Diversity and Distributions

WILEY

Diversity and Distributions

RESEARCH ARTICLE OPEN ACCESS

Diversity and Distribution of Amphibians and Freshwater Fishes on Australian Islands

Samuel C. L. Ho[1] | Simon P. Hart[1] | Michael P. Hammer[2] | Peter W. J. Baxter[1] | Peter J. Unmack[3] | Salit Kark[1]

[1]School of the Environment, Centre for Biodiversity and Conservation Science, The University of Queensland, St Lucia, Queensland, Australia | [2]Museum and Art Gallery of the Northern Territory, Darwin, Northwest Territories, Australia | [3]Centre for Applied Water Science, Institute for Applied Ecology, University of Canberra, Canberra, Australian Capital Territory, Australia

Correspondence: Samuel C. L. Ho (hcl.samuel@uq.net.au)

Received: 6 February 2025 | **Revised:** 10 July 2025 | **Accepted:** 16 July 2025

Editor: Pedro Cardoso

Funding: The authors received no specific funding for this work.

Keywords: amphibians | Australia | biodiversity | conservation | fishes | freshwater ecosystem | island biogeography | islands

ABSTRACT

Aim: Freshwater ecosystems cover less than 3% of the Earth's surface, yet support nearly 10% of all known animal species, majorly represented by freshwater fishes and amphibians, both of which are highly threatened groups. Geographically isolated freshwater species, such as those inhabiting islands, are at high risk. Australia, with nearly 9300 islands, is home to diverse island freshwater fauna. However, the lack of published literature on their island occurrence, threats and management impedes effective conservation across islands. We aim to describe the distributional patterns of amphibians and freshwater fishes on islands and analyse the island characteristics that influence these patterns.

Location: Australia's Islands.

Methods: We compiled the first database of occurrences of amphibians and freshwater fishes across Australia's islands. Utilising the database, we used regression analysis to examine the main drivers of distributional patterns, species richness and species composition on Australia's islands.

Results: We found that 102 amphibians and 95 freshwater fishes occur on Australia's islands. Fifty-five fishes were obligate freshwater species, 21 were euryhaline and 19 were diadromous. Although freshwater fishes showed lower richness on islands than amphibians, potentially due to lower survey efforts, fishes had a higher proportion of threatened and alien species. Islands with more precipitation that are closer to the mainland hosted higher amphibian richness, which likely retained mainland amphibian assemblages or were more easily colonised. In contrast, larger islands hosted higher freshwater fish richness, where diverse habitats were likely to sustain more species.

Main Conclusions: Using the new database compiled, we found that occurrences of amphibians and freshwater fishes on islands were influenced by climate, island size and distance from the mainland. This provides a baseline for follow-up studies on phylogeny and biogeography. This research contributes to future conservation of amphibians and freshwater fishes on islands by revealing islands of potential conservation concern and lays the groundwork for future spatial prioritisation work.

1 | Introduction

Freshwater ecosystems are widely recognised as important to both humans and biodiversity yet are scarce and highly susceptible to threats (Albert et al. 2021; Dudgeon et al. 2006). Approximately 2.5% of Earth's surface water is freshwater (Mishra 2023), providing habitat for over 126,000 animal species (Balian et al. 2008). While freshwater habitats are much smaller than marine habitats, they are disproportionately rich in biodiversity, with freshwater fish species alone accounting for around half of all described fish species (Carrete Vega and Wiens 2012). Freshwater is also crucial to the survival of all amphibian species, the second most diverse freshwater vertebrate group (Balian et al. 2008). Some 4117 of 5828 frog species globally have at least one life stage that lives in water, and a further 177 species are water-dependent (Vences and Köhler 2008). Freshwater ecosystems are hotspots of endangerment due to the convergence between rich biodiversity and many forms of human freshwater exploitation (Reid et al. 2019). Humans exploit freshwater resources for socio-economic development in many ways (Israilova et al. 2023), such as agriculture and electricity generation (Albert et al. 2021; Mishra 2023). In 2022, the World Wide Fund Living Planet Report showed that human-induced threats have led to the greatest decline of freshwater species by 83% (WWF 2022), yet freshwater species continue to be under-represented in the conservation literature (Strayer and Dudgeon 2010).

Island ecosystems are also a hotspot of endangerment due to the large number of threatened and endemic species they harbour (Kier et al. 2009). Islands are particularly vulnerable to a range of threats, including habitat degradation and the introduction of invasive species (Heatwole and Rowley 2018; Hervías et al. 2014). Alarmingly, island endemic species represent 81% of all globally threatened or extinct species (Doherty et al. 2016). Research has typically focused on predation pressure of invasive mammalian predators on island fauna (Rayner et al. 2007; Rees et al. 2023). These predators have collectively contributed to 58% of modern bird, mammal and reptile extinctions globally (Doherty et al. 2015). Although understanding the threats to island fauna is important for conservation, to effectively implement conservation strategies we also need to better understand how geographical factors such as total island area, degree of isolation and latitude influence endemism and diversity (Gillespie et al. 2013). This is poorly documented and overlooked in the literature for non-mammalian organisms, including vertebrates such as amphibians and freshwater fishes which also inhabit highly vulnerable freshwater habitats (Doherty et al. 2016; Legge et al. 2018).

Collectively, Australia has nearly 9300 islands, highly varying in size, climate and distance from the mainland (Baxter et al. 2021). These island characteristics heavily influence the species richness, species composition and levels of endemism on the islands (Gillespie et al. 2013; MacArthur and Wilson 2001). Most of Australia's continental islands exist due to the rise in sea level following each glacial cycle during the Pleistocene epoch (Allen and Kershaw 1996). As the climate warmed and ice melted, rising sea levels flooded low-lying areas, isolating higher landmasses as islands (Allen and Kershaw 1996). Among Australia's many islands, 317 islands host a total of 281 threatened animal and plant species, with notable examples including Norfolk Island and Kangaroo Island, which harbour 55 and 27 nationally threatened species respectively (Baxter et al. 2021). A database documenting the occurrences of threatened and invasive species on Australian islands was developed in recent years to inform conservation management strategies (Baxter et al. 2021). However, noticeable gaps remain in the database, particularly in less-surveyed taxonomic groups, such as freshwater fishes, amphibians and invertebrates, and the omission of records of non-threatened native species.

In Australia, despite the presence of extensive palustrine and lacustrine freshwater wetlands on its islands, large knowledge gaps persist regarding their species diversity, ecology, population sizes and distribution due to a lack of surveying effort (Hines and Meyer 2011; Miles 2007; Miles et al. 2013). Large islands in Australia are relatively well surveyed for freshwater vertebrates, such as the sand islands in Southeast Queensland, where relatively comprehensive freshwater fauna surveys have been conducted and published (Yule 2019). While the diversity and distribution of freshwater vertebrates were studied on some larger islands, the research typically focuses on ecological factors and is specific to the island of interest (Marshall et al. 2011). Overall, there is little research done on the biogeographic factors that influence the species richness and composition on the islands. These knowledge gaps are even more pronounced on smaller islands, with minimal publicly available data on the amphibians and freshwater fishes residing there, albeit with some exceptions such as Magnetic Island (MINCA 2020). Understanding the factors influencing species richness on islands is highly relevant to conservation prioritisation and management efforts (Kier et al. 2009). Currently, the substantial gap in knowledge impedes conservation actions on threatened species on islands, especially when many threatened species on islands are non-migratory, which makes them more vulnerable (Garnett et al. 2022). To reduce this knowledge gap, we created a database of the occurrences of all amphibians and freshwater fishes on Australia's islands. We then used this database to explore the island characteristics that influence freshwater vertebrate fauna richness on these islands. Our key aim was to reveal the spatial patterns for freshwater vertebrates, including threatened and invasive species, and to investigate the island characteristics that influence species diversity. We further aimed to provide evidence-based guidance for biodiversity conservation for freshwater ecosystems on Australia's islands, and to provide a baseline for future prioritisation work.

2 | Methods

2.1 | Data Collection

We addressed the existing knowledge gaps in understanding and conserving freshwater fishes and frogs on Australian islands by collating the first specific database containing the occurrences of freshwater fishes and frogs on Australia's islands. To create this database, we leveraged the Island Occurrences of Threatened Australian Species (IOTAS) dataset and Invasive Species on Australian Islands dataset (Baxter et al. 2021).

These databases were further supplemented by occurrence data from the Atlas of Living Australia (ALA; https://www.ala.org.au/). To obtain a complete species list of freshwater fishes, we integrated the species list from the 'Ecology of Australian Freshwater Fishes' book (Humphries and Walker 2013) and the 'FishBase List of Freshwater Fishes reported from Australia' (Nicholls 2016) in ALA. We updated the nomenclature of our integrated list where relevant. We downloaded all occurrence records of species from the integrated list from Atlas of Living Australia, and obtained the records on islands using *pairwise intersect* on ArcGIS pro (ESRI 2011). We subsequently further filtered out species that are not considered freshwater fish based on the species list from Humphries and Walker (2013) and expert opinion.

To address the gaps in these databases resulting from the scattered nature of occurrence data in the literature, we conducted a manual search for any peer-reviewed articles government reports, consultancy reports and reports from non-profit organisations. We first filtered out islands that do not have freshwater sources using two remoting sensing databases from the Australian government (Geoscience Australia), National Surface Hydrology Database and Digital Earth Australia Waterbodies v3.0 (Crossman and Li 2015; Dunn et al. 2024). After obtaining the list of islands that have freshwater sources ($n=567$), we proceeded to a manual search through grey literature online. We also used Google Incognito Mode as the platform of search to prevent previous searches from influencing the search results. We used the keywords 'freshwater', 'fishes', 'fish', 'frogs', 'amphibian', 'island', in addition to the names of the island as the keywords of search. We further collated and reviewed reports containing the island name alongside any of the five biological keywords for information on the presence of freshwater vertebrates. When species occurrence data was identified, the records were incorporated into the database, with the corresponding literature cited as the source (51 and 52 sources respectively contained records of amphibians and freshwater fishes). In instances where the species was already documented in the Atlas of Living Australia (ALA), the literature source was added as an additional reference for that occurrence (32 and 39 sources respectively contained records of amphibians and freshwater fishes not documented in ALA). We assume that islands that were surveyed specifically for amphibians or freshwater fishes would have higher documented species richness due to supposedly more effective and higher sampling efforts. To address issues raised from varying sampling biases in subsequent statistical analyses, we also recorded whether the data collected from our literature search was derived from a survey targeted towards amphibians or freshwater fishes, or whether it was an incidental record.

In addition to the presence of each species, we included the status information of each species, including IUCN status and origin (native or alien to Australia). For fishes, we also included their life history trait (obligate freshwater, diadromous or euryhaline). Life history trait information was obtained from Allen et al. (2002) and following expert opinion. In this study, we broadly included obligate freshwater, diadromous and euryhaline fish species as freshwater fish species. We incorporated physical characteristics of each island from the IOTAS database into the newly collated database, such as latitude, area (in squares kilometres and hectares) and distance to the mainland (in metres and kilometres; Baxter et al. 2021; Commonwealth of Australia 2015). Climate data of each island was also incorporated into our database using the ABCB Climate Zone Map from the Australian Government. Climate region was categorised into eight climate zones defined by the National Construction Code (NCC) of Australia.

2.2 | Data Analysis

To account for large differences in climate among islands, for our data analyses we generated continuous multivariate metrics of climatic conditions for each island, rather than restricting our analyses to using categorical NCC climate zones. We achieved this by generating a geographic centre point for each island and subsequently extracted all 19 biologically relevant climate variables from WorldClim (Hijmans et al. 2005) for the location of each island's center point. We reduced the dimensionality of the 19 climatic variables using a principal component analysis using the *prcomp* function in the *stats* package in R. We then visualised the results with respect to the first two principal components with a biplot using the *fviz_pca_biplot* function in the *factoextra* package in R (Kassambara and Mundt 2017). We extracted the scores of these principal components for each island and included these scores as predictors in our regression models.

We used generalised linear models to quantify the relationship between species richness and the predictor variables island area, island isolation (distance from mainland) and climate (first and second climate principal components, as described above). Amphibians and fishes were modelled separately, and to account for potential effects of differences in survey effort we also did separate analyses for islands for which there were dedicated surveys, and for islands for which there were no dedicated surveys for each of these faunal groups. We fitted all these models with a negative binomial error distribution with a log link, using the *glm.nb* function in R package *MASS*.

In addition to our analysis of species richness, we also quantified the relationship between the proportion of obligate freshwater species and the predictor variables island area, island isolation (distance from mainland) and climate (first and second climate principal components, as described above). As the proportion of obligate freshwater fish to non-obligate freshwater fish species was distributed between 0 and 1, we used a beta regression using the *betareg* function in the R package *betareg* (Cribari-Neto and Zeileis 2010).

We excluded oceanic islands from all of our analyses. In contrast to continental islands, oceanic islands are often volcanic in origin and were never connected to the mainland (Allen and Kershaw 1996). An island's process of formation and previous connectivity with the mainland can strongly influence colonisation dynamics, species composition and ecological processes (Cáceres-Polgrossi et al. 2024; Whittaker and Fernández-Palacios 2007). For these reasons, we preferred not to include potential biogeographic patterns on oceanic islands with those on continental islands (Cáceres-Polgrossi et al. 2024).

We checked for collinearity between predictor variables for all models by assessing their variance inflation factors (VIF) using the *car* package in R. All predictor variables had a VIF of less than 5 and were all included in the final analysis. To check model assumptions, we used the function *simulateResiduals* from the package *DHARMa* to check for deviated residuals. We also used the function *testZeroInflation* to check for zero inflation. No model assumptions were violated. We conducted all data processing in the R environment version: 4.4.1 (R Core Team 2013).

TABLE 1 | Summary of the total number of amphibian and freshwater fish species occurring on islands, including the number of alien species and their conservation status based on the IUCN Red List. The categories include critically endangered (CR), endangered (EN), vulnerable (VU), near threatened (NT), least concern (LC), data deficient (DD) and not assessed (NA).

	Amphibians	Freshwater fishes
Total number of species	103	95
Total number of alien species	2	9
IUCN status		
CR	0	1
EN	0	7
VU	2	3
NT	4	2
LC	95	76
DD	1	3
NA	1	3

3 | Results

3.1 | Overall Distribution of Island Amphibians and Freshwater Fishes

We found that 567 of Australia's 9285 islands had ephemeral or perennial freshwater sources. Among these islands, 197 islands (35%) had either amphibians, freshwater fishes, or both groups recorded on them. Amphibian richness on islands ranged from 1 to 25 species while freshwater fish richness ranged from 1 to 28 species. K'gari (Fraser Island) had the highest combined amphibian and freshwater fish richness (47 species) of all Australian islands, followed by Groote Eylandt (43 species) and Curtis Island (43 species). Among the amphibians and freshwater fishes recorded, 14 were threatened (Critically Endangered, Endangered, or Vulnerable) and 11 were alien (Table 1). Freshwater fishes had a noticeably higher proportion of threatened species (13%; 12 species) than amphibians (2%; two species) despite having lower total species richness recorded on islands. Similarly, freshwater fishes also had a higher proportion of alien species (9%; nine species) than amphibians (2%; two species) despite having lower total species richness. A larger proportion of amphibian occurrences came from non-targeted sampling methods compared to the occurrences of freshwater fishes. Amphibians were recorded on 176 islands, 67 of which had targeted amphibian surveys conducted. Freshwater fishes were recorded on 84 islands, while 64 of these islands were subject to targeted freshwater fish surveys.

We recorded 102 frog species from six families that occurred on Australia's islands (Figure 1). Nearly half were Australo-Papuan treefrogs (Pelodryadidae; 48 species), while the second most represented family was the Australian water frogs (Myobatrachidae; 30 species) (Figure 1). Two amphibian species recorded were assessed as Vulnerable by the IUCN red list, four species were Near Threatened, 94 species were Least Concern, one species was Data Deficient, and three species were not assessed. The cane toad (*Rhinella marina*) and Asian common toad (*Duttaphrynus melanostictus*) were the only alien

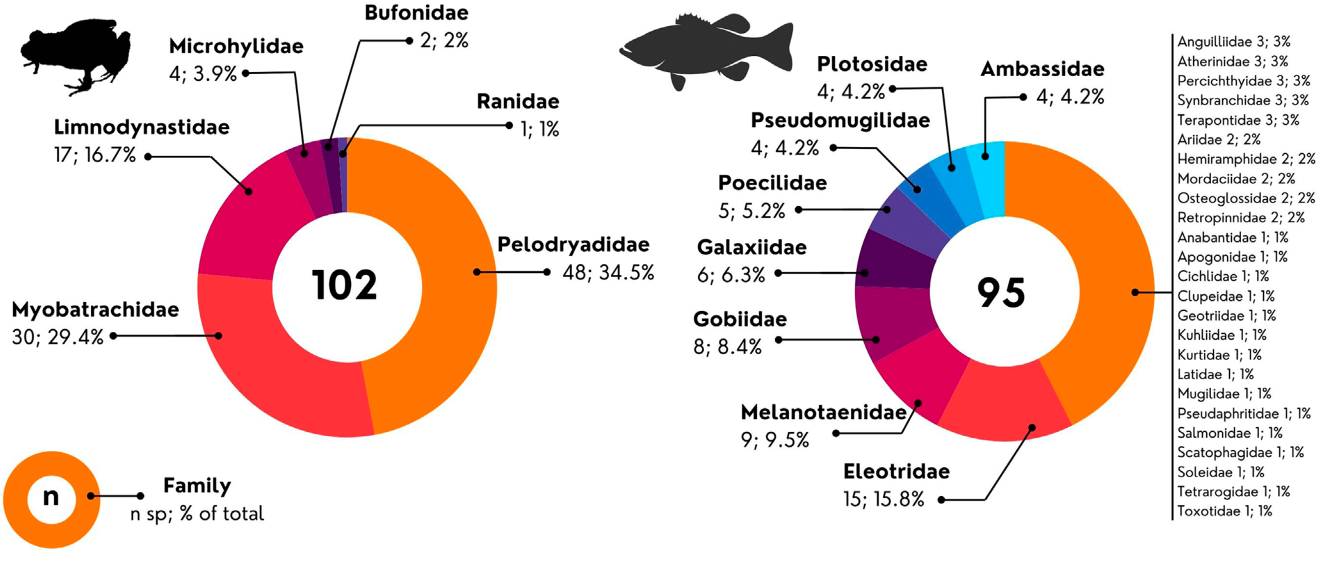

FIGURE 1 | Total number of species (*n*) of amphibians and freshwater fishes recorded on Australian islands, including the number of species per family and its percentage (%) relative to all species.

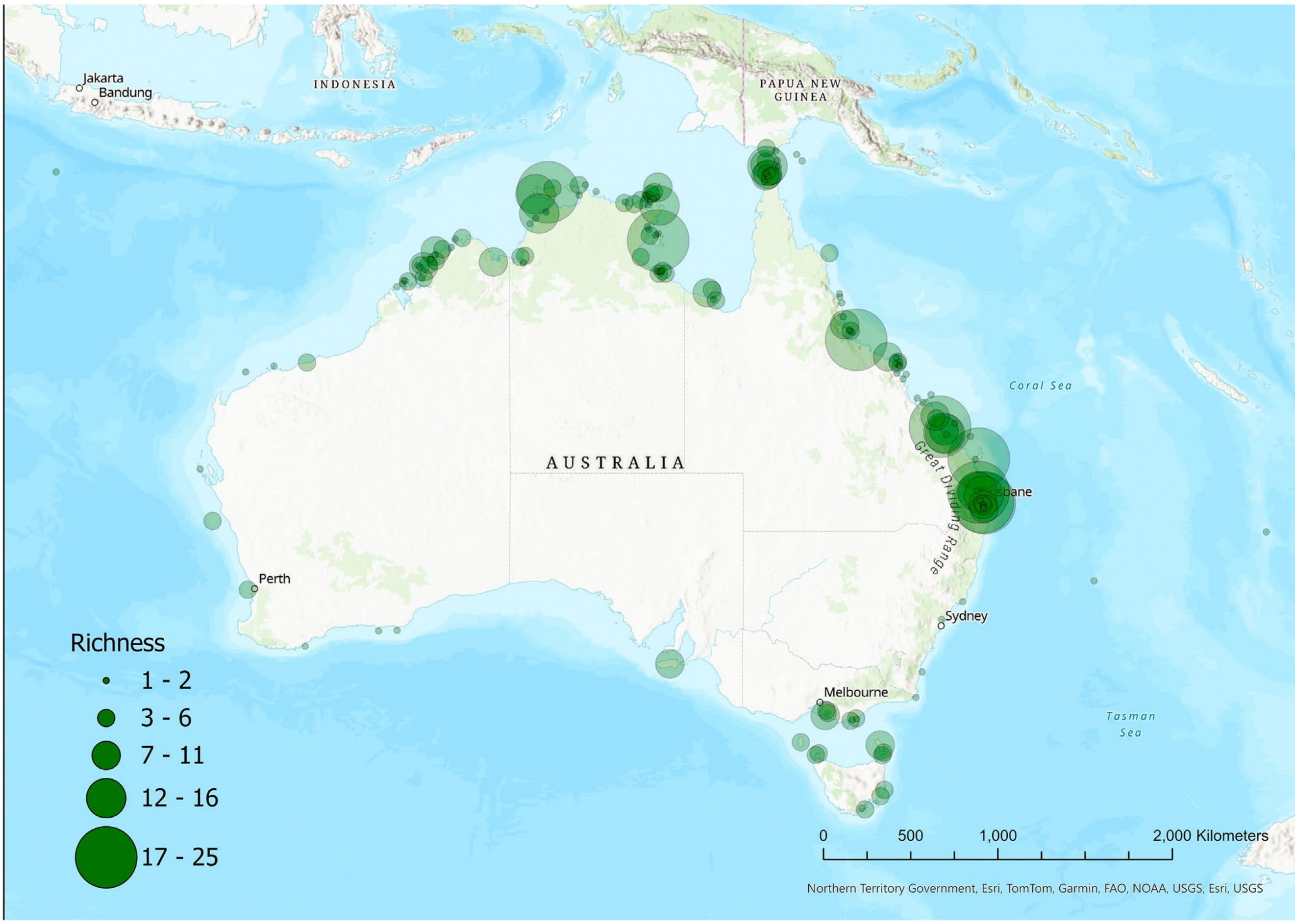

FIGURE 2 | Map showing the number of amphibian species found on each island. The size of each circle represents the number of species recorded on each island. Species counts were obtained from the database on occurrences of amphibians and freshwater fishes of Australia's islands, which was derived from literature reviews, and field survey data where available.

species that occurred on the islands, with the cane toad being the second most widespread species on islands (recorded on 65 islands), after the green tree frog (*Litoria caurulea*; recorded on 69 islands), while the Asian common toad was recorded only on Christmas Island, an oceanic island >1500 km away from mainland Australia. Other oceanic islands with amphibian occurrences included Norfolk Island and Lord Howe Island, both islands had two amphibian species that occurred on them, including the green tree frog which was found on both islands. Despite their occurrence on oceanic islands, most amphibian occurrences were clustered on continental islands in Southeast Queensland and North Queensland (Figure 2). Islands with the highest levels of richness were in these clusters, such as Curtis Island which had the highest amphibian richness recorded (25 species), followed by North Stradbroke Island (Minjerribah; 23 species) and Groote Eylandt (22 species; Table 2).

We found 263 fishes that were recorded in the freshwater or estuarine habitats on Australia's islands. After filtering for freshwater fishes, there were 95 species from 33 families (Figure 1). Of them, 55 fishes were obligate freshwater species, 21 were euryhaline species and 19 were diadromous species. Of all the native freshwater fishes recorded, one species was critically endangered, seven were endangered, three were vulnerable, three were near threatened, 76 were least concern, three were data deficient, and three were not assessed. Among the nine alien species, five of them were live bearers (Poeciliidae). The oceanic Christmas Island had the highest number of alien species, including four live bearers and a cichlid (*Oreochromis* sp.), which comprised most recorded freshwater fishes on the island. Other oceanic islands with freshwater fishes recorded included Norfolk Island, where two poecilids and a freshwater eel species (*Anguilla austris*) were recorded, and Lord Howe Island, where three native diadromous fishes were recorded (*A. australis*, *A. reinhardtii*, *Galaxias maculatas*). However, *G. maculatas* was not recorded in the most recent survey in 2017 (Reader et al. 2018). Overall, freshwater fish occurrences were clustered on continental islands along the east coast of Queensland, north Queensland, Northern Territory and the north of Western Australia (Figure 3). Islands with the highest levels of richness were in these clusters, such as K'gari with the highest freshwater fish richness recorded (28 species), followed by Groote Eylandt (23 species) and North Stradbroke (Minjerribah; 20 species) (Table 3).

3.2 | Drivers of Amphibian and Freshwater Fishes Richness

We reduced the dimensionality of the 19 climatic variables into two principal components. The first and second principal

TABLE 2 | Top 10 Australian islands with the highest amphibian richness, including exotic and threatened species counts, state, tenure, longitude, latitude, distance from mainland in kilometres (km), area in hectares (ha) and climate zone.

Island Name	Richness	Exotic	Threatened	State	Tenure	Longitude	Latitude	Distance (km)	Area (ha)	Climate zone
Curtis Island	25	1	0	QLD	Mixed tenure	151.15	−23.61	0.13	57,646	2
North Stradbroke Island	23	1	2	QLD	Mixed tenure	153.45	−27.54	3.56	26,949	2
Groote Eylandt	22	1	1	NT	Aboriginal freehold—inalienable	136.64	−14.02	40.07	228,518	1
Magnetic Island	21	1	0	QLD	Mixed tenure	146.83	−19.14	4.45	5066.9	1
Peel Island	20	1	2	QLD	Freehold	153.36	−27.50	4.79	520	2
Melville Island	19	0	0	NT	Aboriginal freehold—inalienable	130.96	−11.54	24.08	578,577	1
K'gari	19	1	2	QLD	Conservation reserve	153.14	−25.26	1.27	166,170	2
Bribie Island	18	1	1	QLD	Mixed tenure	153.14	−26.99	0.26	14,757	2
Bathurst Island	16	0	0	NT	Aboriginal freehold—inalienable	130.32	−11.64	56.68	169,318	1
Goat Island	15	1	2	QLD	Conservation reserve	153.07	−26.96	0.68	96	2

components explained 60.8% and 19.4% of the climatic variation respectively. Higher PC1 score corresponded to cooler temperatures, which tended to be associated with negative values in the climatic variables including high annual mean temperature (bio1), high minimum temperature of coldest month (bio6), high mean temperature of warmest quarter (bio10), high mean temperature of coldest quarter (bio11), high precipitation seasonality (bio15), all of which had absolute loadings greater than 0.27 (Figure 3). Higher PC2 scores corresponded to a more humid climate with low temperature variability, including low mean diurnal range (mean of monthly (max temp—min temp); bio2), low temperature annual range (bio7), high annual precipitation (bio12) and high precipitation of warmest quarter (bio18), all of which had absolute loadings greater than 0.35 (Figure 4).

We found that on islands where targeted amphibian survey(s) were conducted ($n = 67$), species richness decreased with increasing island isolation (Estimate = −9.27e-03, $z = -2.26$, $p = 0.0236$) and increased in more humid climates with low temperature variability (PC2: Estimate = 1.41e-01, $z = 2.66$, $p = 0.0076$; Figure 5). On islands where targeted amphibian survey(s) were not conducted ($n = 105$), isolation (Estimate = −7.27e-03, $z = -1.721$, $p = 0.0852$) and island area (Estimate = 1.73e-05, $z = 1.91$, $p = 0.0565$) were nearly significant in influencing amphibian richness, while climate had no significant effects on amphibian richness. Building upon the results from surveyed islands, we identified five of the closest islands to the mainland that have not been subjected to targeted surveys for amphibians (Table 4).

We found that on islands where targeted freshwater fish survey(s) were conducted ($n = 61$), species richness increased with increasing island area (Estimate = 5.29e-06, $z = 2.49$, $p = 0.0093$) (Figure 5), while isolation and climate had no significant effect on freshwater fish richness. For the same model where we included only obligate freshwater fish, we obtained similar results where freshwater fish richness increased only with island area (Estimate = 8.977e-06, $z = 2.204$, $p = 0.0162$). Building upon the results from surveyed islands, we identified five of the largest islands that have not been subjected to targeted surveys for freshwater fishes, including their respective PC scores (Table 5). On islands without targeted fish surveys ($n = 15$), none of the island characteristics had significant effects on freshwater fish species richness on islands. In addition, we found that the proportion of obligate freshwater fishes decreased with cooler temperatures, and a more humid climate with low temperature variability (PC1: Estimate = −2.25e-01, $z = -2.675$, $p = 0.00747$; PC2: Estimate = −5.34e-01, $z = -3.311$, $p = 0.0009$). The proportion of obligate freshwater fishes on islands also increased with increasing distance from the mainland (PC1: Estimate = 1.46e-02, $z = 2.148$, $p = 0.0317$).

4 | Discussion

While substantial work has been done on island biodiversity and the importance of islands in conservation, often with focus on birds and mammals, major gaps remain in our knowledge of other taxonomic groups, such as amphibians and freshwater fish. This study helps to fill major knowledge gaps in our understanding of

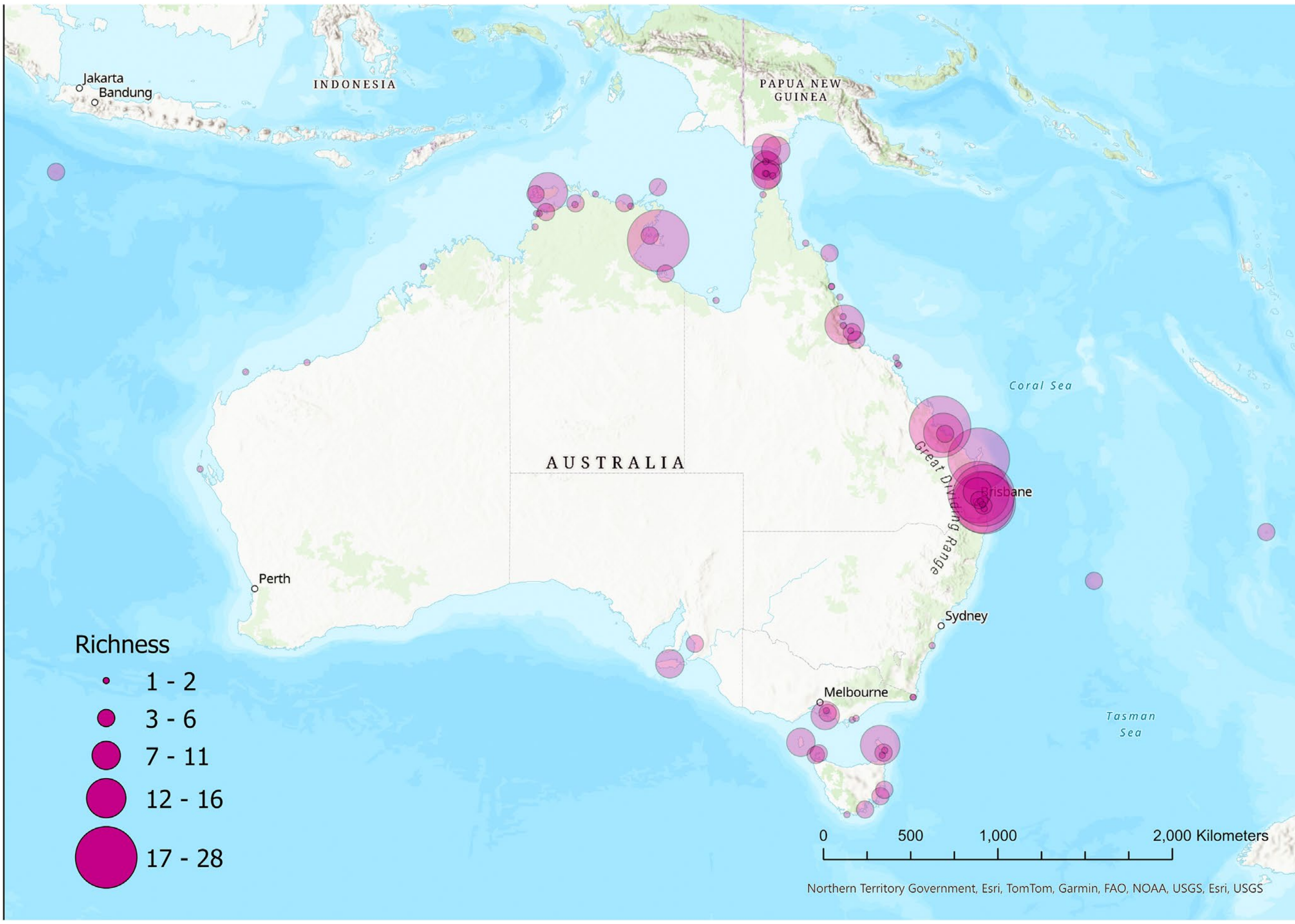

FIGURE 3 | Map showing the number of freshwater fishes found on each island. The size of each circle represents the number of species recorded on each island. Species counts were obtained from the database on occurrences of amphibians and freshwater fishes of Australia's islands, which was derived from literature reviews, and field survey data where available.

the distribution and drivers of richness of amphibians and freshwater fishes on islands by creating and studying the first specific database of occurrences of amphibians and freshwater fishes on all Australian islands. By combining extensive primary and grey literature sources with existing databases such as the Atlas of Living Australia (ALA), further integrated with multi-layer spatial information, we aimed to provide large-scale and comprehensive data important for informing conservation and management decisions and to provide a baseline for future studies on phylogeny, distribution and spatial conservation prioritisation.

Using the database we find that both amphibian and freshwater fishes' diversity hotspots on islands were generally congruent to their known mainland hotspots (Knight and Tyler 2020; Unmack 2001). Factors that shaped species richness on islands were partially in line with the classic island biogeography theory (MacArthur and Wilson 1963, 2001) in that islands closer to the mainland that had a more humid climate and lower temperature variability hosted higher amphibian richness, also matching the general environmental requirements of amphibians (Duellman and Trueb 1994). Larger islands hosted higher freshwater fish richness potentially due to greater habitat diversity and resource availability (Rodriguez-Silva and Schlupp 2021).

The paucity of amphibian and freshwater fish records on islands with freshwater sources relative to the mainland could be due to unsuitable habitats or limited sampling effort on these islands. While the Digital Earth Australia Waterbodies database (Dunn et al. 2024) included water bodies larger than 2700 square metres that are present for more than 10% of the time, it could include ephemeral freshwater sources that were dry for approximately 90% of the year. To survive in such ephemeral habitats, amphibians and freshwater fishes usually require special adaptations to avoid desiccation (Kerezsy et al. 2017; Walls et al. 2013). The lack of freshwater fauna records could also be due to the limited sampling effort. For instance, only 67 of the 176 islands with amphibian occurrences had targeted amphibian surveys, highlighting the overall lack of dedicated surveys on islands where amphibians were already known to exist. For freshwater fishes, while most islands with freshwater fishes recorded also had targeted surveys conducted, this does not necessarily indicate that freshwater fishes were sampled comprehensively. Freshwater fishes may be less represented in citizen science efforts than frogs (Feldman et al. 2021), potentially due to lower detectability as frogs produce vocalisations during mating seasons that can be recorded and uploaded to citizen science platforms (Rowley et al. 2019). In contrast, detecting fish traditionally

TABLE 3 | List of top 10 islands with the highest freshwater fish richness in Australia, including the island's latitude, longitude, area (ha), distance from mainland (km) and climate zone.

Island Name	Richness	Exotic	Threatened	State	Tenure	Longitude	Latitude	Distance (km)	Area (ha)	Climate zone
K'gari	28	1	5	QLD	Conservation reserve	153.14	−25.26	1.27	166,170	2
Groote Eylandt	21	0	0	NT	Aboriginal freehold—inalienable	136.64	−14.02	40.07	228,518	1
North Stradbroke Island	20	2	3	QLD	Mixed tenure	153.45	−27.55	3.56	26,949	2
Bribie Island	19	3	4	QLD	Mixed tenure	153.14	−26.99	0.26	14,757	2
Peel Island	19	4	2	QLD	Freehold	153.36	−27.50	4.79	520	2
Curtis Island	18	2	0	QLD	Mixed tenure	151.15	−23.61	0.13	57,646	2
Moreton Island	19	1	3	QLD	Conservation reserve	153.41	−27.15	21.23	17,149	2
Boyne Island	16	2	0	QLD	Conservation reserve	151.32	−23.93	0.14	3285	2
Melville Island	15	0	0	NT	Aboriginal freehold—inalienable	130.96	−11.54	24.08	578,577	1
Hinchinbrook Island	13	0	1	QLD	Conservation reserve	146.24	−18.36	0.72	39,613	1

requires dedicated methods such as snorkelling, electrofishing, or netting (Gundelund et al. 2021; Portt et al. 2006), which likely resulted in fewer citizen science records compared to frogs. The discrepancy in recorded number of species of freshwater fishes and amphibians could be attributed to the fact that fewer islands were subjected to both targeted and non-targeted sampling for freshwater fishes, which could lead to a lower overall total number of species documented on islands. This emphasises the need for more systematic and targeted surveys to record the distribution of freshwater fishes on islands, which may be underrepresented in current data.

4.1 | Amphibian Occurrences on Islands

Amphibians were well represented on islands (102 species), with nearly half of all Australia's ~230 species. The hotspots of amphibian richness on continental islands corresponded closely with hotspots in mainland Australia, including the north of Northern Territory, Cape York Peninsula of northern Queensland, the extreme southwest of Western Australia and the south-east of Australia. The overlap in species richness hotspots could be due to similar ecological conditions of the island to the mainland, where the island was able to sustain the mainland's larger source pool of amphibian species. These islands may have retained habitat for mainland lineages at the time of isolation which supports the persistence of pre-existing amphibian populations. The most dominant family on islands (Pelodryadidae) is ecologically and morphologically diverse, occupying different niches (Knight and Tyler 2020). On islands the Australo-Papuan treefrogs were only represented by *Litoria* spp. and *Cyclorana* spp., including both terrestrial and arboreal species. The second-most represented family is Myobatrachidae which is endemic to Australia. Of all Australian amphibian families, Myobatrachidae has the greatest diversity in life history traits, ranging from aquatic to direct development (Anstis 2018). Their diverse life history traits, hypothesized to be evolving towards being direct developers (Anstis 2018), potentially contributed to their success in colonising or surviving on islands.

The two IUCN-listed Vulnerable amphibian species in the database—southern bell frog (*Litoria raniformes*) and wallum sedge frog (*Litoria olongburensis*)—both face various threats including chytrid fungus, habitat degradation and invasive species (Geyle et al. 2021; Gillespie et al. 2020; Wassens 2008). Both species can also be found on mainland Australia, however this does not diminish the conservation significance of their populations on islands. In fact, a considerable portion of their populations may reside on islands, where levels of threat could potentially be higher than the mainland (Russell and Kueffer 2019; Tye et al. 2018), and/or they act as important refuge populations (Mills et al. 2004). The island populations could also represent cryptic species yet to be formally described (Parkin et al. 2024). For example, scarlet-sided pobblebonk (*Limnodynastes terraereginae*) was initially believed to occur on K'gari (Fraser Island), North Stradbroke Island (Minjerribah) and Whitsunday Islands. However, recent genetic analysis revealed that *L. terraereginae* is a cryptic species, and the individuals found on these islands belong to *L. grayi*, a newly described species (Parkin et al. 2024).

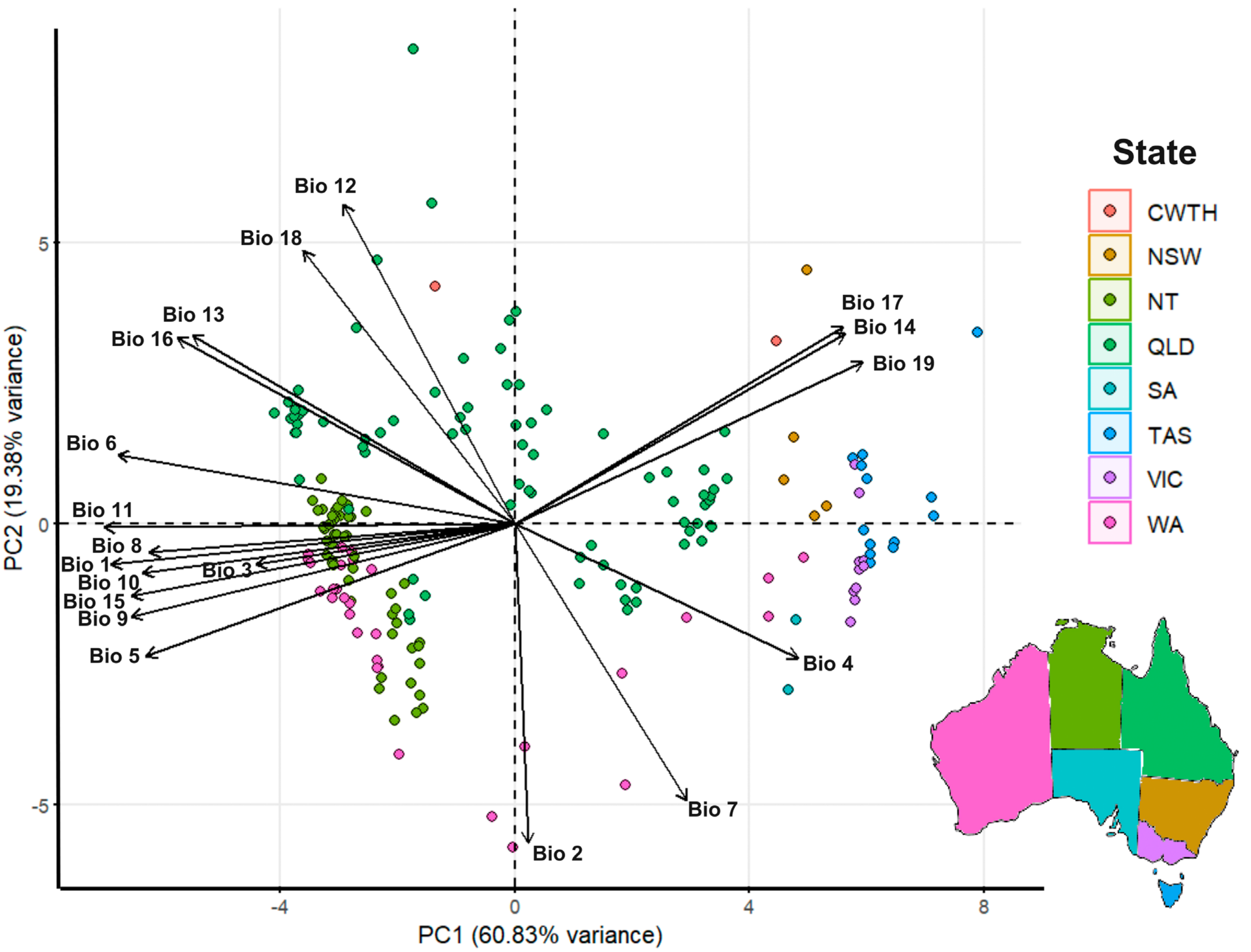

FIGURE 4 | A biplot from principal component analysis of 19 bioclimatic variables (bio1–bio19) from WorldClim on all Australian islands where amphibians or freshwater fishes were recorded (n = 197). Islands were coloured by the Australian state they were in.

The high number of occurrences of cane toads on islands is concerning given their well-documented impact on native wildlife (Shine 2010). Cane toads (*Rhinella marina*) not only compete with native amphibians and fishes for food and breeding sites, but their toxicity throughout all life-stages poses significant threats to a range of native predators (Burnett 1997; Doody et al. 2021). Some native freshwater fishes were known to die from eating eggs and tadpoles of toads in captivity (Greenlees and Shine 2011), however the extent of this interaction in the wild is unknown. Moreover, the recorded number of alien amphibian species on Australian islands likely underestimated the true extent of amphibian invasions. Amphibians that are native to specific regions of mainland Australia could act as invasive species when introduced to other parts of the continent, including islands (Plenderleith et al. 2015). For example, the green tree frog (*Litoria caerulea*) and bleating tree frog (*Litoria dentata*), although native to many parts of mainland Australia, have established populations on islands where it did not historically occur such as oceanic islands like Norfolk Island and Lord Howe Island via anthropogenic means (McCormack and Coughran 2009; Plenderleith et al. 2015). Therefore, even “native” species that were found on these islands could be resulted from human-mediated introductions. Due to their regional nativeness, these species are often overlooked in assessments of invasiveness, making them “silent” aliens that are harder to detect and manage.

4.2 | Freshwater Fish Occurrence on Islands

Areas of highest freshwater fish richness were generally congruent with mainland hotspots (Unmack 2001), particularly on the east coast of Queensland, north Queensland, the Northern Territory and the north of Western Australia. Their presence on islands, like amphibians, could be due to the islands retaining the mainland assemblage from the most recent period of connectivity during low sea-levels, or due to the fishes colonising the islands after isolation (primarily diadromous or euryhaline species). These islands are also likely to share relatively similar climatic conditions and habitat types with adjacent mainland regions, which may facilitate the persistence of mainland lineages. However, the continental part of Cape York Peninsula, which showed the highest recorded richness in freshwater fishes, only had moderate richness on its adjacent islands. This could be due to the generally small island size in Cape York Peninsula, where freshwater fish richness was limited by the availability and diversity of freshwater habitats on the island (Rodriguez-Silva and Schlupp 2021).

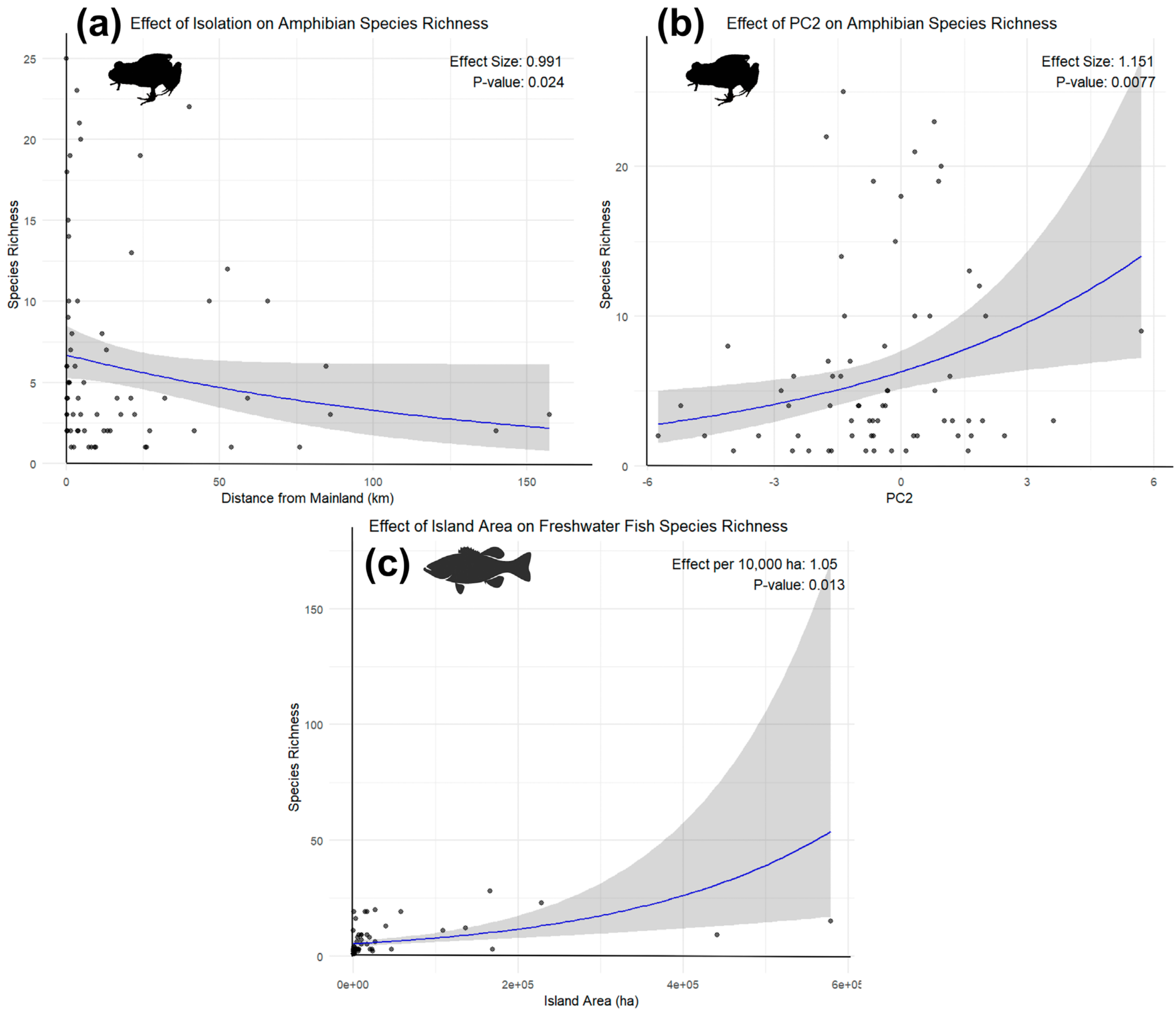

FIGURE 5 | The effect of island variables on amphibian and freshwater fishes richness on Australian islands. The black dots represent individual islands, and the grey shaded area represents the 95% confidence interval for the regression. (a) The effect of isolation (distance from mainland in square kilometres) on amphibian richness ($n=67$). (b) The effect of PC2 (humid climate with low temperature variability, associated with bio2, bio7, bio12 and bio18) on amphibian richness ($n=67$). (c) The effect of island area (hectares) on freshwater fish richness ($n=61$).

Several families of freshwater fishes were particularly prominent on islands, potentially attributable to their life history traits, adaptability and overall diversity in mainland Australia. Notably, the sleepers (Eleotridae), rainbowfishes (Melanotaeniidae), galaxids (Galaxiidae) and gobies (Gobiidae) were well-represented on the islands (Figure 1). Many species of sleepers, galaxids and gobies are not obligate freshwater species, tolerating a certain degree of salinity or being diadromous (R. McDowall 2004). These traits facilitate their dispersal across marine barriers, allowing them to colonise islands more readily than obligate freshwater species (R. McDowall 2004; Miles 2007). Rainbowfishes (Melanotaeniidae), although not diadromous, are diverse on the mainland and exhibit remarkable adaptability to different freshwater habitats (Humphries and Walker 2013; McGuigan et al. 2003). Therefore, a high diversity of rainbowfish persisted on islands after being separated from the mainland.

Several factors potentially contributed to the higher proportion of threatened freshwater fishes than amphibians found on islands, but notably, geographical isolation is likely important (Angermeier 1995; Lintermans et al. 2020). Non-migratory freshwater fishes, in particular, are highly vulnerable to localised threats due to their limited ability to respond to imminent danger (Garnett et al. 2022). For instance, the Barrow cave gudgeon (*Milyeringa justitia*) is found in aquifers accessed via freshwater bore holes on Barrow Island, where its limited habitat is threatened by water abstraction, sedimentation and water pollution from mining, leading to its Critically Endangered status (IUCN 2023; Larson et al. 2013). Other examples include the Oxleyan pygmy perch (*Nannopercaa oxleyana*) and ornate rainbowfish (*Rhadinocentris ornatus*), both restricted to Australia's eastern coast, and also classified as Endangered and Vulnerable by the IUCN red list (IUCN 2023). Non-obligate freshwater species may have higher mobility in

TABLE 4 | List of top 5 islands closest to mainland Australia that have not been subjected to targeted amphibian surveys, including the island's amphibian richness, state, tenure, longitude, latitude, distance from mainland (km), area (ha), climate zone and their PC values.

Island Name	Richness	State	Tenure	Longitude	Latitude	Distance (km)	Area (ha)	Climate zone	PC1	PC2
Howard Island	3	NT	Aboriginal freehold—inalienable	135.40	−12.15	0.05	27,324	1	−3.11106	−0.69487
NA	1	NT		130.33	−12.89	0.06	10	1	−3.09927	−0.74374
NT Island Number C033	4	NT		129.78	−14.81	0.06	1868	1	−2.2681	−2.73759
NA	1	QLD		153.08	−26.91	0.08	11	2	2.895586	0.012299
St Margaret Island	4	VIC	Conservation Reserve	146.83	−38.62	0.09	1889	6	5.805823	−1.3591

TABLE 5 | List of top 5 largest islands in Australia that have not been subjected to targeted freshwater fish surveys, including the island's freshwater fish richness, state, tenure, longitude, latitude, distance from mainland (km), area (ha), climate zone and their PC values.

Island name	Richness	State	Tenure	Longitude	Latitude	Distance (km)	Area (ha)	Climate zone	PC1	PC2
Dirk Hartog Island	2	WA	Crown leasehold	113.05	−25.79	1.51	62,775	3	1.882565	−4.65187
Bruny Island	3	TAS	Mixed tenure	147.29	−43.33	1.35	35,552	7	7.111917	0.460283
Augustus Island	1	WA	Aboriginal reserve	124.55	−15.36	1.588	19,179	1	−3.32523	−1.19583
Clarke Island	1	TAS	Vacant crownland	148.17	−40.53	21.12	8176	7	6.068104	−0.37087
Magnetic Island	6	QLD	Mixed tenure	146.83	−19.14	4.45	5067	1	−0.07313	0.334549

responding to localised threats, however they face different threats such as the blockage of ocean-freshwater linkages that could be detrimental to their reproductive cycles involving movement (Beger et al. 2010).

The introduction of invasive freshwater fish species poses a significant threat to native island ecosystems. Among the nine alien species recorded, five were livebearers from the family Poeciliidae, known for their rapid reproduction and adaptability which contributes to them being successful invaders worldwide (Deacon et al. 2011). The oceanic Christmas Island presents a stark example, where most recorded freshwater fishes are alien species, including four livebearers and a cichlid (*Oreochromis* sp.). The complete dominance of invasive species on Christmas Island suggests that native freshwater fishes were either absent or have been entirely displaced. In contrast, Lord Howe Island, which is also an oceanic island, has only native diadromous species. Overall, the variation in the distribution of invasive species across islands is likely influenced by factors such as geographical location and frequency of freight from the mainland, which in turn affect each island's susceptibility to different introduction pathways (García-Díaz et al. 2018; Tye et al. 2018).

4.3 | Influence of Island Characteristics on Amphibian Diversity

For islands where targeted amphibian surveys were conducted, islands close to the mainland hosted more amphibian species. This pattern aligns with the classic island biogeography theory which states that island species richness declines with increasing isolation due to reduced immigration rates (MacArthur and Wilson 2001). Because amphibians typically have limited dispersal abilities across saltwater barriers (Duellman and Trueb 1994), islands closer to the mainland are more accessible for colonisation events (e.g., hitch-hiking on floating vegetation or debris; Vences et al. 2003), leading to higher species richness. It is also possible that islands closer to the mainland were more likely to retain mainland amphibian richness and assemblages following geographical isolation. Islands with high precipitation and climatic stability (positive PC2 value) tended to support more amphibian species. Amphibians are highly water-dependent, relying on moist environments for physiological processes such as cutaneous respiration and for breeding (Duellman and Trueb 1994). Therefore, these findings are consistent with the ecological requirements of amphibians, highlighting the importance of sufficient rainfall, high humidity and stable temperatures for their persistence and reproductive success.

Amphibian richness not increasing with temperature is somewhat counterintuitive, given the common trend of amphibian richness being higher closer to the tropics where temperatures are typically warmer (Harvey et al. 2020; Willig et al. 2003). This discrepancy could potentially be explained by a combination of ecological and biogeographical factors. Warmer climates in the context of Australia's islands could be associated with high evaporation rates and less reliable water sources, increasing the risk of desiccation. Moreover, some species may possess physiological and behavioural adaptations that enable them to thrive in cooler environments (Feder and Burggren 1992). These adaptations may allow them to exploit niches that are less accessible to species in warmer regions, contributing to relatively high local richness in these environments.

Our finding that island area did not have a significant effect on amphibian richness in this subset of islands contrasts with the species-area relationship commonly observed in island biogeography, where larger islands tend to support more species due to greater habitat diversity and resource availability (MacArthur and Wilson 2001). For amphibians, however, factors such as habitat quality, availability of freshwater and microclimatic stability may be more critical than island size (Hortal et al. 2009). Smaller islands with suitable freshwater sources, especially the ones closer to the mainland, may still retain amphibian populations that originated from the mainland, while habitat quality and climatic suitability may outweigh the benefits of larger island area in determining amphibian diversity. Furthermore, other factors such as the elevation and topography in each island could also obscure the effect of island size on richness (Rodriguez-Silva and Schlupp 2021). For example, the richness of macroinvertebrates on Caribbean islands could not be fully explained by the island biogeography theory, where other ecological factors such as elevation and rainfall could outweigh the importance of island size (Bass 2003).

On islands where no targeted amphibian surveys were conducted, sampling biases likely contributed to the higher recorded richness on islands that are larger and closer to the mainland. Records in this subset, as far as we know, were derived from incomprehensive sampling methods, such as incidental records or data from citizen science platforms such as iNaturalist (Roger et al. 2023). These data are often biassed towards more accessible locations that are frequently visited by humans, leading to underrepresentation of more remote or less accessible areas (Geldmann et al. 2016). In the context of our study, islands that are larger and closer to the mainland are more likely to be visited by humans; hence, they were more subjected to opportunistic sampling, which could inflate the observed richness of those islands.

4.4 | Influence of Island Characteristics on Freshwater Fishes Richness

On islands where targeted freshwater fish surveys were conducted, larger islands supported significantly more freshwater fish species. This pattern aligns with the classic island biogeography theory which states that island species richness tends to increase with island size due to greater habitat diversity and resource availability (MacArthur and Wilson 2001). Larger islands are more likely to have a variety and permanency of freshwater habitats, including streams, ponds and wetlands, which can support a greater diversity of fish species. Islands that exhibited the highest freshwater fish richness were the larger islands such as K'gari, Groote Eylandt and North Stradbroke Island (Table 3), all of which possess substantial freshwater habitats, including lakes, streams and wetlands, which provide suitable environments for a variety of freshwater fishes (Hammer et al. 2021; Marshall et al. 2011; Yule 2019).

Isolation may not play a crucial role in determining freshwater fish richness on islands, as it did for amphibians. Geological events such as past land connections during lower sea levels and bathy river connections may have increased connectivity between island freshwater systems and the mainland, facilitating the dispersal of freshwater fishes (Unmack 2001). The non-significant effect of isolation can also be potentially attributed to the presence of euryhaline and diadromous species, which can tolerate a range of salinities and migrate between marine and freshwater environments. The marine phase of diadromous fish life cycles facilitates dispersal via ocean currents, enhancing their likelihood of establishing populations in island freshwater habitats (R. McDowall 2004). This is particularly evident in amphidromous fish species, such as gobies in the subfamily Sicydiinae and catadromous species like members of the genus *Kuhlia*, which are frequently encountered on islands (R. McDowall 2004). These species are better suited to overcome the dispersal barriers imposed by high salinity, allowing them to colonise islands regardless of their distance from the mainland (Miles et al. 2013).

If dispersal abilities were solely responsible for the distributional patterns, we would expect lower obligate freshwater fish richness on islands further away from the mainland as we assume they have a limited capacity to disperse across saltwater. Additionally, we might anticipate that the proportion of obligate freshwater fishes relative to non-obligate fishes (euryhaline and diadromous species) would decrease further away from the mainland. Interestingly, our results were counterintuitive: island area remained the only significant predictor for obligate freshwater fish richness, while the proportion of obligate freshwater fishes increased strongly with warmer temperatures, drier climate with high temperature variability, and increased weakly with increasing distance from themainland.

There are two potential explanations for this phenomenon. First, the current species present on islands may be remnants of mainland populations that persisted after the islands were isolated from the mainland. In this scenario, fishes did not disperse from the mainland to colonise the islands but were already present when the islands became isolated. Second, distance from the mainland may not play an important role in geographical isolation for all freshwater fishes, possibly due to the inherent higher salinity tolerance of many Australian freshwater fish species (although most cannot survive full salinity) (R. M. McDowall 1997; Miles 2007; Myers 1938). Some believe that most Australian fish families are secondarily freshwater (Myers 1938) and moved inland only in the last few million years (Myers 1938; Unmack 2001), and consequently, numerous fish species may still retain marine traits inherited from their ancestors, giving them an advantage in colonising islands (Augspurger et al. 2017; Franklin and Gee 2019). Historical geological events have reduced the barriers imposed by marine habitats on fish dispersal. In this context, parameters such as maximum sea depth and the channel flow rate between the island and mainland could be better at representing isolation than distance from the mainland. These two explanations are not mutually exclusive as new species from the mainland could still colonise islands with existing fish populations.

Unlike amphibians, the overall diversity of freshwater fishes on islands was not significantly influenced by the island's climate. However, when examining community composition, we found that the proportion of obligate freshwater fishes on islands increased with warmer temperatures, drier climate with high temperature variability and increased weakly with increasing distance from the mainland. This pattern may be attributed to a relative decrease in diadromous or euryhaline fishes in such climates; however, substantial knowledge gaps persist regarding the global distribution of diadromous and euryhaline fishes.

4.5 | Conservation Implications

This study provides insights into the richness and distribution of freshwater fishes and amphibians on Australian islands, highlighting key factors influencing their occurrences. Our findings have important implications for the conservation of the two groups, particularly in the context of habitat conservation, protection of threatened species, management of invasive species and creating a baseline database for future work on conservation prioritisation. Protecting islands close to the mainland could be effective in conserving amphibian richness on islands, while conserving diverse freshwater habitats on islands could be effective for conserving freshwater fish richness. Our study identifies key knowledge gaps in amphibian and freshwater fish surveys on Australian islands, highlighting islands with potential for high species richness that have not had a targeted survey conducted (Tables 4 and 5; Supporting Information). These islands may have environmental conditions that can sustain high amphibian and freshwater fish richness; however, they were yet to be surveyed specifically for the two groups. Given that amphibian richness is higher on islands closer to the mainland and freshwater fish richness is higher on larger islands, prioritising the surveying of closer and larger islands could reveal previously undocumented diversity. Future targeted surveys on these islands would improve our understanding of island amphibian and freshwater fish diversity to inform conservation decisions. In addition to biogeographic and climatic factors, anthropogenic variables such as habitat degradation and invasive species can lead to extirpation or extinctions which will influence documented amphibian and freshwater fish richness on islands (Lintermans et al. 2020). These anthropogenic impacts may obscure biogeographic patterns, particularly on more urbanised islands. While this study focused primarily on natural drivers of amphibian and freshwater fish richness on islands, future work incorporating anthropogenic pressures could help understanding the novel factors shaping island freshwater biodiversity. We recommend future work to conduct a dedicated spatial conservation prioritisation analysis, incorporating variables such as anthropogenic factors, potential for richness and cost of sampling to guide the planning of surveys and conservation actions on Australia's islands.

Extraction of freshwater sources on islands should be carefully monitored to prevent over-exhaustion of the resources (Lehner and Döll 2004), which could degrade the habitat of threatened species, such as the Barrow cave gudgeon (Larson et al. 2013). It is also important to maintain ocean-freshwater linkages for diadromous species (Pelicice et al. 2015; Su et al. 2021). Amphibians and obligate freshwater fish are highly dependent on a wet climate. As climate change alters precipitation patterns and increases temperature extremes, amphibian populations on these islands are likely to face heightened risks of habitat loss and population declines (Hof et al. 2011). Tims and Saupe (2023) reported that fishes in higher latitudes, particularly those that are already threatened, face increased risk of climate-driven habitat degradation and loss. Tims and Saupe (2023) further predicted that climate change will drive a poleward shift in the distribution of Australian freshwater fishes, though their data primarily concern mainland populations rather than island occurrences. If these predictions hold true, obligate freshwater fishes on islands may be at even greater risk, as their isolation and geographic fixation limit opportunities for migration to more suitable habitats in response to changing climate conditions.

Invasive species pose a significant threat to global biodiversity, ranking as the second biggest threat, particularly to island ecosystems (Allendorf and Lundquist 2003). In freshwater environments, invasive species are known to predate upon native species, outcompete them and transmit diseases (Britton 2023; Cucherousset and Olden 2011; Kiruba-Sankar et al. 2018). Presently, Australia hosts 34 freshwater fish species that have established feral populations, a few of which are present on islands (Diggles et al. 2007). Notable examples include guppies (*Poecilia reticulata*), mosquito fish (*Gambusia affinis*), green swordtail (*Xiphophorus hellerii*) and Mozambique tilapia (*Oreochromis mossambicus*), all of which are notoriously invasive species with documented damages to local ecosystems (Esmaeili et al. 2014; Russell et al. 2012; Shine 2010). Research indicates that these invasive species prey upon native freshwater fauna, including amphibians and other fishes, thereby posing a significant threat to species with restricted distributions on islands (Heatwole and Rowley 2018; Kiruba-Sankar et al. 2018; Sorensen 2021). Of particular concern is the successful colonisation of remote islands such as Norfolk Island, where the number of invasive freshwater fauna may surpass that of native species (McCormack and Coughran 2009). While most alien freshwater fishes in Australia were introduced via aquarium trade (García-Díaz et al. 2018), it has been a growing concern that new species invade Australia via range expansion from Papua New Guinea, with Mozambique tilapia and climbing perch already recorded on northern islands of the Torres Strait (Waltham et al. 2023). To manage the impacts of invasive species, direct removal of invasive species from islands has been a successful management strategy (Saunders et al. 2010). However, this strategy has mostly been applied to every other animal except fish (Britton et al. 2011). Britton et al. (2011) have discussed the possibility of removing invasive freshwater fauna from islands; however, the lack of funding and available removal techniques remains a barrier to controlling invasive species impacts on islands (Britton et al. 2011; Leprieur et al. 2009).

4.6 | Considerations and Future Directions

While these findings provide valuable insights, several limitations must be considered when interpreting our results. (1) The heterogeneity and availability of freshwater habitats on many islands is poorly documented despite its known positive association with species richness in most cases (Agra et al. 2023). Although large islands with high amphibian and freshwater fish richness were documented as having stable and heterogeneous freshwater habitat types, that may not represent all islands, especially islands located in drier climates. (2) We did not control adaptive radiation of freshwater fauna on islands, which could inflate the richness of species (Losos and Ricklefs 2009). However, more than 90% of the species recorded in our database were not island endemic species, which likely limited the effect of inflation on our results. (3) Sampling biases may not have been fully addressed by classifying islands into those with or without targeted surveys. We only recorded whether data was derived from a targeted survey for records collected from our online literature search. There are potentially islands where targeted surveys were conducted for which we obtained the data from ALA but did not find surveys for during the manual literature search. These islands would not be treated as islands with targeted surveys in our analysis. There were potentially many islands that fell into this category, notably for amphibians, which would lower the sample size in the analysis for surveyed islands only. However, this limitation unlikely affected the validity of the results drawn from surveyed islands as the analyses were still only drawing results from islands that had targeted surveys conducted on them. (4) On islands where targeted surveys were conducted, the differences in sampling methods and sampling effort were not accounted for, which would affect the comparability of the data collected from the islands. However, in many cases the sampling methods on these islands were unknown, and given the lack of details on surveying effort, comparing islands that were surveyed using the same sampling method was not possible. (5) Some species on islands could represent cryptic species and the lack of taxonomical or phylogenetic research on island populations could lead to the overlooking of island endemic species that are yet to be classified. (6) Our new dataset presents presence-only data rather than presence–absence records. Overall, due to inconsistent and insufficient sampling effort across many islands, it was not possible to confidently validate species absences. In cases where false absences occur, the estimate of species richness of an island would be underestimated. Additionally, false absences may not be equally distributed among surveyed islands, which could affect the validity of the regression models. (7) Climate variables of each island were extracted from the centroid of each island, which may not capture the full climatic heterogeneity within an island, particularly the large islands with complex topography. While this method may oversimplify climatic variation on larger islands, it offers a practical and standardised way to approximate general island climate across a large spatial scale and enables comparability among islands of varying size and location.

Despite the limitations, this study has created an important resource for future research and provided important insights into the patterns and distribution of amphibians and freshwater fishes on Australia's islands. Future studies could build on our findings by conducting targeted field sampling for noted gaps, and phylogenetic analyses to compare island populations with their mainland counterparts. This can provide insights into evolutionary divergence and potential speciation events driven by geographic isolation. These studies could help identify unique evolutionary lineages on islands that could potentially be a concern for conservation. Additionally, further conservation efforts should be directed towards islands with high species richness, particularly those supporting a high number and proportion of threatened species. Identifying conservation priorities will be crucial for mitigating the impacts of habitat loss, invasive species and climate-driven changes on island biodiversity.

5 | Conclusion

By conducting a comprehensive literature search online in addition to collating existing databases, we created the first database documenting the occurrences of freshwater fishes and frogs on Australian islands. The database encompasses records of 102 amphibian and 98 freshwater fish species: 55 fishes were obligate freshwater species, 21 were euryhaline and 19 were diadromous. Amphibians were recorded on more islands and exhibited greater richness, likely due to limited survey efforts for fishes. Despite this, fishes had a higher proportion of threatened and alien species. Using regression analysis, we explored how island area, isolation (distance from mainland in kilometres) and climate affect species richness. We found that both amphibians and freshwater fish richness were higher on islands with wet climates. Islands closer to the mainland hosted higher amphibian richness, likely from retaining mainland amphibian assemblages after isolation or being more easily colonised. In contrast, larger islands hosted more freshwater fishes, where diverse habitats were likely to sustain more species. Isolation had no significant effect on freshwater fish richness on islands, potentially due to geological events that facilitated their colonisation of islands, or most species were already present on the land masses prior to isolation. Our study lays important groundwork for conservation and management, enhancing our understanding of the distributional patterns of island-dwelling amphibians and freshwater fishes in Australia. By further analysing the potential drivers of such patterns, we provide a reference for follow-up studies on their phylogeny. This research also reveals islands of potential conservation concern and provides a baseline for future spatial prioritisation work.

Author Contributions

Samuel C.L. Ho, Salit Kark, Simon P. Hart, Peter W.J. Baxter contributed to the study conception and design. Material preparation, data collection was performed by Samuel C.L. Ho. Data analysis was performed by Samuel C.L. Ho and Simon P. Hart. Michael P. Hammer contributed to the verification of presence absence, and the life history traits of freshwater fishes. Samuel C.L. Ho, Peter J. Unmack and Simon P. Hart contributed to interpretation and discussion of results. The first draft of the manuscript was written by Samuel C.L. Ho and were edited and revised by all co-authors. All authors read, revised and approved of the final manuscript.

Acknowledgements

We would like to thank Nga Yee Lai, James Tweed, Jessica Colins and Freshwater Collective for their feedback and support. We thank Andrew Rogers for preparing the shape files used in data extraction. We thank Ian Tibbetts and Hugh Possingham for their feedback on the interpretation of results. Open access publishing facilitated by The University of Queensland, as part of the Wiley - The University of Queensland agreement via the Council of Australian University Librarians.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The Occurrences of Freshwater Fishes and Frogs of Australian Islands database is available in the Supporting Information.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ddi.70062.

References

Agra, J., T. Cornelissen, A. B. Viana-Junior, and M. Callisto. 2023. "A Global Synthesis and Meta-Analysis of the Environmental Heterogeneity Effects on the Freshwater Biodiversity." *Oikos* 2024: e10186.

Albert, J. S., G. Destouni, S. M. Duke-Sylvester, et al. 2021. "Scientists' Warning to Humanity on the Freshwater Biodiversity Crisis." *Ambio* 50, no. 1: 85–94.

Allen, G., S. Midgley, and M. Allen. 2002. "A Field Guide to the Freshwater Fishes of Australia."

Allen, J., and P. Kershaw. 1996. "The Pleistocene—Holocene Transition in Greater Australia." In *Humans at the End of the Ice Age: The Archaeology of the Pleistocene—Holocene Transition*, 175–199. Springer.

Allendorf, F. W., and L. L. Lundquist. 2003. "Introduction: Population Biology, Evolution, and Control of Invasive Species." *Conservation Biology* 17: 24–30.

Angermeier, P. L. 1995. "Ecological Attributes of Extinction-Prone Species: Loss of Freshwater Fishes of Virginia." *Conservation Biology* 9, no. 1: 143–158.

Anstis, M. 2018. *Tadpoles and Frogs of Australia*. 2nd ed. New Holland Publishers.

Augspurger, J. M., M. Warburton, and G. P. Closs. 2017. "Life-History Plasticity in Amphidromous and Catadromous Fishes: A Continuum of Strategies." *Reviews in Fish Biology and Fisheries* 27: 177–192.

Balian, E. V., H. Segers, K. Martens, and C. Lévéque. 2008. *The Freshwater Animal Diversity Assessment: An Overview of the Results*. Springer.

Bass, D. 2003. "A Comparison of Freshwater Macroinvertebrate Communities on Small Caribbean Islands." *Bioscience* 53, no. 11: 1094–1100.

Baxter, P. W. J., A. M. Rogers, and S. Kark. 2021. "Saving Species on Australian Islands – Final Report."

Beger, M., H. S. Grantham, R. L. Pressey, et al. 2010. "Conservation Planning for Connectivity Across Marine, Freshwater, and Terrestrial Realms." *Biological Conservation* 143, no. 3: 565–575.

Britton, J., R. E. Gozlan, and G. H. Copp. 2011. "Managing Non-Native Fish in the Environment." *Fish and Fisheries* 12, no. 3: 256–274.

Britton, J. R. 2023. "Contemporary Perspectives on the Ecological Impacts of Invasive Freshwater Fishes." *Journal of Fish Biology* 103, no. 4: 752–764.

Burnett, S. 1997. "Colonizing Cane Toads Cause Population Declines in Native Predators: Reliable Anecdotal Information and Management Implications." *Pacific Conservation Biology* 3, no. 1: 65–72.

Cáceres-Polgrossi, L., F. Buldrini, V. Bruzzaniti, et al. 2024. "Climatic and Biogeographic Factors Show Contrasted Effects on Continental and Volcanic ISARs." *Community Ecology* 25: 1–359.

Carrete Vega, G., and J. J. Wiens. 2012. "Why Are There So Few Fish in the Sea?" *Proceedings of the Royal Society B: Biological Sciences* 279, no. 1737: 2323–2329.

Commonwealth of Australia. 2015. *Islands of Australia*. Commonwealth of Australia.

Cribari-Neto, F., and A. Zeileis. 2010. "Beta Regression in R." *Journal of Statistical Software* 34: 1–24.

Crossman, S., and O. Li. 2015. *Surface Hydrology Polygons (National)*. Geoscience Australia. https://pid.geoscience.gov.au/dataset/ga/83135.

Cucherousset, J., and J. D. Olden. 2011. "Ecological Impacts of Nonnative Freshwater Fishes." *Fisheries* 36, no. 5: 215–230.

Deacon, A. E., I. W. Ramnarine, and A. E. Magurran. 2011. "How Reproductive Ecology Contributes to the Spread of a Globally Invasive Fish." *PLoS One* 6, no. 9: e24416.

Diggles, B., C. Jubb, R. McDowall, A. Moore, A. Richards, and D. Rowe. 2007. "Review of the Impacts of Introduced Aquarium Fish Species That Have Established Wild Populations in Australia." Prepared for the Australian Government Department of Environment and Water Resources.

Doherty, T. S., R. A. Davis, E. J. van Etten, et al. 2015. "A Continental-Scale Analysis of Feral Cat Diet in Australia." *Journal of Biogeography* 42, no. 5: 964–975.

Doherty, T. S., A. S. Glen, D. G. Nimmo, E. G. Ritchie, and C. R. Dickman. 2016. "Invasive Predators and Global Biodiversity Loss." *Proceedings of the National Academy of Sciences of the United States of America* 113, no. 40: 11261–11265.

Doody, J. S., C. McHenry, D. Rhind, C. Gray, and S. Clulow. 2021. "Impacts of Invasive Cane Toads on an Endangered Marsupial Predator and Its Prey." *Endangered Species Research* 46: 269–277.

Dudgeon, D., A. H. Arthington, M. O. Gessner, et al. 2006. "Freshwater Biodiversity: Importance, Threats, Status and Conservation Challenges." *Biological Reviews* 81, no. 2: 163–182.

Duellman, W. E., and L. Trueb. 1994. *Biology of Amphibians*. JHU Press.

Dunn, B., C. Krause, V. Newey, et al. 2024. "Digital Earth Australia Waterbodies V3.0." https://doi.org/10.26186/148920.

Esmaeili, H. R., A. Teimori, O. Feridon, K. Abbasi, and W. C. Brian. 2014. "Alien and Invasive Freshwater Fish Species in Iran: Diversity, Environmental Impacts and Management." *Iranian Journal of Ichthyology* 1, no. 2: 61–72.

ESRI. 2011. *ArcGIS Desktop: Release 10*, 315–325. Environmental Systems Research Institute.

Feder, M. E., and W. W. Burggren. 1992. *Environmental Physiology of the Amphibians*. University of Chicago Press.

Feldman, M. J., L. Imbeau, P. Marchand, M. J. Mazerolle, M. Darveau, and N. J. Fenton. 2021. "Trends and Gaps in the Use of Citizen Science Derived Data as Input for Species Distribution Models: A Quantitative Review." *PLoS One* 16, no. 3: e0234587.

Franklin, P., and E. Gee. 2019. "Living in an Amphidromous World: Perspectives on the Management of Fish Passage From an Island Nation." *Aquatic Conservation: Marine and Freshwater Ecosystems* 29, no. 9: 1424–1437.

García-Díaz, P., A. Kerezsy, P. J. Unmack, et al. 2018. "Transport Pathways Shape the Biogeography of Alien Freshwater Fishes in Australia." *Diversity and Distributions* 24, no. 10: 1405–1415.

Garnett, S. T., B. K. Hayward-Brown, R. K. Kopf, et al. 2022. "Australia's Most Imperilled Vertebrates." *Biological Conservation* 270: 109561.

Geldmann, J., J. Heilmann-Clausen, T. E. Holm, et al. 2016. "What Determines Spatial Bias in Citizen Science? Exploring Four Recording Schemes With Different Proficiency Requirements." *Diversity and Distributions* 22, no. 11: 1139–1149.

Geyle, H. M., C. J. Hoskin, D. S. Bower, et al. 2021. "Red Hot Frogs: Identifying the Australian Frogs Most at Risk of Extinction." *Pacific Conservation Biology* 28, no. 3: 211–223.

Gillespie, G. R., J. D. Roberts, D. Hunter, et al. 2020. "Status and Priority Conservation Actions for Australian Frog Species." *Biological Conservation* 247: 108543.

Gillespie, T. W., G. Keppel, S. Pau, J. P. Price, T. Jaffré, and K. O'Neill. 2013. "Scaling Species Richness and Endemism of Tropical Dry Forests on Oceanic Islands." *Diversity and Distributions* 19, no. 8: 896–906.

Greenlees, M. J., and R. Shine. 2011. "Impacts of Eggs and Tadpoles of the Invasive Cane Toad (*Bufo marinus*) on Aquatic Predators in Tropical Australia." *Austral Ecology* 36, no. 1: 53–58.

Gundelund, C., P. Venturelli, B. W. Hartill, K. Hyder, H. J. Olesen, and C. Skov. 2021. "Evaluation of a Citizen Science Platform for Collecting Fisheries Data From Coastal Sea Trout Anglers." *Canadian Journal of Fisheries and Aquatic Sciences* 78, no. 11: 1576–1585.

Hammer, M., A. Bourke, O. Biriukova, and J. Archibald. 2021. *Groote Eylandt Bush Blitz Freshwater and Estuarine Fishes*. BushBlitz.

Harvey, M. G., G. A. Bravo, S. Claramunt, et al. 2020. "The Evolution of a Tropical Biodiversity Hotspot." *Science* 370, no. 6522: 1343–1348.

Heatwole, H., and J. Rowley. 2018. *Status of Conservation and Decline of Amphibians: Australia, New Zealand, and Pacific Islands*. CSIRO Publishing.

Hervías, S., S. Oppel, F. M. Medina, et al. 2014. "Assessing the Impact of Introduced Cats on Island Biodiversity by Combining Dietary and Movement Analysis." *Journal of Zoology* 292, no. 1: 39–47.

Hijmans, R., S. Cameron, J. Parra, P. Jones, and A. Jarvis. 2005. "Very High Resolution Interpolated Climate Surfaces of Global Land Areas." *International Journal of Climatology* 25: 1965–1978. https://doi.org/10.1002/joc.1276.

Hines, H. B., and E. Meyer. 2011. "The Frog Fauna of Bribie Island: An Annotated List and Comparison With Other Queensland Dune Islands." *Proceedings of the Royal Society of Queensland* 117: 261–274.

Hof, C., M. B. Araújo, W. Jetz, and C. Rahbek. 2011. "Additive Threats From Pathogens, Climate and Land-Use Change for Global Amphibian Diversity." *Nature* 480, no. 7378: 516–519.

Hortal, J., K. A. Triantis, S. Meiri, E. Thébault, and S. Sfenthourakis. 2009. "Island Species Richness Increases With Habitat Diversity." *American Naturalist* 174, no. 6: E205–E217.

Humphries, P., and K. Walker. 2013. *Ecology of Australian Freshwater Fishes*. CSIRO Publishing.

Israilova, E., A. Voronina, and K. Shatila. 2023. "Impact of Water Scarcity on Socio-Economic Development." E3S Web of Conferences 458, 8027.

IUCN. 2023. "The IUCN Red List of Threatened Species." Version 2023-1. https://www.iucnredlist.org.

Kassambara, A., and F. Mundt. 2017. "Package 'Factoextra'. Extract and Visualize the Results of Multivariate Data Analyses." 76, no. 2.

Kerezsy, A., K. Gido, M. F. Magalhães, and P. H. Skelton. 2017. "The Biota of Intermittent Rivers and Ephemeral Streams: Fishes." In *Intermittent Rivers and Ephemeral Streams*, 273–298. Elsevier.

Kier, G., H. Kreft, T. M. Lee, et al. 2009. "A Global Assessment of Endemism and Species Richness Across Island and Mainland Regions." *Proceedings of the National Academy of Sciences of the United States of America* 106, no. 23: 9322–9327.

Kiruba-Sankar, R., J. P. Raj, K. Saravanan, et al. 2018. "Invasive Species in Freshwater Ecosystems–Threats to Ecosystem Services." In *Biodiversity and Climate Change Adaptation in Tropical Islands*, 257–296. Elsevier.

Knight, F., and M. Tyler. 2020. *Field Guide to the Frogs of Australia*. CSIRO Publishing.

Larson, H. K., R. Foster, W. F. Humphreys, and M. I. Stevens. 2013. "A New Species of the Blind Cave Gudgeon Milyeringa (Pisces: Gobioidei, Eleotridae) From Barrow Island, Western Australia, With a Redescription of *M. veritas* Whitley." *Zootaxa* 3616, no. 2: 135–150.

Legge, S., J. C. Woinarski, A. A. Burbidge, et al. 2018. "Havens for Threatened Australian Mammals: The Contributions of Fenced Areas and Offshore Islands to the Protection of Mammal Species Susceptible to Introduced Predators." *Wildlife Research* 45, no. 7: 627–644.

Lehner, B., and P. Döll. 2004. "Development and Validation of a Global Database of Lakes, Reservoirs and Wetlands." *Journal of Hydrology* 296, no. 1–4: 1–22.

Leprieur, F., S. Brosse, E. Garcia-Berthou, T. Oberdorff, J. Olden, and C. Townsend. 2009. "Scientific Uncertainty and the Assessment of Risks Posed by Non-Native Freshwater Fishes." *Fish and Fisheries* 10, no. 1: 88–97.

Lintermans, M., H. M. Geyle, S. Beatty, et al. 2020. "Big Trouble for Little Fish: Identifying Australian Freshwater Fishes in Imminent Risk of Extinction." *Pacific Conservation Biology* 26, no. 4: 365–377.

Losos, J. B., and R. E. Ricklefs. 2009. "Adaptation and Diversification on Islands." *Nature* 457, no. 7231: 830–836.

MacArthur, R. H., and E. O. Wilson. 1963. "An Equilibrium Theory of Insular Zoogeography." *Evolution* 17: 373–387.

MacArthur, R. H., and E. O. Wilson. 2001. *The Theory of Island Biogeography*. Vol. 1. Princeton University Press.

Marshall, J. C., P. M. Negus, A. L. Steward, and G. McGregor. 2011. "Distributions of the Freshwater Fish and Aquatic Macroinvertebrates of North Stradbroke Island Are Differentially Influenced by Landscape History, Marine Connectivity and Habitat Preference." *Proceedings of the Royal Society of Queensland* 117: 239–260.

McCormack, R. B., and J. Coughran. 2009. Norfolk Island Freshwater Aquatic Survey 2009.

McDowall, R. 2004. "Ancestry and Amphidromy in Island Freshwater Fish Faunas." *Fish and Fisheries* 5, no. 1: 75–85.

McDowall, R. M. 1997. "The Evolution of Diadromy in Fishes (Revisited) and Its Place in Phylogenetic Analysis." *Reviews in Fish Biology and Fisheries* 7: 443–462.

McGuigan, K., C. E. Franklin, C. Moritz, and M. W. Blows. 2003. "Adaptation of Rainbow Fish to Lake and Stream Habitats." *Evolution* 57, no. 1: 104–118.

Miles, N. G. 2007. Biology and Ecology of Diadromous Fishes in South Eastern Australia.

Miles, N. G., C. T. Walsh, G. Butler, H. Ueda, and R. J. West. 2013. "Australian Diadromous Fishes–Challenges and Solutions for Understanding Migrations in the 21st Century." *Marine and Freshwater Research* 65, no. 1: 12–24.

Mills, H. R., D. Moro, and P. B. Spencer. 2004. "Conservation Significance of Island Versus Mainland Populations: A Case Study of Dibblers (*Parantechinus apicalis*) in Western Australia." *Animal Conservation* 7, no. 4: 387–395.

MINCA. 2020. "Frogs (Amphibians) of Magnetic Island."

Mishra, R. K. 2023. "Fresh Water Availability and Its Global Challenge." *British Journal of Multidisciplinary and Advanced Studies* 4, no. 3: 1–78.

Myers, G. S. 1938. *Fresh Water Fishes and West Indian Zoogeography*. US Government Printing Office.

Nicholls, M. 2016. *Fishbase List of Freshwater Fishes Reported From Australia*. Atlas of Living Australia. https://lists.ala.org.au/speciesListItem/list/dr3608.

Parkin, T., J. J. Rowley, G. L. Gillard, J. Sopniewski, G. M. Shea, and S. C. Donnellan. 2024. "Systematics and Taxonomy of the Northern Banjo Frog (Anura: Limnodynastidae: *Limnodynastes terraereginae*) and Allied Taxa." *Ichthyology & Herpetology* 112, no. 1: 76–105.

Pelicice, F. M., P. S. Pompeu, and A. A. Agostinho. 2015. "Large Reservoirs as Ecological Barriers to Downstream Movements of Neotropical Migratory Fish." *Fish and Fisheries* 16, no. 4: 697–715.

Plenderleith, T. L., K. L. Smith, S. C. Donnellan, R. D. Reina, and D. G. Chapple. 2015. "Human-Assisted Invasions of Pacific Islands by Litoria Frogs: A Case Study of the Bleating Tree Frog on Lord Howe Island." *PLoS One* 10, no. 5: e0126287.

Portt, C. B., G. Coker, D. Ming, and R. G. Randall. 2006. *A Review of Fish Sampling Methods Commonly Used in Canadian Freshwater Habitats*. Department of Fisheries and Oceans.

R Core Team. 2013. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.

Rayner, M. J., M. E. Hauber, M. J. Imber, R. K. Stamp, and M. N. Clout. 2007. "Spatial Heterogeneity of Mesopredator Release Within an Oceanic Island System." *Proceedings of the National Academy of Sciences of the United States of America* 104, no. 52: 20862–20865.

Reader, S., A. Hay, and M. McGrouther. 2018. "The Australian Museum Lord Howe Island Expedition 2017—Freshwater Fishes." *Technical Reports of the Australian Museum Online* 26: 69–76. https://doi.org/10.3853/j.1835-4211.26.2018.1702.

Rees, M. W., J. H. Pascoe, M. Le Pla, et al. 2023. "Mesopredator Release Among Invasive Predators: Controlling Red Foxes Can Increase Feral Cat Density and Alter Their Behaviour." *Journal of Applied Ecology* 60, no. 6: 1100–1114.

Reid, A. J., A. K. Carlson, I. F. Creed, et al. 2019. "Emerging Threats and Persistent Conservation Challenges for Freshwater Biodiversity." *Biological Reviews* 94, no. 3: 849–873.

Rodriguez-Silva, R., and I. Schlupp. 2021. "Biogeography of the West Indies: A Complex Scenario for Species Radiations in Terrestrial and Aquatic Habitats." *Ecology and Evolution* 11, no. 6: 2416–2430.

Roger, E., D. Kellie, C. Slatyer, et al. 2023. "Open Access Research Infrastructures Are Critical for Improving the Accessibility and Utility of Citizen Science: A Case Study of Australia's National Biodiversity Infrastructure, the Atlas of Living Australia (ALA)." *Citizen Science* 8, no. 1: 56. https://doi.org/10.5334/CSTP.564.

Rowley, J. J., C. T. Callaghan, T. Cutajar, et al. 2019. "FrogID: Citizen Scientists Provide Validated Biodiversity Data on Frogs of Australia." *Herpetological Conservation and Biology* 14, no. 1: 155–170.

Russell, D., P. Thuesen, and F. Thomson. 2012. "A Review of the Biology, Ecology, Distribution and Control of Mozambique Tilapia, *Oreochromis mossambicus* (Peters 1852) (Pisces: Cichlidae) With Particular Emphasis on Invasive Australian Populations." *Reviews in Fish Biology and Fisheries* 22: 533–554.

Russell, J. C., and C. Kueffer. 2019. "Island Biodiversity in the Anthropocene." *Annual Review of Environment and Resources* 44, no. 1: 31–60.

Saunders, G., B. Cooke, K. McColl, R. Shine, and T. Peacock. 2010. "Modern Approaches for the Biological Control of Vertebrate Pests: An Australian Perspective." *Biological Control* 52, no. 3: 288–295.

Shine, R. 2010. "The Ecological Impact of Invasive Cane Toads (*Bufo marinus*) in Australia." *Quarterly Review of Biology* 85, no. 3: 253–291.

Sorensen, P. W. 2021. "Introduction to the Biology and Control of Invasive Fishes and a Special Issue on This Topic." *Fishes* 6: 69.

Strayer, D. L., and D. Dudgeon. 2010. "Freshwater Biodiversity Conservation: Recent Progress and Future Challenges." *Journal of the North American Benthological Society* 29, no. 1: 344–358.

Su, G., M. Logez, J. Xu, S. Tao, S. Villéger, and S. Brosse. 2021. "Human Impacts on Global Freshwater Fish Biodiversity." *Science* 371, no. 6531: 835–838.

Tims, A. R., and E. E. Saupe. 2023. "Forecasting Climate-Driven Habitat Changes for Australian Freshwater Fishes." *Diversity and Distributions* 29, no. 5: 641–653.

Tye, A., G. Key, and J. A. Copsey. 2018. "Threats to Islands: Invasive Species and Their Impacts." In *Species Conservation: Lessons From*

Islands, edited by J. A. Copsey, S. A. Black, J. J. Groombridge, and C. G. Jones, 83–120. Cambridge University Press. https://doi.org/10.1017/9781139030243.006.

Unmack, P. J. 2001. "Biogeography of Australian Freshwater Fishes." *Journal of Biogeography* 28, no. 9: 1053–1089.

Vences, M., and J. Köhler. 2008. "Global Diversity of Amphibians (Amphibia) in Freshwater." In *Freshwater Animal Diversity Assessment*, 569–580. Springer Netherlands.

Vences, M., D. R. Vieites, F. Glaw, et al. 2003. "Multiple Overseas Dispersal in Amphibians." *Proceedings of the Royal Society of London, Series B: Biological Sciences* 270, no. 1532: 2435–2442.

Walls, S. C., W. J. Barichivich, and M. E. Brown. 2013. "Drought, Deluge and Declines: The Impact of Precipitation Extremes on Amphibians in a Changing Climate." *Biology* 2, no. 1: 399–418.

Waltham, N. J., N. Snape, C. Villacorta-Rath, and D. Burrows. 2023. "New Australian Frontier in Freshwater Fish Invasion via Torres Strait Islands." *Biodiversity and Conservation* 32, no. 14: 4551–4571.

Wassens, S. 2008. "Review of the Past Distribution and Decline of the Southern Bell Frog *Litoria raniformis* in New South Wales." *Australian Zoologist* 34, no. 3: 446–452.

Whittaker, R. J., and J. M. Fernández-Palacios. 2007. *Island Biogeography: Ecology, Evolution, and Conservation*. Oxford University Press.

Willig, M. R., D. M. Kaufman, and R. D. Stevens. 2003. "Latitudinal Gradients of Biodiversity: Pattern, Process, Scale, and Synthesis." *Annual Review of Ecology, Evolution, and Systematics* 34, no. 1: 273–309.

WWF. 2022. *Living Planet Report 2022 – Building a Naturepositive Society*. WWF.

Yule, C. 2019. *K'Gari Survey of Freshwater Lakes and Streams*. University of the Sunshine Coast.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Appendix S1:** ddi70062-sup-0001-AppendixS1.csv. **Appendix S2:** ddi70062-sup-0002-AppendixS2.csv. **Appendix S3:** ddi70062-sup-0003-AppendixS3.docx.