitoring by analysing observations of a widely distributed but cryptic monotreme in Australia, the short-beaked echidna (*Tachyglossus aculeatus*). This iconic species is found throughout Australia in a wide variety of habitats (Brice et al., 2002; Grigg et al., 1989; Rismiller, 1999) but is usually difficult to locate in the wild (Rismiller and McKelvey, 2003). Echidnas are opportunistic foragers, feeding on a wide variety of invertebrates, including ants and termites (Abensperg-Traun, 1994; Abensperg-Traun and Steven, 1997; Sprent et al., 2016). Current population estimates range from 5 to 50 million, indicating the uncertainty around the abundance of this species (Aplin et al., 2015).

Previous research (Stenhouse et al., 2021) showed that large numbers of observations of this species have been recorded through both CS and scientific sources, such as government departments and research organisations, and that these were well distributed geographically over long periods. There were some differences between CS and scientific observations (SO), especially related to relative contributions in PA and very remote areas, while CS has provided greater numbers of observations in recent years.

A successful CS program gathering data on short-beaked echidna in Australia is the Echidna Conservation Science Initiative (echidnaCSI). This has collected over 10,000 observations since September 2017 from around Australia using both a bespoke mobile app and a web portal (Perry et al., 2022; Stenhouse et al., 2021). Using a mobile app provided several benefits including standardised responses and accurate data through utilising built-in sensors of mobile phones to automatically record location and time. The app uses the national biodiversity repository at the Atlas of Living Australia (https://www.ala.org.au) as the data repository, which enabled rapid upload and sharing. This had additional benefits of making the project easily discoverable and providing interoperable and reusable data according to the FAIR principles (Wilkinson et al., 2016). Widespread participation from around Australia has provided a large source of CS observations of echidna for augmenting scientific data from traditional sources.

We investigate how data from echidnaCSI compare to data recorded in three state-based biodiversity repositories. We look at how pandemic-related restrictions vary by Australian state and explore the effects of these restrictions on spatial and temporal aspects of echidna observations. We analyse for differences in restriction level effects on the location of CS and SO by comparing observation locations in different classes of protected areas, reserves and parks, as well as an index of remoteness and accessibility. We hypothesise that: 1. CS observations were reduced by COVID-19 restrictions, especially in states where restrictions were harsher; 2. SO were also reduced by pandemic restrictions due to limitations on fieldwork activity; 3. Observations in PA were reduced by COVID-19 restrictions, as many PA were closed; and 4. The geographic remoteness of observations was reduced by COVID-19 restrictions.

2. Materials and methods

2.1. Data summary

For this study, we have selected all echidna observations submitted to the echidnaCSI project between 01/01/2018 and 31/12/2020. These observations contain accurate location information (latitude and longitude), accurate date and time, a photo, along with standardised responses to a small range of questions. We also downloaded all echidna records from the state governmental biodiversity data repositories for NSW (01/03/2021), Victoria (01/03/2021) and South Australia (04/03/2021) (Table S1). We selected these three states for analysis as they contain large numbers of echidna observations and had substantial differences in state pandemic responses. We selected state data from 01/01/2018 to 31/12/2020 to compare to the data gathered in the echidnaCSI project for the same period. Some records were removed as a result of data cleaning. Further details on data sources and filtering of these records for use in this study are provided in Supplementary Information (S1.1 Data cleaning). For the purposes of this paper, the remaining data were classified as scientific observations (SO) as they have been curated and assessed as acceptable for state repositories.

COVID restrictions were collated from Australian federal and state government websites that provided official COVID-19 advice during 2020. From these announcements, information on restrictions was classified according to the criteria in Table 1. We included restrictions that were applied over large areas and not those that applied at fine geographic scale, such as suburb level. The resulting periods of restrictions for each state are in Table S2.

To analyse how coverage within PA was affected by COVID restrictions, we used the Collaborative Australian Protected Areas Database (CAPAD) 2018 (Australian Government Department of Agriculture, Water and the Environment, 2019) which provides spatial and textual information about national, state and private PA for Australia. This version includes 12,052 terrestrial PAs covering 151,787,501 ha (19.74%) of the Australian landmass (Department of Agriculture, Water and the Environment, 2019). For classification of PA, we used the IUCN categories (Table S3) which are an internationally recognised standard and classify PA according to their management objectives (Dudley et al., 2013). We used the QGIS vector analysis tools (QGIS Development QGIS Development Team, 2020) to determine if observations were contained in PA.

To analyse how the geographic distributions of observation locations were affected by COVID restrictions, we used the Accessibility and Remoteness Index of Australia 2016 Plus (ARIA+) (Hugo Hugo Centre, 2018). ARIA+ is a continuously varying index of relative remoteness for Australian locations with values ranging from 0 (high accessibility) to 15 (high remoteness). A nationally recognised measure that has been used to derive the Australian Bureau of Statistics (ABS) Remoteness Area classification for Australia since 2001 (Taylor and Lange, 2016), the 1 km^2 ARIA+ 2016 grid was used to assign ARIA+ scores to all of our observations.

2.2. Analysis

We classified the origin of data from the state systems as CS or SO based on several attributes (see Supplementary information S1.1 for details). Each state records observations differently, as they originate from varying sources such as state government departments, non-governmental organisations and other groups and individuals. Apart from the filtering to remove records as described in S1.1, for the purposes of this analysis, we classify the remainder as scientific observations as they have been curated and accepted into the state repositories. This resulted in three groups of data for analysis: echidnaCSI (CS), which is all of CS origin; State-CS data and SO data. As there were only two records identified as State-CS data for 2020, this group was excluded from further analysis. Using the COVID restrictions data, we classified each observation into one of five levels according to state-level restrictions and the observation date. To determine if these restrictions resulted in differences between the COVID-affected 2020 and previous years, and to account for possible seasonal variations, we identified control periods for observations from 2018 and 2019 that corresponded to the restricted periods in 2020. To test if COVID restriction levels had an effect on observation counts between 2020 and prior years grouped by data source and state, we used Pearson's chi-squared test of independence with Cramer's V for effect size (Cohen, 1988; Howell, 2011).

To test for possible effects of COVID restrictions on observations in PA categories, we used Pearson's chi-squared test of independence with Cramer's V for effect size to test if there were differences in observation counts in 2020 between restriction levels for each data source, including and excluding non-PA. We then compared observation counts in PA categories for 2020 to prior years and compared these counts grouped by data source and restriction level.

We used the ARIA+ index to assess possible differences in geographic distribution between the CS and SO data sources and how they were affected by COVID restrictions. We first used the Shapiro-Wilk test of normality on each source. As all sources were not normally distributed, we used the non-parametric Kruskal-Wallis test (Dodge, 2008) and Dunn's pairwise post-hoc test with the Benjamini-Hochberg adjustment method to test for mean differences in ARIA+ values between restriction levels for each data source and then for each state. The effect size – rank Epsilon squared – is appropriate for non-parametric tests of differences between 2 or more samples. Values range from 0 to 1, with larger values indicating larger differences between groups.

We used Mann-Whitney tests to evaluate restriction level effects on geographic distribution, as represented by ARIA+ remoteness values, between 2020 and prior years broken down by state and data source. To do this, we compared the ARIA+ distributions, for each set of COVID restriction level periods in 2020, against the ARIA+ distributions for the same periods in 2018 and 2019. We performed these analyses for all CS and SO and also for each state.

Analyses were performed using RStudio version 1.4.1106 (RStudio Team, 2021) with R version 4.0.5 using the following packages: data cleaning and preparation for analysis with tidyverse (Wickham et al., 2019), statistical analysis and graphs with ggstatsplot (Patil, 2018) and statsExpressions (Patil, 2021), graphs with ggplot2 (Wickham, 2016) and maps with ggmap3 (Kahle and Wickham, 2013). Final maps were prepared with QGIS 3.16 (QGIS Development Team, 2021).

3. Results

3.1. Observations

There were 12,164 short-beaked echidna observations in total from 2018 to 2020, spread over the three data groups and across three states - New South Wales (NSW) with 5280, South Australia (SA) with 2473 and

Table 1
Criteria for determining Australian COVID-19 restriction level classifications used in this study.

Level	Criteria
0	Effectively no or few restrictions - free to move and gather in larger groups. International and inter-state travel restrictions may be in place.
1	Some restrictions on gathering (<500). Limits on some activities outside. Stay at home mostly guidance. Only essential work done outside home. Many public facilities closed. Schools open.
2	Restrictions on movement to some areas, probably movement limited to <25 km from home. Non-essential movement limited. Gathering limits at home <10. Schools etc. closed.
3	No non-essential movement outside home. Limit to distance from home e.g. <5 km. Tight limitations on gatherings in public and private.
4	Very limited movement outside home allowed. Possible curfew. No gatherings in private or public.

Table 2
Short-beaked echidna observation totals by data source, year and state.

Data source	Year	NSW	SA	Vic	Total
CS	2018	899	838	1266	3003
	2019	774	515	1059	2348
	2020	780	527	991	2298
State-CS	2018	684	0	115	799
	2019	265	0	73	338
	2020	0	0	2	2
SO	2018	520	117	411	1048
	2019	778	293	415	1486
	2020	580	183	79	842
Totals		5280	2473	4411	12,164

Victoria (Vic) with 4411 (Table 2). There were differences in numbers recorded within states and within data groups, with a decline in 2019 and 2020 for state CS observations in NSW and Vic and in 2020 for SO in Vic. There was a small decline in CS observations in Vic from 2018 to 2020.

Observations during 2020 stratified by data source, state and COVID restriction level show large differences in mean daily observation rates between levels, especially for both CS and SO in Vic level 0 and the other levels of restrictions (Table S4).

3.1.1. Temporal patterns

Fig. 1 shows the overall numbers of observations separated by data source and by state, and varying temporal patterns by state. COVID restrictions are coloured by severity level with initial restrictions starting around mid-March 2020 in all states. Restrictions in NSW covered 108 days, with level 3 restrictions lasting 44 days. Vic had the longest and severest restrictions totalling 288 days, with level 3 and 4 restrictions in place for 151 days. Restrictions in SA totalled 102 days with only 3 days of severe restrictions. The observations are separated into those in PA and those in non-PA, which shows the large contribution that non-PA observations make to CS and the high proportion of PA observations from SO. During the 3 years of this study, CS observation counts display clear seasonal peaks from around September to January (spring-summer) in NSW and Vic, while in SA there are dual shorter and smaller peaks around April/May and September/October. All states show a trough in observations around May and June. SO show less seasonality with no repeating peaks. There is a notable decline in SO in Vic during 2020.

3.1.2. Spatial patterns

Fig. 2 shows the spatial distribution of echidna observations, coloured by COVID restriction level, in southeastern Australia for 2020, with the base map showing ARIA+2016 categories of remoteness. There are many more CS observations (Fig. 2a) than SO (Fig. 2b), with similar geographic distributions. There is a sharp contrast in both the number and geographic distribution of observations in Vic during 2020. In Vic, CS provided 991 widespread observations in 2020 while there were just 79 SO, and in 2019, for comparison, there were 415 SO (Table 2).

3.2. Effects of COVID restrictions on observations

Observation counts for each restriction level, data source, State and period are detailed in Table 3. Note that the number of days varies between restriction level and State, which affects between-State and between-level comparisons. However, the number of days remains the same between periods for each restriction level and State.

Numbers of CS observations were not affected by different COVID restriction levels. SA and Vic showed highly significant differences but with negligible effect and NSW showed no significant difference between restriction levels (Table S5). SO were affected by restriction levels. There were highly significant differences with small to moderate effects, with observation numbers in Vic being most affected by COVID restrictions (χ^2 (4, N = 3316) = 81.82, p < 0.001, Cramer's V = 0.29) followed by SA (χ^2 (3, N = 1880) = 24.04, p < 0.001, Cramer's V = 0.19) and NSW (χ^2 (3, N = 2452) = 44.88, p < 0.001, Cramer's V = 0.15). Interestingly, although SO in Vic decreased as restrictions were applied, in SA and NSW the results are more mixed, with some increases apparent in NSW.

3.3. Effects of COVID restrictions on observations in protected areas

Observation counts for the periods of each level of restrictions by data source and PA status show clearly the differences between CS and SO in observations in PA and non-PA (Table S6). Observation counts by source, state, year and PA IUCN category also show large variations (Table S7), with an especially large reduction for SO in "Strict Nature Reserves" in Vic from 147 observations in 2018–2019 down to a single observation in this PA category in 2020.

CS observations in PA IUCN categories showed no significant differences in 2020 compared to 2018–2019 overall. However, SO showed a significant association between period and PA category, with small effects, when including non-PA (χ^2 (7, N = 3374) = 159.39, p < 0.001,

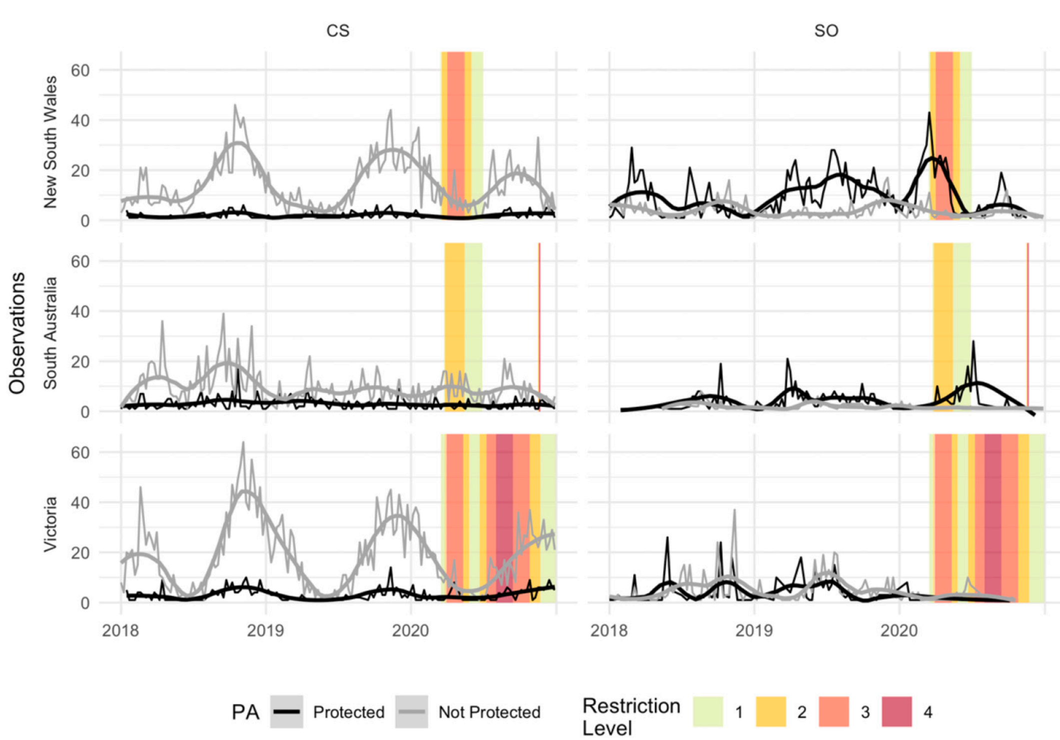

Fig. 1. Weekly observation counts of short-beaked echidna in PA and non-PA from 2018 to 2020 with COVID-restriction level periods in 2020 shown, broken down by state and data source. Trend lines have been calculated using the loess method (Jacoby, 2000) and a smoothing window of approximately 9 months.

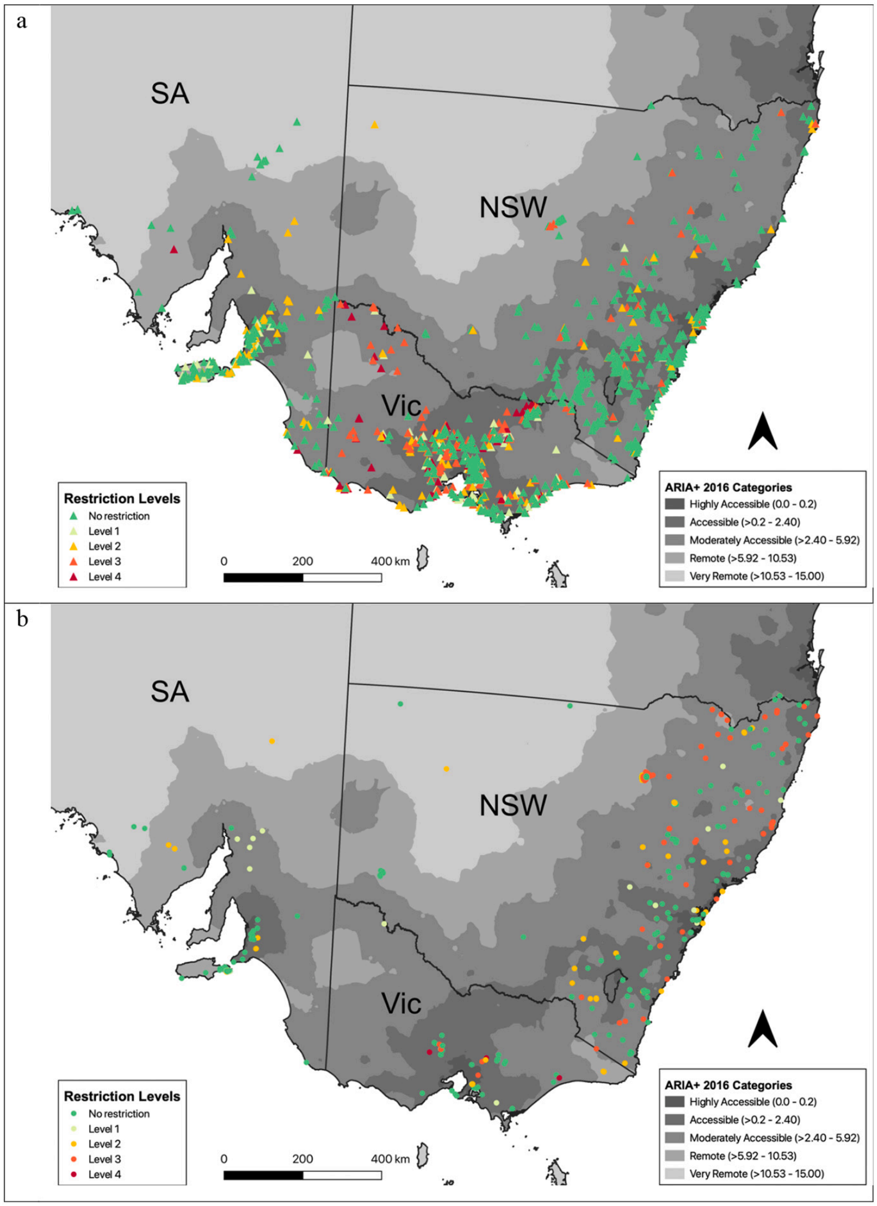

Fig. 2. Distribution and number of 2020 short-beaked echidna observations coloured by lockdown level in south-east Australia, with ARIA+ (2016) remoteness categories (Hugo Centre, 2018) indicated on the base map. **2a** All CS observations; **2b** All SO.

Table 3
Short-beaked echidna observation counts per restriction level by data source, state and period.

			Restriction level				
Data source	State	Period	0	1	2	3	4
CS	NSW	2018–2019	1460	32	79	102	0
	NSW	2020	675	12	35	58	0
	SA	2018–2019	973	127	241	–	12
	SA	2020	354	79	90	–	4
	Vic	2018–2019	542	521	459	611	192
	Vic	2020	290	205	140	260	96
SO	NSW	2018–2019	904	71	123	200	0
	NSW	2020	317	31	87	145	0
	SA	2018–2019	266	66	76	–	2
	SA	2020	89	61	33	–	0
	Vic	2018–2019	93	150	215	283	85
	Vic	2020	37	13	19	6	4

Cramer's V = 0.21) and also when excluding non-PA (χ^2 (6, N = 2138) = 70.59, p < 0.001, Cramer's V = 0.17) (Table 4).

When comparing proportions of observations made in all PA IUCN categories and non-PA between COVID restriction levels in 2020 (Fig. S2), CS observations were not significantly affected (χ^2 (28, N = 2297) = 46.81, p = 0.014, Cramer's V = 0.05). SO were moderately affected by COVID restriction levels, showing a highly significant association (χ^2 (24, N = 842) = 142.07, p < 0.001, Cramer's V = 0.19).

When non-PA are excluded from the analysis, the distribution of CS observations across PA IUCN categories showed no significant difference between COVID restriction levels (χ^2 (24, N = 324) = 28.32, p = 0.247, Cramer's V = 0.06). Distribution of SO in PA showed significant differences between levels, with moderate to strong effects (χ^2 (15, N = 642) = 112.41, p < 0.001, Cramer's V = 0.23).

3.3.1. *Comparing effects of COVID restrictions to prior years*

No significant associations were found between COVID restriction levels and observations inside and outside PAs for CS observations. For

Table 4
Pearson's Chi-squared test results for comparing echidna observations in IUCN PA categories during COVID restrictions in 2020 with observations for the same periods during 2018–2019, separated by data source groups and including and excluding non-PA.

	Data source	Statistic	DF	*p*-value	Cramer's V (adj.)	95% CI	Sig
Including non-PA	CS	7.82	7	0.35	0.01	0–0	
	SO	159.39	7	<0.001	0.21	0.17–0.24	***
Excluding non-PA	CS	6.13	6	0.41	0.01	0–0	
	SO	70.59	6	<0.001	0.17	0.12–0.21	***

SO, however, there were highly significant associations at each level of restriction, except for level 4, which had very few observations in 2020, all being in non-PA (Table 5 and Fig. S3).

3.4. Effects of COVID restrictions on geographic distribution of observations

COVID-19 restriction levels varied by location over time and we examined how these affected the geographic distribution of our observations. Aggregated overall, mean ARIA+ values ranged from 3.09 ± 2.66 for level 0 observations to 1.76 ± 1.75 for observations under level 4 restrictions (Table S8). A Kruskal-Wallis test showed highly significant but negligible effect of restriction level on mean remoteness values overall, as measured by ARIA+ (2016) (χ^2 (4, N = 3140) = 41.95, $p <$ 0.001, $\varepsilon^2 = 0.01$). A post-hoc pairwise comparison using Dunn's test with Benjamini-Hochberg correction showed significant differences between level 0 (no restrictions) and all other levels. There were also significant differences between levels 1 to 3 and level 4 (Table S9).

3.4.1. By data source

When we analyse observations in 2020 by data source, restriction level shows a significant weak-moderate effect on mean geographic remoteness, as measured by ARIA+ (2016), indicated by the Kruskal-Wallis test results for both CS observations (χ^2 (4, N = 2300) = 61.2, $p < 0.001$, $\varepsilon^2 = 0.03$) and SO (χ^2 (4, N = 842) = 42.8, p < 0.001, ε^2 = 0.05) (Table S10). CS observations showed significant differences but with a small effect between groups at level 0 (no restrictions) and all restriction levels, as shown by the pairwise post-hoc Dunn test with Benjamini-Hochberg correction. SO showed more variation between groups, with significant differences between levels 0 and 3, also between level 1 and all other levels, and lastly between levels 2 and 3 (Table S11).

3.4.2. Within states

Restriction level shows little effect on the geographic distribution of observations within each state (Fig. 3), though differences between states are clear. New South Wales shows a significant but weak effect between levels (χ^2 (3, $N = 1360$) = 27.9, $p < 0.001$, $\varepsilon^2 = 0.02$). There are negligible effects in both South Australia (χ^2 (3, N = 710) = 7.2, p = 0.06, ε^2 = 0.01) and Victoria (χ^2 (4, N = 1072) = 10.1, p = 0.04, ε^2 = 0.01) (Table S12). Pairwise comparisons between levels for each state showed small but significant differences between geographic distribution at level 0 (no restrictions) and all other restriction levels for NSW, with the median remoteness index surprisingly higher for all restriction levels than for level 0. This indicates that with no COVID-19 restrictions in place, more observations were made in accessible locations which is perhaps an indication of people being more active but still in proximity to populated or accessible areas. There were no significant differences between levels for SA or Vic (Fig. 3 & Table S13).

3.4.3. Between periods

Comparing ARIA+ values for remoteness between the same restriction periods in prior years to 2020 indicates no difference in geographic distributions for all restriction levels in CS observations (Fig. 4) except for level 2 which showed a small significant difference (Mann–Whitney U = 11.62, n1 = 779, n2 = 265, M1 = 1.32, M2 = 0.95, $P < 0.05$ two-tailed). The geographic distribution of SO was more affected by restrictions. ARIA+ remoteness distribution for SO (Fig. 4) showed significant increases at restriction levels 1, 2 and 3 in 2020 compared to the same periods in the previous 2 years (Table S14), while at level 4 there were very few SO.

To better evaluate the varied effects of restriction levels on the geographic distribution of observations, we then split the data by state (Fig. S4). For CS observations, there were significant differences in the geographic distribution in NSW under restriction level 3 and in SA under levels 2 and 4, with no significant differences in Vic (Table S15). This is interesting as Victoria had the severest and longest restrictions but it appears this did not impact the distribution of observations. For SO, however, there are highly significant differences in geographic distribution in NSW under restriction levels 2 and 3, in SA under levels 0 and 1 and in Vic under levels 1 and 2. For summary statistics of ARIA+ by year, data source, state and restriction level see Table S16.

4. Discussion

This study evaluated the impacts of COVID-related restrictions on observations of short-beaked echidna recorded using both CS and scientific methods in three states of Australia. There were many differences in COVID restrictions between states which led to variations in recording activity, though some interesting patterns are apparent. SO were most affected by restrictions, with significant reductions in Victoria where the

Table 5
Chi-square test results when comparing the effects of COVID restriction levels on observations in PA categories and non-PA during 2020 with observations during 2018–2019 for the same periods, separated into data source groups of CS and SO.

Data source	Restriction level	Statistic	DF	p-value	Cramer's V (adj.)	95% CI	Sig	N 2018–19	N 2020
CS	0	11.55	7	0.12	0.03	0–0.04		2975	1319
	1	11.2	6	0.08	0.07	0–0.11		680	296
	2	6.35	7	0.5	0	0–0		779	265
	3	6.49	7	0.48	0	0–0		713	318
	4	9.4	6	0.15	0.11	0–0.15		204	100
SO	0	79.12	7	<0.001	0.21	0.15–0.25	***	1263	443
	1	59.19	6	<0.001	0.37	0.25–0.45	***	287	105
	2	44.25	6	<0.001	0.26	0.16–0.33	***	412	139
	3	90.53	6	<0.001	0.37	0.27–0.43	***	483	151
	4	2.5	3	0.48	0	0–0		87	4

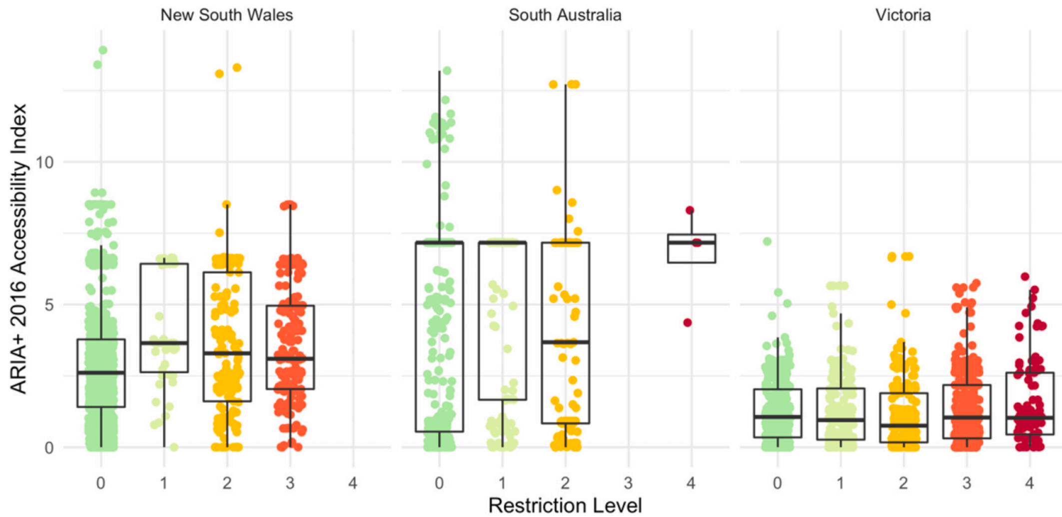

Fig. 3. Comparison of COVID-19 restriction levels effect on ARIA+ 2016 remoteness values by state for observations in 2020. Boxplots for each state's restriction levels, showing median and inter-quartile range with outliers, are shown over observations coloured according to restriction level as in Fig. 2. Note that New South Wales had no period of level 4 restrictions and South Australia no level 3 restricted period.

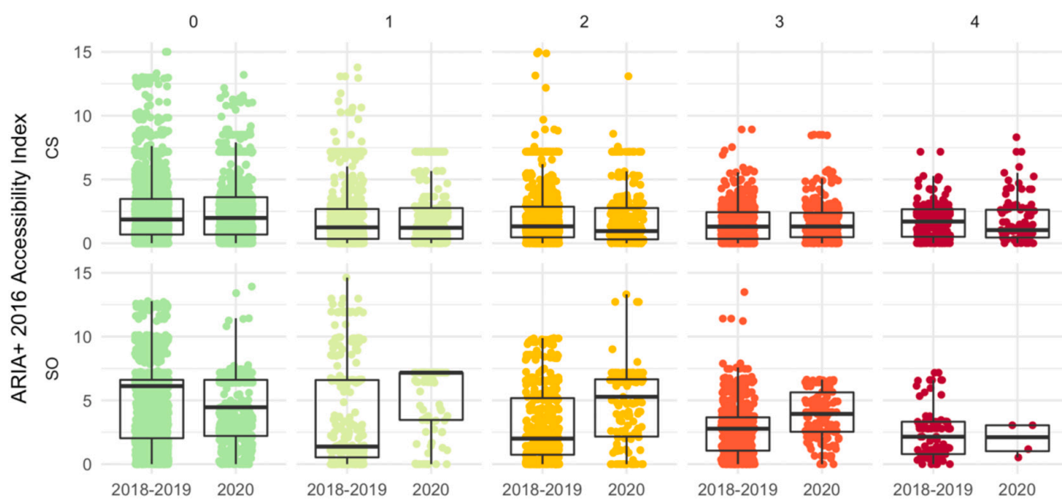

Fig. 4. Effect of COVID-19 restrictions on ARIA+ (2016) remoteness index between COVID-affected 2020 and prior years (2018–2019). Boxplots show median and distribution of ARIA+ values plotted over observation points coloured by restriction levels as in Fig. 2. Citizen science (CS) observations in the top row show a significant difference between periods in level 2 only, while scientific observations (SO) in the second row show significant differences between periods at restriction levels 1, 2 and 3.

restrictions were severest, while CS observations showed few impacts.

4.1. COVID-19 restrictions effects on observation counts

Somewhat surprisingly, our results show that observation counts from CS were not affected by COVID restrictions. While we had expected that observations would decrease, this did not occur, even in Victoria where restrictions were long and severe. One reason for this could be that echidnaCSI relies on opportunistic observations rather than formal or group surveys, thus the work-from-home restrictions may have contributed to more observations, as people remained at home and consequently explored local green spaces. This may have offset other negative effects, such as from reduced travelling and tourism. In addition, many echidna observations are in peri-urban areas where there is still abundant habitat, so people remaining at home have more opportunities to observe activity in their backyard and neighbourhood.

Numbers of SO were significantly affected by COVID restrictions, especially in Victoria, where there was a large decrease in SO overall, and the numbers of daily observations during each restriction level also decreased. This was expected due to the limitations on non-essential travel and fieldwork and in Victoria the restrictions were long and severe. In addition, it is possible that people contributing SO live in populated centres and were more affected by fieldwork restrictions. The other states had fewer restrictions and showed few effects. Of interest is the increase in observations per day in NSW under restriction levels two and three. It is unclear why this might be the case, but possibly due to later inclusion, after processing, of observations from camera traps, which continually record without human presence.

The variations apparent in Fig. 1 are likely due to citizen scientists being more active at certain times of the year or in good weather (August et al., 2020; Boakes et al., 2010), as well as variable echidna activity. Echidnas are known for seasonal variations in activity which occur for several reasons, including breeding, weather patterns, particularly temperature, prey availability and periods of torpor and hibernation, all of which show regional variations (Abensperg-Traun and Boer, 1992; Brice et al., 2002; Clemente et al., 2016; Nicol and Andersen, 2007). Interestingly, CS observations in NSW and Vic show similar seasonal changes with large peaks corresponding to the warmer periods of the year while those in SA are flatter. These variations may be due to people being more active outside during summer months combined with longer daylight hours, or to seasonal changes in echidna activity, or, most likely, to a combination of these factors. The scientific data show more variations and again it is difficult to determine possible causes, though it is likely also due to variations in scientific fieldwork intensity and echidna activity.

4.2. COVID-19 restrictions effects on protected area observations

Observations from scientific sources in protected areas (PA) were significantly affected by COVID-19 restrictions while CS observations were not. This is interesting as we expected that both restrictions on personal movement and PA closures would most constrain CS observations but this was not the case. SO in Vic showed the biggest impact, as might be expected from a state with the most severe and long restrictions. This points to the probable classification of monitoring work as non-essential during a time of crisis, despite some PA being critical for ecosystem health and biodiversity preservation. In contrast, it appears that many CS participants remained active during periods of extreme restrictions and were in sufficient proximity to PA that they could still record wildlife observations.

SO in non-PA were significantly reduced for all periods of restriction in 2020, including under level 0, while CS showed a slight overall decline. This may be due to an increased focus on scientific monitoring and management in important conservation areas as a result of the varied restrictions placed on organisations due to the pandemic, while other non-essential work was postponed (Waithaka et al., 2021). This is reflected in the increased proportion of observations in highly protected IUCN PA categories "Strict Nature Reserve" and "Wilderness Area" in 2020 compared to prior years in NSW and SA. In Vic, however, observations in PA were severely reduced suggesting that even work in important conservation areas was restricted.

4.3. COVID-19 restrictions effects on geographic distribution of observations

With no restrictions (level 0), observations were more remote overall than under all other restriction levels as was expected, as restrictions on movement impacted travel. When split by data source, this pattern was also apparent for CS observations but not for SO. When comparing remoteness values for 2020 against 2018–2019 for the same periods determined by restriction level (Fig. 4), CS shows little difference between periods while SO are more impacted. This appears to be due to significant state variations in observations counts and remoteness values when we compare the same periods for each state (Fig. S4). The higher population density of Vic than the other states, combined with few remote and no very remote regions, result in a reduced range of remoteness values for all echidna records in Vic compared to the other states. As SO in Vic were markedly reduced during restrictions in 2020, while the other states were not, the effect on geographic distribution is skewed upwards when combining all states data and comparing 2020 to 2018–2019, and thus shows an apparent increase in remoteness values in 2020 under restriction levels one to three.

Also interesting is the lack of significant difference in Vic CS observations between 2018–2019 and 2020 restricted level periods. Vic had the longest and strictest restrictions and despite this, the CS remoteness index values did not significantly change, which was not expected. This may be related to the regional characteristics of Vic, with many participants taking advantage of abundant green spaces in peri-urban and rural areas, which coincide with the echidna's habitat and dietary requirements. It highlights a strength of this CS program that it was able to continue to provide similar geographic coverage during varying levels of restrictions as in normal, unrestricted periods.

The major series of bushfires in 2019–2020 in Australia affected large areas within the study area and severely impacted the ecosystems and animals within them, the people who lived there and subsequently the conservation focus of many organisations. The impacts of the bushfires are many and varied (Khan, 2021; Wintle et al., 2020) and require a separate study, but a potential effect here is a decrease in monitoring activity in some areas during and after the fires, as activity by conservation and research organisations, other than wildlife emergency rescue and recovery, was often limited. At the same time, the general public was prohibited from these areas, which would have curtailed CS monitoring there.

We expected that the restrictions which curtailed travelling and tourism would have resulted in fewer CS observations, though this does not appear to be the case. Perhaps this is an indication of the strong interest in, and knowledge of, local areas by the participants as well as increased local activity due to the various restrictions, which included bans on international travel but offset by support for inter- and intrastate tourism. To evaluate one effect of restrictions on travel, comparing the numbers and locations of echidnas killed on roads may provide insights. Reduced travelling by car probably results in fewer animals being hit by vehicles, as well as fewer roadside observations. Reductions in wildlife roadkill due to reduced travelling have been detailed elsewhere (Driessen, 2021; Shilling et al., 2021) and it would be valuable to document these to further inform conservation management and transport planning.

This study has shown contrasting results to other international studies evaluating the effects of COVID-19 restrictions on biodiversity observations using CS. In 2020, our CS observation numbers were not significantly affected by the varying restriction levels, even under the severest restrictions, while other international studies reported declines from CS projects of 50–70% (Kishimoto and Kobori, 2021; Rose et al., 2020). Similarly, the geographical distribution of our CS observations showed little variation compared to prior years, in contrast to the changes to CS-based urban/rural bird observations in Italy and Spain (Basile et al., 2021) and in the USA (Crimmins et al., 2021), which decreased in rural areas but increased in urban areas. Echidnas are not as mobile nor commonly found in urban areas compared to birds and are more likely to be found in the peri-urban, rural and wilderness areas of Australia, thus it might be expected that the geographic distribution of these observations shows little change.

Our findings are influenced by the classification of levels of restriction on activity and movement of citizens and we acknowledge the reliance on human interpretation of government policy announcements to classify those restriction levels. A global database tracking COVID restrictions discusses some of the difficulties associated with classifying restrictions at varying scales (Hale et al., 2021b). Our interpretation and classification of the announcements might be done differently, though we believe the relative rankings of restriction severities would remain similar.

A strength of the echidnaCSI program is that it directly uploads observations to a national biodiversity repository, hence there are no delays in collating this data and it is immediately available for use. Scientific biodiversity monitoring is often slower to process and share observational data and thus it is possible that the state datasets did not reflect what had been recorded, but only what had been processed so far. Directly uploading data to a national or central repository also enables other activities to take place, such as data curation or classification, which can be performed both by experts and the public via crowdsourcing platforms. Such activities showed benefits of stay-at-home COVID-19 restrictions in some places (Crimmins et al., 2021) and illustrate another method where technology-supported CS can provide important contributions to biodiversity conservation research while fieldwork is disrupted. Such crowdsourced contributions will become even more useful as our fieldwork tools improve and increased connectivity enables direct data upload from the tools themselves (such as internet-connected and intelligent camera traps and other sensors). These tools will also be vital for scientific studies where disruptions to monitoring should be prevented, such as for threatened species.

We expect that traditional monitoring of other species will also have been affected and that it is important for researchers to be aware of the potential for temporal and spatial data gaps when analysing data from these timeframes in future. The distributed and consistent activities of the participants in the echidnaCSI project have demonstrated the potential value of CS to biodiversity and wildlife monitoring even under restrictions caused by a global pandemic.

5. Conclusions

The COVID pandemic has affected wildlife monitoring in Australia in varying ways. In this paper, using the iconic but cryptic short-beaked echidna as a case study, SO were most affected by restriction levels but the effects varied between states. Perhaps surprisingly, CS, through the echidnaCSI program, continued to provide numerous and widespread observations even during periods with severe COVID-related restrictions, while scientific monitoring was greatly reduced under the same restrictions. This highlights the value of CS, as widespread participation appears to be less affected by movement restrictions than scientific monitoring, which often involves remote fieldwork and fewer people. However, differences between CS and scientific monitoring remain, such as the lack of coverage in very remote regions and PA by CS. Thus, further research on alternative monitoring and detection methods to better cover these areas in the face of restrictions is vital to avoid gaps in monitoring coverage. Finally, this study illustrates the potential value of a national CS project for continued wildlife monitoring, even in times of crisis when other approaches may be more severely impacted.

Data availability statement

Data is available for download from the DOIs and websites listed in Supplementary Information S2.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

AS and TP were supported by Australian Government Research Training Program Scholarships. LPK is supported by the Singapore National Research Foundation (NRF-RSS2019-007). FG was supported by an ARC Future Fellowship (FT160100267). Thanks to other members of the echidnaCSI team: Isabella Wilson, Ella West, Ima Perfetto and Michelle Coulson. Jarrod Lange from the Hugo Centre for Population and Housing at the University of Adelaide kindly provided assistance and advice on evaluating geographic distribution using ARIA+ (2016) and extracted ARIA+ values for our observations. We acknowledge the use of the Atlas of Living Australia, (https://www.grid.ac/institutes/grid.506668.b) and the state biodiversity repositories of New South Wales, South Australia and Victoria.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2022.109470.

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