Review

Are tropical oceanic islands overlooked? Knowledge gaps regarding the vulnerability of amphibians to global anthropogenic threats

RENOIR J. AUGUSTE*, AMY E. DEACON and MARK F. HULME

Abstract Climate and land-use changes are major threats to amphibian conservation. However, amphibians on tropical oceanic islands appear to have been overlooked with regards to their vulnerability to global anthropogenic threats. Here we examine whether there are gaps in research evaluating the vulnerability of tropical oceanic island amphibians to climate and land-use changes. We carried out a systematic review of the literature on experimental studies published during 1 July 1998–30 June 2022, to evaluate whether there are knowledge gaps in relation to geographical scope, taxonomic representation, life stage assessment, the factors affecting amphibians and how species and populations respond to these factors. Of 327 articles on climate change and 451 on land-use change, the research of only 18 was carried out on tropical oceanic islands, only on anurans, and < 20% of the authors were affiliated with an oceanic island institution. These 18 studies were on only five islands, and the range of families and life stages assessed was limited. We also found uneven research into the factors affecting oceanic island amphibians and their responses; analyses involving the effect of temperature on amphibian range expansion or contraction were the most common, with few studies of the effects of salinity. The scarcity and unevenness of research from oceanic islands limit our understanding of the effects of climate and land-use changes on amphibians. We discuss potential reasons for these knowledge gaps and recommend ways to address them, such as more equitable distribution of resources and provision of training and research opportunities for island-based biologists.

Keywords Anurans, climate change, conservation management, global threats, island biodiversity, land-use change, research gaps, small-island developing states

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Introduction

Amphibians are important both to the environment and to people (Hocking & Babbitt, 2014), but many are threatened with extinction, predominantly because of global threats posed by anthropogenic activities. Amphibians are the most imperiled vertebrate class, with > 40% of species categorized as threatened on the IUCN Red List (Luedtke et al., 2023). Of the many threats to amphibians, climate and land-use changes are amongst the most significant (Cushman, 2006; Lawler et al., 2010; Souza et al., 2019; Luedtke et al., 2023). Both can have detrimental impacts on amphibian habitats, resulting in negative effects on all amphibian life stages (Cushman, 2006; Bickford et al., 2010). For example, amphibian eggs and larvae are particularly vulnerable to desiccation (Carey & Alexander, 2003), which can be worsened by climate and land-use changes. The impacts of both threats overlap spatially (Hof et al., 2011) and could exacerbate other pervasive and pressing global threats to amphibians (Manzoor et al., 2021), and thus the evaluation of their effects is vital for global amphibian conservation.

Although amphibians are distributed globally, species richness is greatest in the tropics (AmphibiaWeb, 2024), where anthropogenic threats such as climate and land-use changes can have severe impacts (Becker & Zamudio, 2011; Hof et al., 2011). However, conservation assessments focused on amphibians have been more common in North America, Australia and Europe (Winter et al., 2016; Cordier et al., 2021). Amphibians on tropical islands appear to be less well evaluated yet are likely to be more vulnerable to climate and land-use changes because most have restricted ranges or are poor dispersers (Beebee, 1996). Furthermore, many already face harsh environmental conditions that are likely to be worsened by increasing anthropogenic activities (Foden et al., 2013; Pörtner et al., 2022).

Oceanic islands have never been connected to continents (Dawson, 2016). They vary considerably in size, age and topography and tend to have high endemism through isolation (MacArthur & Wilson, 1967), and thus are considered model systems for studying ecology and biodiversity (Graham et al., 2017). They are particularly vulnerable to climate and land-use changes that lead to droughts, temperature fluctuations, hurricanes and socio-economic constraints (Robinson, 2020;

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Pörtner et al., 2022). The high endemism, isolation and small size of many tropical oceanic islands make amphibian populations especially vulnerable to global threats (Ríos-López & Heatwole, 2023). Conservation efforts on tropical oceanic islands require particular attention because the capacity to effectively manage their biodiversity can be limited (Burt et al., 2022). However, there is little peer-reviewed literature on the adaptive capacity of species on tropical oceanic islands (Robinson, 2017), and information on the responses of tropical oceanic island amphibians to climate and land-use changes is sparse. Many amphibian species are endemic to tropical oceanic islands, and some are categorized as Data Deficient on the IUCN Red List and/or are found within a small area of occupancy (IUCN, 2023; AmphibiaWeb, 2024), further highlighting the need for improved conservation management. For example, 94% of amphibian species in Cuba and 84% of those in Jamaica are endemic (AmphibiaWeb, 2024). A better understanding of the responses of such amphibians to growing global anthropogenic threats could provide much-needed insights to help tropical oceanic islands fulfil the United Nations Sustainable Development Goals (e.g. Goal 15: Life on Land; United Nations, 2023) and preserve amphibian biodiversity.

Given the urgent need to assess the effects of climate and land-use changes on amphibians on tropical oceanic islands, we ask: (1) Is there less research into the effects of climate and land-use changes on amphibians on tropical oceanic islands compared to continental areas? (2) What are the taxonomic gaps in our knowledge of amphibians and their responses to these global anthropogenic threats? (3) Are there gaps in our knowledge of the life stages of amphibians and their responses to these threats? (4) Has there been an even distribution of research into climate or land-use factors impacting amphibians, and how do species and populations respond to these factors?

Methods

Author RJA systematically searched the peer-reviewed literature published during 1 July 1998–30 June 2022 using Web of Science (Clarivate Analytics, Philadelphia, USA) supplemented with Google Scholar (Google, Mountain View, USA) on 11 November 2022. The search protocol is outlined in Fig. 1. The search terms included a combination of the threats and either 'caecilian', 'anuran', 'frog' or 'toad', but not 'salamander', as salamanders do not naturally occur on tropical oceanic islands (AmphibiaWeb, 2024). We grouped the locations of studies as North America (the USA, Canada and Mexico), Europe (including the UK), Central and South America (inclusive of continental islands), Asia (inclusive of continental islands), Australia and New Zealand, Africa (including Madagascar) and tropical islands that are true oceanic islands (between the Tropic of Cancer 23.5°N and Tropic of Capricorn 23.5°S), with amphibian orders as documented in AmphibiaWeb (2024). For all studies that took place on tropical oceanic islands, we noted the location of each author's affiliation. If an author was listed on more than one paper, we only counted them once. We generated data visualizations using the package *ggplot2* (Wickham, 2016) in *R 4.1.2* (R Core Team, 2021) to illustrate the geographical scope and author affiliations of the studies on tropical oceanic islands.

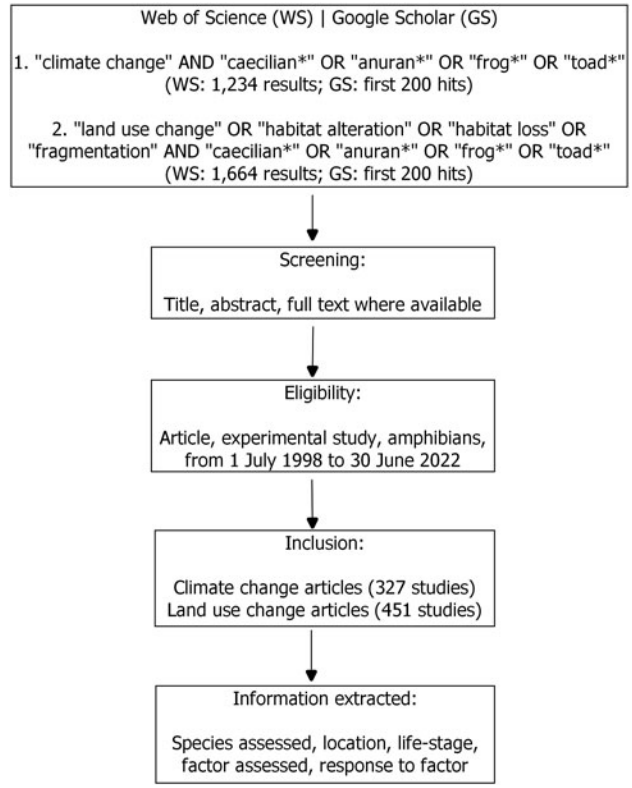

FIG. 1 Search protocol used for a systematic review of the literature on experimental studies examining the effects of climate and land-use changes on amphibians published during 1 July 1998–30 June 2022.

In addition to recording the study location, species and life stage, we noted the factors assessed and the biological responses to these factors for each tropical oceanic island-based study. The factors analysed in these studies were temperature, precipitation, relative humidity and salinity in relation to climate change, and habitat disturbance in relation to land-use change. The responses were range expansion or contraction, body size change, changes in calling activity (e.g. call duration), changes in species diversity, detection and occupancy, changes in abundance, and changes in biochemistry (e.g. concentration of defence chemicals produced). We generated a radar chart using the *R* package *fmsb* (Nakazawa, 2022) to illustrate the degree of evenness in factors and responses.

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Results

From the literature search we found 327 articles assessing amphibian responses to climate change (Supplementary Material 1) and 451 articles assessing amphibian responses to land-use change (Supplementary Material 2). These articles only included amphibians of the order Anura. Eighteen of the 778 articles reported research on five oceanic islands (Table 1), of which 13 were focused on climate change and six on land-use change (one study assessed both). North American anurans were represented by five times more studies (Fig. 2). The distribution of the scientists conducting the studies on oceanic islands was also skewed; c. 20% were affiliated with an institution on the island where the study took place, and nearly 80% with institutions elsewhere, mostly in the USA (Fig. 3). The 18 studies assessed 21 species of six families (Bufonidae, Eleutherodactylidae, Hylidae, Hyperoliidae, Leptodactylidae and Sooglossidae; Table 2). Two of 13 climate change studies of oceanic island amphibians comprised assessments of tadpoles from two families (Bufonidae and Leptodactylidae), with the remainder assessing adults or post-metamorphic individuals only (Table 1). All land-use change studies on tropical oceanic islands evaluated adults only. The influence of temperature was the most common factor assessed, followed by precipitation, habitat disturbance, humidity and salinity (Fig. 4). Range expansion or contraction was the most commonly assessed response to change, followed by changes in calling activity, body size, abundance, detection and occupancy, species diversity and biochemistry (Fig. 4).

Discussion

Our review revealed that studies of tropical oceanic islands formed only c. 2% of research on amphibian responses to the global threats of climate and land-use changes published during 1998–2022. Although the small sample size limits our ability to analyse these studies quantitatively, it is clear there are notable research gaps in terms of geographical scope, taxonomic representation and life stage. There is also unevenness in the factors and responses evaluated, with few studies focusing on biochemical responses or salinity as a factor. These gaps represent limitations to global amphibian conservation.

Geographical scope

For both climate and land-use changes, more studies emerged from Central and South America during 2010–2020 compared to the previous decade (Fig. 2). This region hosts the highest species richness of amphibians (AmphibiaWeb, 2024). However, in Africa, which is also rich in amphibian species, these global threats remain poorly evaluated (Fig. 2), further highlighting spatial gaps hindering amphibian conservation efforts.

Globally, land-use change studies outnumbered climate change studies before 2010, but during 2016–2020 this trend reversed, with twice as many climate change studies published as those on land-use change (Fig. 2). Nonetheless, studies of amphibians on tropical oceanic islands remain limited. This is of concern given that these populations are vulnerable to the impacts of both climate and land-use changes (Wanger et al., 2010; Courchamp et al., 2014). Gathering more information on island amphibians is particularly important as current limitations to amphibian conservation on oceanic islands include a lack of knowledge of adaptation in these specific habitats (Robinson, 2020), a low number of local researchers, limited ecological data on the effects of global threats on amphibian survivorship (IUCN, 2023), and weak or limited policies specifically focusing on amphibians (Powell & Henderson, 2023).

Geographical biases are common in scientific research (Skopec et al., 2020). For example, Blaustein et al. (2018) found geographical biases in research carried out on infectious diseases in amphibians, with most studies being in North America. This bias has also been noted in research on pollution, another global threat to amphibians (Schiesari et al., 2007). These biases probably occur because larger, well-funded institutions such as those in North America employ more researchers and often focus on common, widely distributed species (Schiesari et al., 2007). The use of common species as model systems is an established research tool in ecological assessments (Scheiner & Gurevitch, 2001). In contrast, many oceanic island amphibian species are endemic, uncommon or not widely distributed because of their microhabitat preferences (Ríos-López & Heatwole, 2023).

The remoteness of tropical oceanic islands could be another reason for the low number of studies assessing amphibian responses to climate and land-use changes. This may be a particular issue in the Pacific (for which we found no studies) but perhaps less so in the Caribbean (where most oceanic island-based studies occurred). Limited resources impeding local experts on developing oceanic islands could be another factor (Burt et al., 2022). Of the 21 amphibian species evaluated for their responses to climate or land-use changes on tropical oceanic islands, most were on Puerto Rico (Table 1), which is geographically and politically close to the USA. Historically there has been a disproportionate amount of ecology and conservation biology research carried out in Puerto Rico compared to other Caribbean islands (Vallès et al., 2021). The sixth Intergovernmental Panel on Climate Change report warned that small islands are likely to face significant effects of climate change, and these effects are likely to be compounded by increasing land-use change (Pörtner et al., 2022). We

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Table 1 Studies published during 1 July 1998–30 June 2022 assessing the responses of amphibians on oceanic islands to climate and land-use changes.

Taxa	IUCN Red List status[1]	Location	Climate change responses assessed?	Land-use change responses assessed?	Life stage	Source
Bufonidae						
Rhinella marina	LC	Puerto Rico	Yes	No	Tadpole	Ríos-López (2008)
Peltophryne longinasus	CR	Cuba	Yes	Yes	Adult	Cobos & Alonso Bosch (2018)
Eleutherodactylidae						
Eleutherodactylus coqui	LC	Puerto Rico	Yes	Yes	Adult	Delgado-Acevedo & Restrepo (2008), Rödder (2009), Ospina et al. (2013), Narins & Meenderink (2014), Hughey et al. (2017), Matlaga et al. (2021), Rivera-Burgos et al. (2021), Delgado-Suazo & Burrowes (2022)
Eleutherodactylus antillensis	LC	Puerto Rico	Yes	Yes	Adult	Delgado-Acevedo & Restrepo (2008), Ospina et al. (2013), Barker et al. (2015), Monroe et al. (2017), Rivera-Burgos et al. (2021)
Eleutherodactylus cochranae	LC	Puerto Rico	Yes	No	Adult	Ospina et al. (2013)
Eleutherodactylus brittoni	LC	Puerto Rico	Yes	Yes	Adult	Ospina et al. (2013), Monroe et al. (2017), Campos-Cerqueira et al. (2021), Rivera-Burgos et al. (2021), Delgado-Suazo & Burrowes (2022)
Eleutherodactylus portoricensis	EN	Puerto Rico	Yes	No	Adult	Barker et al. (2015), Campos-Cerqueira et al. (2021)
Eleutherodactylus wightmanae	EN	Puerto Rico	Yes	Yes	Adult	Monroe et al. (2017), Campos-Cerqueira et al. (2021), Rivera-Burgos et al. (2021)
Eleutherodactylus locustus	EN	Puerto Rico	Yes	No	Adult	Campos-Cerqueira et al. (2021)
Eleutherodactylus richmondi	EN	Puerto Rico	Yes	No	Adult	Campos-Cerqueira et al. (2021)
Eleutherodactylus hedricki	EN	Puerto Rico	Yes	No	Adult	Campos-Cerqueira et al. (2021)
Eleutherodactylus gryllus	CR	Puerto Rico	Yes	No	Adult	Campos-Cerqueira et al. (2021)
Eleutherodactylus unicolor	CR	Puerto Rico	Yes	No	Adult	Campos-Cerqueira et al. (2021)
Hylidae						
Osteopilus septentrionalis	LC	Cuba, The Bahamas	Yes	No	Adult	Rödder & Weinsheimer (2009), Lukens & Wilcoxen (2020)
Hyperoliidae						
Hyperolius molleri	LC	São Tomé Island	No	Yes	Adult	Strauß et al. (2018), Bell & Irian (2019)
Hyperolius thomensis	EN	São Tomé Island	No	Yes	Adult	Strauß et al. (2018), Bell & Irian (2019)
Leptodactylidae						
Leptodactylus albilabris	LC	Puerto Rico	Yes	No	Tadpole	Ríos-López (2008)
Sooglossidae						
Sooglossus sechellensis	EN	Seychelles	Yes	No	Adult	Labisko et al. (2022)
Sooglossus thomasseti	CR	Seychelles	Yes	No	Adult	Labisko et al. (2022)
Sechellophryne gardineri	EN	Seychelles	Yes	No	Adult	Labisko et al. (2022)
Sechellophryne pipilodryas	CR	Seychelles	Yes	No	Adult	Labisko et al. (2022)

[1]LC, Least Concern; EN, Endangered; CR, Critically Endangered.

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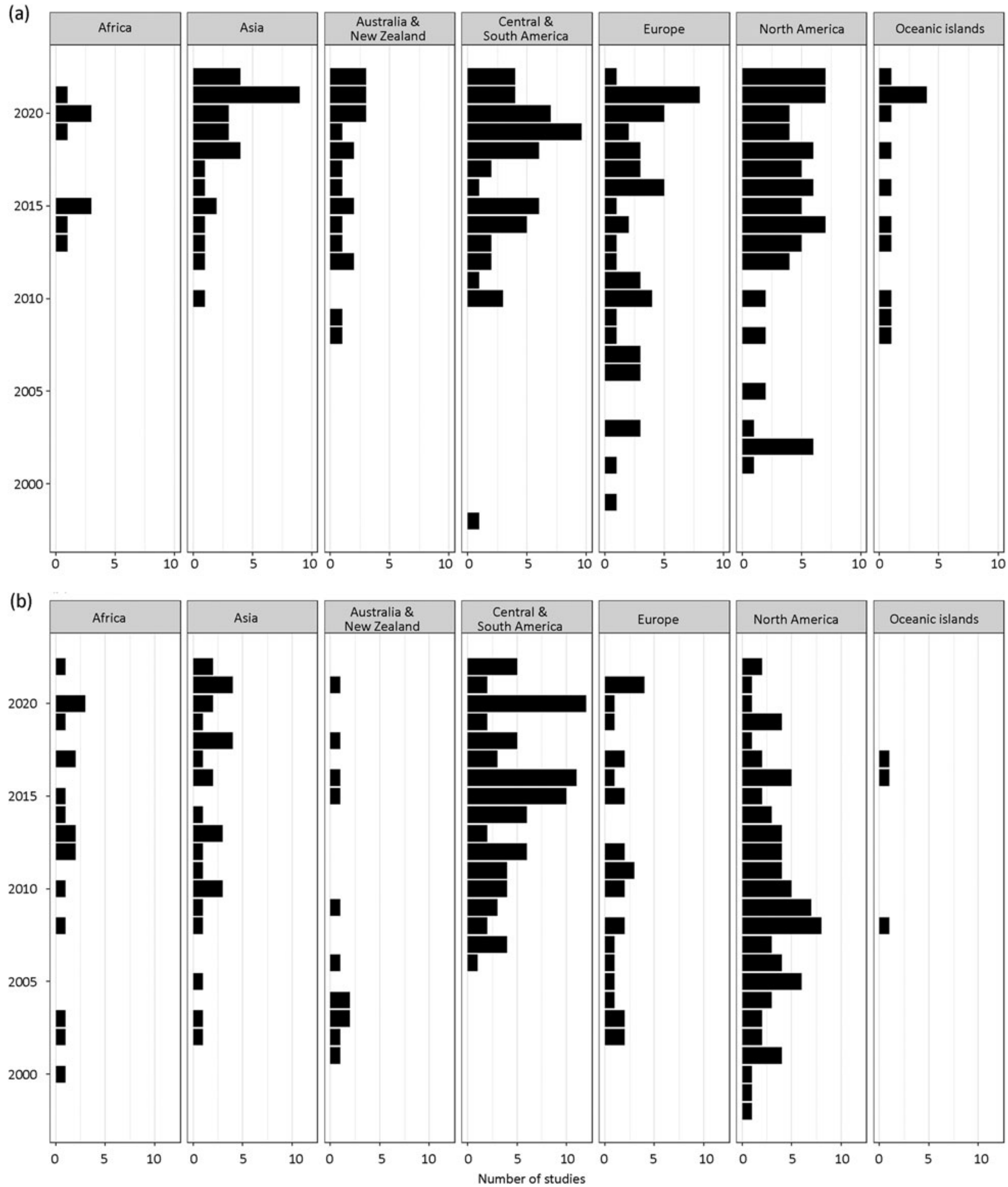

FIG. 2 Number of experimental studies evaluating amphibian responses to (a) climate change and (b) land-use change published during 1 July 1998–30 June 2022, illustrating there have been few studies on tropical oceanic islands compared to most continental areas.

located studies conducted in only five tropical oceanic island countries. There are many other islands where, to our knowledge, there have been no published studies evaluating amphibian vulnerability to climate and land-use changes, despite the presence of native amphibians. For example, we found no studies from Dominica, Grenada, Jamaica or Tobago in the Caribbean, the archipelago of Mayotte in the Indian Ocean, or Fiji or the Solomon Islands in

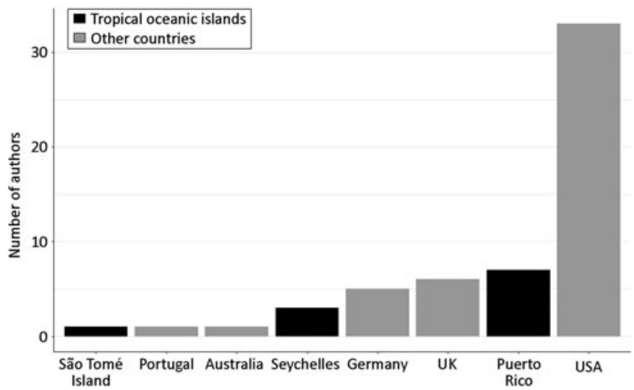

FIG. 3 Locations of the affiliations of authors who published research evaluating amphibian vulnerability to climate and land-use changes on tropical oceanic islands during 1 July 1998–30 June 2022. Note there were no authors from Cuba or The Bahamas in the studies in these countries (Table 1).

Oceania, yet each hosts endemic and threatened amphibians (AmphibiaWeb, 2024). It is therefore imperative to develop research on amphibians on tropical oceanic islands, expanding on the work of Bickford et al. (2010) in Southeast Asia and Oliver et al. (2022) in Melanesia, to ensure there is adequate coverage of amphibians when it comes to understanding the impacts of global threats on oceanic islands.

Taxonomic representation

Taxonomic biases in amphibian research have been documented previously, particularly in countries with high scientific capacity (da Silva et al., 2020). It is more difficult to assess taxonomic biases for countries with sparse research output. We acknowledge that some countries are larger and have more amphibian species than some oceanic islands; for example, the USA, with a total area of 9.8 million km^2, hosts 345 amphibian species, compared to the Seychelles, which has a total area of 455 km^2 and hosts 14 amphibian species (AmphibiaWeb, 2024). However, it is clear there is inadequate taxonomic representation of amphibians assessed on oceanic islands. For example, Cuba hosts 67 endemic amphibian species, yet the effects of climate and land-use changes appear to have been evaluated for only one species during 1998–2022 (Cobos & Alonso Bosch, 2018). This limits the extent of our understanding of how amphibians of families with different life history traits are likely to be affected by these threats. There have been attempts to identify vulnerable amphibians based on a sample of species (Foden et al., 2013; Pottier et al., 2022), but these global assessments also have limited data on amphibians on oceanic islands.

Life stage assessment

The unevenness of knowledge on amphibian adults and larval stages globally has been reported (Vera Candioti et al., 2023). In our review only two of the 18 studies we located evaluated tadpoles. The lack of studies evaluating life stages other than post-metamorphic adults is a major gap for tropical oceanic islands. To put this into perspective, in the USA approximately three quarters of studies on global threats to amphibians evaluated the responses of multiple life stages to climate change (Supplementary Material 1). This disparity is of concern as the tadpoles of many anuran species on tropical oceanic islands require water bodies for survival (AmphibiaWeb, 2024). With higher temperatures, higher rates of desiccation and sea-level rise projected as a result of climate change (Pörtner et al., 2022), and increasing changes in land use, amphibian tadpoles on tropical oceanic islands face increasing pressures. Studies on temperate anurans highlight the negative impacts tadpoles

TABLE 2 Taxonomic representation of research on oceanic islands, highlighting the limited number of amphibian families and species evaluated. Islands for which no species were evaluated are not listed.

Oceanic island country	Families assessed	Families occurring in the country	Number of species assessed[1]	Number of species in country[2]	Number of native species[3]
Bahamas	Hylidae	Eleutherodactylidae, Hylidae, Microhylidae, Ranidae	1	6	3
Cuba	Bufonidae, Hylidae	Bufonidae, Eleutherodactylidae, Hylidae, Ranidae	2	71	69
Puerto Rico	Eleutherodactylidae	Bufonidae, Eleutherodactylidae, Hylidae, Leptodactylidae, Microhylidae, Ranidae	11	26	21
São Tomé Island	Hyperoliidae	Arthroleptidae, Hyperoliidae, Phrynobatrachidae, Ptychadenidae	2	9	9
Seychelles	Sooglossidae	Hyperoliidae, Ptychadenidae, Sooglossidae	4	14	13

[1]All species assessed were native except for one in Puerto Rico (*Rhinella marina*).
[2]From AmphibiaWeb (2024).
[3]From Ríos-López & Heatwole (2023; Bahamas, Cuba and Puerto Rico) and AmphibiaWeb (2024; São Tomé Island and Seychelles).

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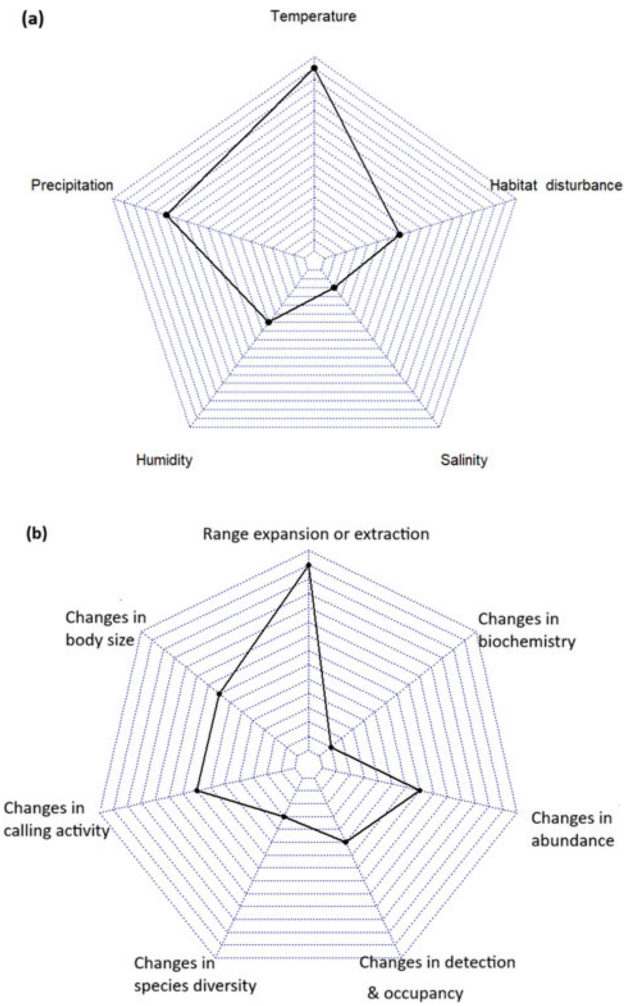

FIG. 4 Uneven research effort into (a) factors and (b) responses evaluated in climate and land-use change studies of tropical oceanic island amphibians published during 1 July 1998–30 June 2022. Each contour represents a single study for factors and responses.

can face, such as reduced ranges (Perotti et al., 2018) and changes in growth and development (Norlin et al., 2016; Colomer et al., 2021). Although some amphibians appear to be able to tolerate, and to an extent even benefit from, changes in the environment (Brüning et al., 2018), negative impacts are likely to predominate (Murray et al., 2021). These global threats would not only affect amphibians with larval stages but also those that undergo direct development (e.g. species of Eleutherodactylidae), for which temperature and moisture (through evaporative water loss) play important roles in egg survival (Blaustein et al., 2018). Scheffers et al. (2013) found evidence to suggest that direct-developing frog metamorphs and adults may be more sensitive to increasing temperatures than amphibians with larval development.

Factors and responses

Amongst the 21 species of tropical oceanic island amphibians assessed, there was uneven research across the factors and responses evaluated (Fig. 4). Temperature was the dominant factor assessed in most studies. Temperature affects all aspects of ectotherm biology and is therefore a key factor to assess, especially as climate change is projected to increase global temperatures (Pörtner et al., 2022) and is a significant driver of amphibian extinction (Sodhi et al., 2008). We located a limited number of studies evaluating the effects of salinity (Fig. 4), but this is a factor requiring attention given that sea level rise will have a significant impact on small tropical oceanic islands (Pörtner et al., 2022). Rising sea levels expanding into freshwater swamps could be detrimental to amphibians inhabiting this habitat as many amphibian species have low salt tolerance (Auguste et al., 2023). In our review, range expansion or contraction was the most common response evaluated (Fig. 4), which is unsurprising as it is the most commonly observed response to climate change (Parmesan, 2006). The paucity of studies evaluating biochemical responses (Fig. 2) is of concern as amphibians produce chemicals in their skin that have implications not only for the animals themselves, but also for human health (Mechkarska et al., 2018).

Other considerations

This review focuses on the impacts of climate and land-use changes on tropical oceanic island amphibians, but invasive species are another major threat (IUCN, 2023) and islands are disproportionately more vulnerable to invasive species than continental areas (Russell et al., 2017). Not only have human activities facilitated the introduction of invasive species to islands (Powell & Henderson, 2023), but land-use and climate changes can also increase the spread of invasive species (Manzoor et al., 2021). For example, the invasive frog *Eleutherodactylus johnstonei* appears to be restricted to urban areas upon establishment in a new island country (Downie et al., 2017) but expansion of urban development could facilitate its spread. Climate change can also affect the ranges of invasive species (Hellmann et al., 2008). Invasive species, climate and land-use changes and other major global threats such as disease, exploitation and pollution, both individually and in synergy, will affect amphibian communities globally, including on tropical oceanic islands.

Conclusions and recommendations

Global studies assessing amphibian responses to climate and land-use changes have provided valuable information for conservation (Winter et al., 2016; Cordier et al., 2021) but our findings highlight the need for additional research on tropical oceanic islands. We make the following recommendations: (1) improve training opportunities for researchers based on islands, (2) improve the equitable distribution of resources, (3) improve inclusion of island-based researchers in local studies, and (4) promote conservation actions that can be implemented in the short to medium term.

Training opportunities One of the factors contributing to the low number of studies on tropical oceanic islands is the paucity of resources and training opportunities for amphibian conservationists. Authors from across the Neotropics have advocated for the removal of barriers such as limited funding, exclusion from international research leadership and poor dissemination of knowledge to biologists living and working in the Global South (Vallès et al., 2021; Soares et al., 2023). Provision of training, funded by wealthier countries, to herpetologists, conservation practitioners and students would allow them to use their experience to build local conservation capacity for amphibian research (Wanger et al., 2011; Verdade et al., 2012).

More equitable distribution of resources Research on amphibian conservation has largely been published from the wealthier countries of the Northern Hemisphere. Initiatives in countries where research has been neglected are needed to address the geographical and taxonomic gaps in amphibian research. For example, in South Africa, conservation of amphibians has received less funding than conservation of other vertebrate groups (Tarrant et al., 2016). However, even in data-rich countries such as the USA there are disparities in the funding of amphibian conservation (Gratwicke et al., 2012), and this is of even greater concern for Small Island Developing States (Soares et al., 2023). Improvements in local wildlife policies and political will are needed for amphibian conservation.

Greater inclusion of island-based researchers Extensive work is required across tropical oceanic islands and other tropical areas, especially Africa (Fig. 2), to address geographical, taxonomic, life stage and ecological research gaps. However, this research must be conducted ethically: the dominance of so-called parachute science can be detrimental to tropical ecology (Ocampo-Ariza et al., 2023). Our review shows that the few studies that have been conducted on tropical oceanic islands were predominantly authored by researchers based elsewhere (Fig. 3).

Short- to medium-term efforts Conservation interventions in the short to medium term will be important for improving amphibian conservation on islands, especially where local expertise is currently limited. Examples of actions that could be applied by tropical oceanic island governments are detailed in the Amphibian Conservation Action Plan (Wren et al., 2024) and the Brazilian Amphibian Conservation Action Plan (Verdade et al., 2012). Ways in which authorities can protect amphibians from the effects of climate and land-use changes include improving public awareness of these threats (e.g. via schools and through public outreach events) and protecting key habitats. Other potential actions include captive breeding, ex situ conservation and biobanking (Gascon et al., 2007; Verdade et al., 2012). These measures may be vital for protecting threatened species that are difficult to study in situ, and will require collaboration between local wildlife authorities and external organizations that already have experience with the appropriate techniques.

Author contributions Study design, literature compilation, data visualization: RJA; writing: all authors.

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Conflicts of interest None.

Ethical standards No specific approval was required for this review. Our research abided by the *Oryx* guidelines on ethical standards.

Data availability All references used for this review are in the Supplementary Material.

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