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Abstract:

The majority of vulnerability assessments of biodiversity to global changes have so far focused on mainland systems, ignoring islands. However, islands harbour unique biodiversity and are epicentres of ongoing extinctions. We thus introduce a new framework for quantifying the vulnerability of terrestrial insular biota to multiple threats. This framework uses markers of exposure, sensitivity, and adaptive capacity that reflect the unique characteristics of island biodiversity, from population to island levels. Our framework involves four steps: (1) identifying the scope of the vulnerability assessment, (2) selecting the most appropriate markers, (3) computing the vulnerability, and (4) provide recommendations for conservation. We discuss the need and urgency to deploy this framework to guide evidence-based decisions for the conservation of insular biodiversity and for an improved attention of insular biota at the science-policy interface.

Introduction:

Islands are among the most vulnerable ecosystems affected by global change (Fernández-Palacios et al., 2021). Approximately ca. 75% of extinctions have occurred on islands, and over half of all terrestrial species that face imminent extinction are island-dwellers, with invasive alien species and land-use change, as leading drivers of species' declines. Climate change emerges as a growing threat for island biota and it may interact in unexpected ways with invasive alien species and land-use change (Capdevila et al., 2021; Mantyka-Pringle et al., 2011). As a result, islands are commonly considered the epicentres of past, imminent, and potential future species extinctions (Supplementary appendix S1).

At least three reasons can explain the disproportionate vulnerability of island ecosystems. First, insular species are usually intrinsically more sensitive to any given threat due to specific traits deriving from the so-called 'island syndrome'(Benítez-López et al., 2021; Biddick et al., 2019; Lomolino, 1985). Second, insular species are less likely to adapt to new threats due to their inherent demographic features (e.g., small population sizes, naturally fragmented distribution ranges) (Fernández-Palacios et al., 2021). Lastly, the physiography of islands, specifically in the case of isolated, small-sized ones, renders their biota more exposed to threats and also less able to escape compared to their continental counterparts (Harter et al., 2015, p. 201).

Despite the urgency needed to protect the unique and highly vulnerable island biodiversity from ongoing global change, insular biota is only briefly mentioned in international biodiversity policy frameworks. In December 2022 the 196 parties of the Convention on Biological Diversity (CBD) adopted the Kunming-Montreal Global Biodiversity Framework (GBF), involving 23 action-oriented global targets. Among them, only one target explicitly mentions islands as priority areas for conservation (though not explicitly mentioning insular biota) and only two other targets require strong actions on islands. This lack of attention

reflects the scientific bias towards mainland and charismatic species (Albert et al., 2018; Rodrigues et al., 2010), with remote islands being marginally considered in biodiversity assessments, which hinders the development of effective conservation plans on insular biota (Troudet et al., 2017). Here, we introduce a novel framework specifically designed to assess the vulnerability of insular biota to global change, across multiple biodiversity dimensions, and based on insular biota's exposure, sensitivity, and adaptive capacity to multiple threats. We first describe the characteristics that contribute to the vulnerability of island biota to global change, which need to be considered in insular biodiversity vulnerability assessments. Then, we describe how our framework can address some of the ongoing questions on island biota vulnerability.

Challenges

The uniqueness of insular biota enhances their vulnerability to threatening processes

The inherent uniqueness of insular biota (e.g., endemic species, distinct traits, unique lineages) increases their overall vulnerability to global change drivers (Fernández-Palacios et al., 2021). Their isolated nature and complex topography, prone to extreme events, make them more exposed to threats (Russell & Kueffer, 2019) (Figure 1A) because islands per se harbour fewer potential refugia (compared with continental landmasses). Islands are also known to host a large number of endemic species: up to 90% of endemic non-vagile taxa (i.e., non-flying vertebrates, seed plants, molluscs or arthropods) occur in oceanic islands and continental fragments (e.g., Madagascar, Antonelli et al., 2022). Endemics have small population sizes and restricted geographical ranges (sometimes limited to an archipelago, an island or even a single peak, volcano or cliff), increasing their extinction probability (Manes et al., 2021). Iconic examples are the radiation of the Hawaiian silversword alliance, which

gave rise to the radiation of Hawaiian Honeycreepers that are particularly vulnerable to threats **(Box 1)**.

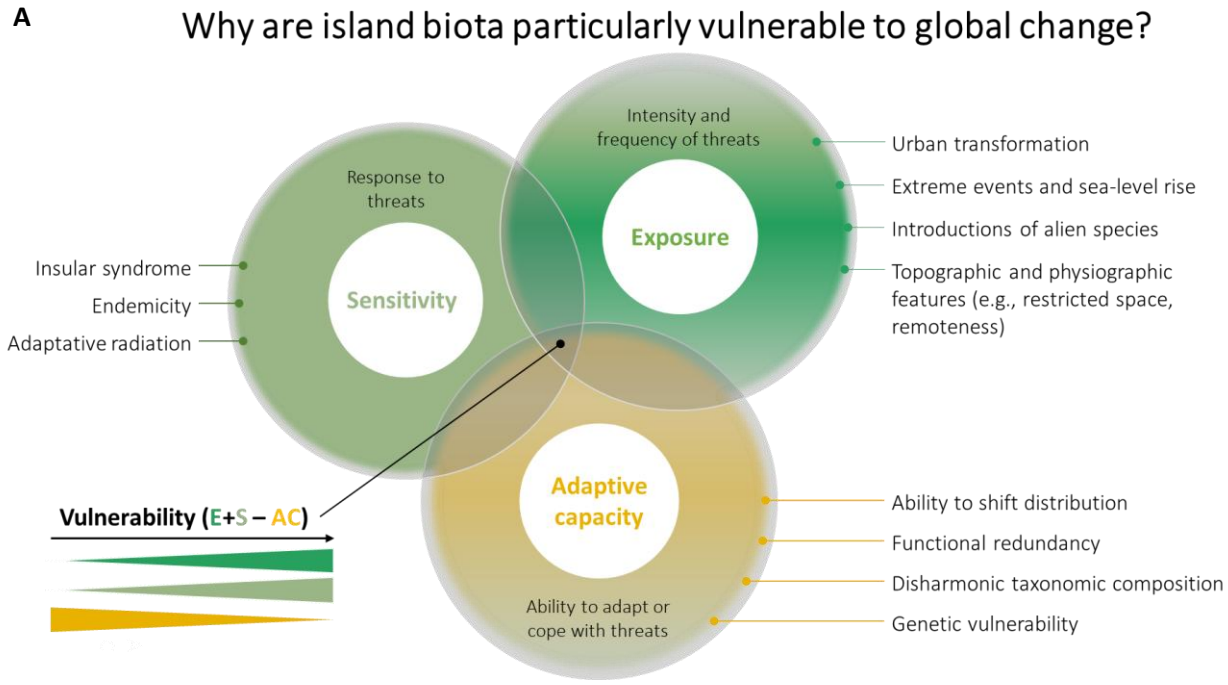


Figure 1: A *Conceptual figure of the vulnerability of insular biota to global change with a non-exhaustive list of the characteristics contributing to each vulnerability component (i.e., exposure, sensitivity, and adaptive capacity). For example, insular syndrome traits, endemicity, and adaptive radiation are characteristics that increase the sensitivity of insular biota to global change compared to mainland biota, whereas lack of functional redundancy, disharmonic taxonomic composition, and genetic vulnerability are characteristics that decrease adaptive capacity.* ***B*** *Bias in current climate change vulnerability assessments in terms of island biota representation, taxonomic representation, and vulnerability components, numbers calculated from* (de los Ríos et al., 2018).

Insular species have also evolved distinct and predictable ecological, physiological, behavioural, morphological, and life-history traits, a phenomenon commonly referred to as

147 the ‘island syndrome’ (Baeckens & Van Damme, 2020), worsening their sensitivity to current
148 and future anthropogenic threats, including overharvesting, habitat loss, increased drought and
149 alien invasive species (Rozzi et al., 2023; Zizka et al., 2022), (Figure 1A). This phenomenon
150 is for example associated with dioecism in plants, which makes them more likely to disappear
151 if their mutualists disappear, presumably causing higher vulnerability to human induced
152 perturbations (Schrader et al., 2021). The reduced herbivory and predation pressure on islands
153 leads to low levels of spinescence compared to mainland, which makes island species more
154 likely to be affected by the introduction of exotic herbivores and predators (K. Burns, 2016;
155 Clavero et al., 2009, p. 200). The loss of flight capacities also makes insular birds unable to
156 escape from anthropogenic threats (Sayol et al., 2021) and more likely to be threatened by
157 extreme events, such as hurricanes, or gradual environmental change (e.g., progressive
158 directional changes such as climate change) (Burns, 2019; Roff, 1990).

159 Additionally, the intricate and often rugged topography of oceanic islands frequently leads to
160 isolations of populations, which may result in genetic drift and then inbreeding when the
161 population sizes are small. Subsequent island colonization within archipelagos and isolation
162 by distance could too led to high population structure between island (Parmakelis et al., 2015;
163 White & Searle, 2007). These populations are thus more prone to genetic diversity loss, which
164 may lead to fewer opportunities to adapt to changes. Although this does not necessarily
165 increase their vulnerability *per se*, the loss of genetic diversity due to disturbances, especially
166 when exposed to disturbances over a short time period (Inamine et al., 2022), can cause a
167 demographic or genetic collapse. Thus, losing an insular population can cause demographic
168 and genetic loss, whereas it causes only demographic loss on mainland. Because of that, the
169 effective conservation units on islands should be at the population level, rather than species
170 level (e.g., (Melo & O’Ryan, 2007)).

Besides population- and species-level characteristics, the composition of insular species' assemblages harbours features that make them more vulnerable. An example is their disharmonic taxonomic composition, which refers to the systematic over- or under-representation of certain taxonomic groups compared to continental assemblages. Notable examples include the absence of several families of non-volant mammals on many isolated islands (Brace et al., 2015), and the over-representation of pteridophytes in plant communities (Kreft et al., 2010). The absence of certain functional groups, although partially compensated by in-situ diversification and differentiation, allows the establishment of new exotic species (Vitousek et al., 1997). These exotic species can exert a new role (predation, competition) unknown to the native community, which is evolutionarily and functionally unequipped to withstand these novel pressures. Additionally, species traits in island communities are often complementary rather than redundant, leading to communities with low functional redundancy (Harter et al., 2015; Whittaker et al., 2014), making them more sensitive to threats (McConkey & Drake, 2015) and with no 'ecological insurance' to replace the missing functions (Loreau et al., 2021).

State of the art of vulnerability assessments on insular biota

Despite the inherent vulnerability of insular biota to global changes, the majority of vulnerability assessments of biodiversity have so far focused on mainland systems, ignoring islands. Climate change vulnerability assessments emerged in the 1990s to pre-empt impacts and prepare appropriate responses (Foden et al., 2019; Solomon et al., 2007). Most definitions concur that a species' vulnerability to a threat is determined by three factors: **exposure**, **sensitivity**, and **adaptive capacity** (Butt et al., 2022; Foden et al., 2013, 2019). Using this definition, a recent review showed that among the 741 studies assessing climate change vulnerability, the large majority focused on mainland systems, and less than one third (n=231) included islands (de los Ríos et al., 2018) (see Table S2 for examples) and with only 136

196 studies associated with a specific insular country. Those island vulnerability assessments were
197 often geographically or taxonomically restricted towards high income countries (e.g.,
198 Australia, the UK, and the USA account for 60% of studies on insular biota), and plants (49%
199 of studies) (Figure 1B). In addition, the large majority of vulnerability assessments do not
200 consider the influence of multiple threats (but see Santos et al., 2021; Sousa et al., 2021; Ureta
201 et al., 2022), which are likely to act together and be exacerbated by climate change (e.g.,
202 habitat loss, overexploitation, biological invasions).

203 Making the assumption that exposure is a suitable proxy for the impact of a particular threat,
204 most vulnerability assessment studies focused on exposure alone, and less than 10% relied on
205 the three specified components of vulnerability (Butt et al., 2016; de los Ríos et al., 2018).
206 The implicit associated assumption is that all species will have equal responses to a threat,
207 which is highly unlikely. In fact, species' responses to threats, either on mainland or islands,
208 are modulated by their traits (Fromm & Meiri, 2021; Leclerc, Villéger, et al., 2020; Marino et
209 al., 2022; Soares et al., 2022). We argue here that, applied to a range of taxa and threats, trait-
210 based vulnerability assessments can provide a useful approach for (i) developing a more
211 comprehensive index of vulnerability to threats, and (ii) informing effective management
212 actions for conservation (Gallagher et al., 2021).

213 **Perspective**

214 We present a conceptual framework divided in four steps that provides a roadmap for
215 vulnerability assessments in insular systems, considering the three components of
216 vulnerability (i.e., exposure, sensitivity, and adaptive capacity; Figure 2). We built upon
217 previous works focused on taxonomic diversity in mainland ecosystems (Foden et al., 2013;
218 Parravicini et al., 2014) to include in our framework various markers for each vulnerability
219 component related to the inherent characteristics of island biota, as well as multiple threats,
220 taxa, and dimensions of diversity (i.e., taxonomic, functional and phylogenetic diversity; TD,

221 FD and PD). The development of this framework is part of a larger initiative to meet
222 international policy targets that better integrate biodiversity threats and dimensions (Box 2).

223 *Step 1: Identify the scope and aim of the vulnerability of insular biota*

224 The first step is to define the scope of the vulnerability assessment in terms of spatial and
225 temporal extent, relevant threats, and studied biota (taxonomic group, biological level,
226 species biogeographical origin). This challenging task is pivotal for the assessment design,
227 which in turn affects the final step of informing conservation actions (Step 4). For example,
228 broad-scale assessments (e.g., at the global extent or among several archipelagos) contribute
229 to strategic planning and to establish a common baseline of vulnerability information (e.g.,
230 IPBES assessments), while local-scale assessments (e.g., within archipelagos or group of
231 islands) are appropriate for informing site-level management decisions. Also at the global
232 scale, special attention should be paid to endemic species or insular populations, since island
233 biodiversity conservation operates at the population level.

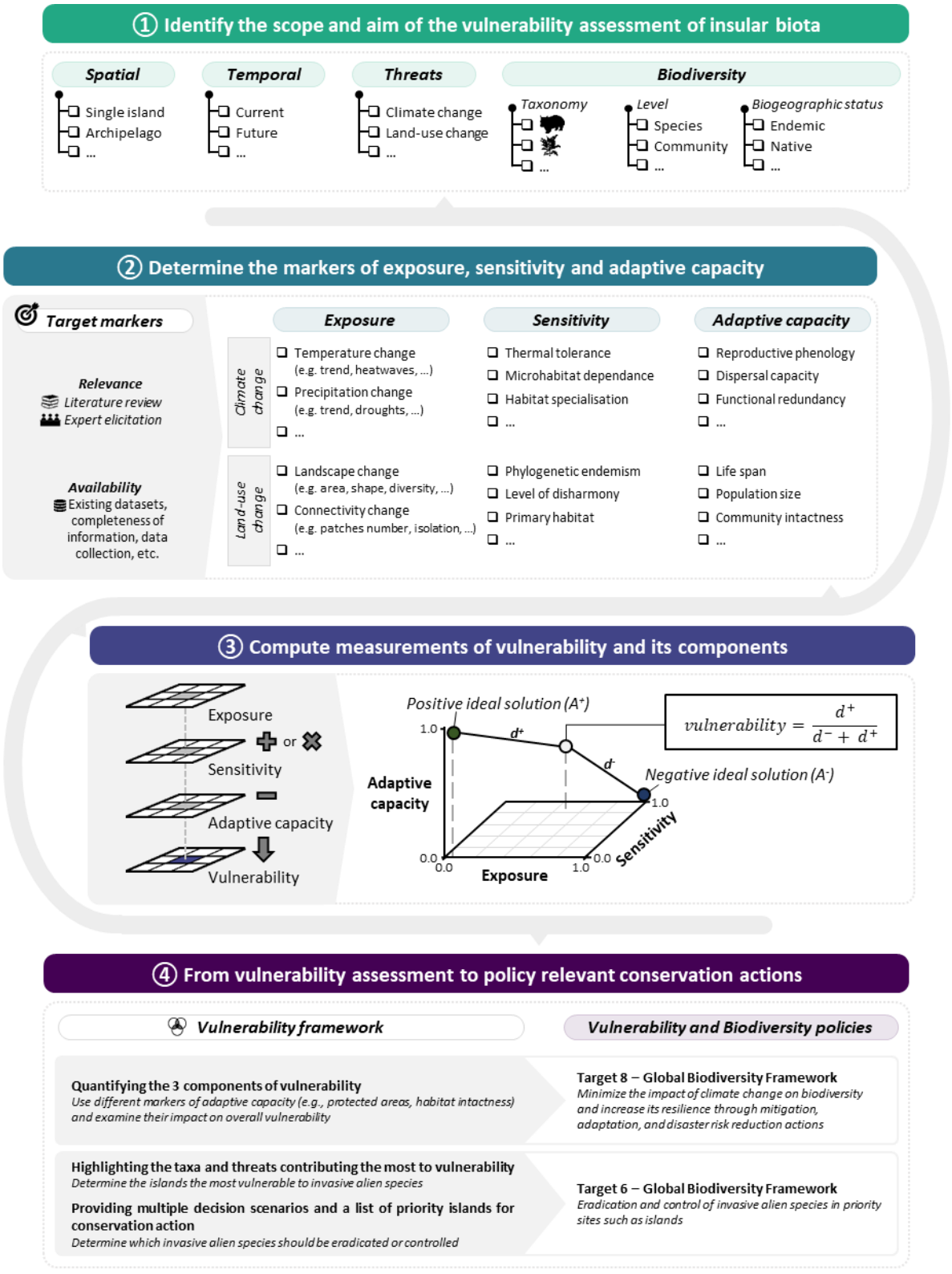


Figure 2: *Conceptual framework for assessing island biodiversity vulnerability to global change.*

Step 2: Determine the markers of exposure, sensitivity, and adaptive capacity

There are many different relevant markers associated with species' vulnerability to threats. Those markers may vary in type (e.g., ecological or demographic) and organisation level (e.g., population, species, community, or ecosystem). One can review the scientific literature and elicit expert opinion to identify and collect relevant markers for each component of vulnerability based on the scope and purpose of the assessment. For instance, assessing the vulnerability of terrestrial species to land use change and climate change requires markers of exposure to climate change (e.g., change in precipitation regimes, sea-level rise) and land use change (e.g., urbanization rates, forest conversion into agriculture, infrastructure development, shift from agriculture to tourism). Moreover, a list of biological traits to infer the sensitivity and adaptive capacity of the studied insular species to those threats are needed (Figure 2 and Table S1 for examples of exposure, sensitivity, and adaptive capacity markers). Markers for exposure can be linked to the focal threat(s) or general to global changes, and multiple markers should be used to capture the multiple dimensions of changes (e.g., temperature change, heat waves, droughts). Species' sensitivity is determined by their intrinsic traits (e.g., climatic niche breadth, habitat specialization, diet breadth, body size, etc.). Some sensitivity traits might be specific to a given threat (e.g., temperature tolerance), while others are general and encompass the sensitivity to different threats (e.g., body size, dependence on interspecific interactions). Note that for both sensitivity and adaptive capacity, a long list of markers is applicable at either the population or species level (see (Thurman et al., 2020) for a list and Table S1). However, markers applicable at the community level such as functional or phylogenetic diversity could also be included (Table 1 for example).

Adaptive capacity refers to the ability of insular biota to respond to a stressor by persisting *in situ* in the face of threats or novel conditions, or by shifting in space or time (following (Thurman et al., 2020)). Acclimation, behavioural change, phenotypic plasticity and

evolutionary adaptation may all contribute to adaptative capacity (Foden et al., 2018; Royer-Tardif et al., 2021). For mobile animals, especially the most vagile organisms, markers of adaptive capacity can incorporate traits linked to movement or mobility (e.g., migration frequency and distance, site fidelity) (Butt et al., 2022; Thurman et al., 2020). Note that for plants and sessile organisms in general, adaptive capacity mostly refers to their capacity to persist *in situ* with mating system and fecundity as strong markers. Finally, adaptive capacity of insular biota can also be modulated by extrinsic factors, such as habitat quality, area connectivity and level of protection, factors which could therefore be included in the measure of adaptive capacity at the system level (i.e., island, archipelago).

	Functional-based markers	Phylogeny-based markers

Table 1: Proposed functional-based and phylogeny-based metrics that could be used as markers at the community level in vulnerability frameworks.

Sensitivity	***Functional rarity:***	***Phylogenetic endemism:***
	Definition - Functional rarity, expressed at the species level, is the combination of the functional uniqueness, the scarcity and the geographic restrictedness of a species (Violle et al., 2017).	*Definition* - Phylogenetic endemism is the spatial restriction of the phylogenetic diversity of a community (ROSAUER et al., 2009). In other words, this is a relative measure of endemism that represents the degree to which lineages or branches of the tree of life are spatially restricted.
	Rationale - Given that functionally rare species can play a critical role in ecosystem functioning, and that they rarity make them heightened sensitivity to anthropogenic pressures (Davies et al., 2004; Loiseau et al., 2020), areas with a high proportion of functionally rare species are particularly susceptible to threats?	*Rationale* - Areas with high phylogenetic endemism are characterized by the presence of species that have diversified and evolved in response to specific environmental conditions within a particular location. Among the drivers shaping phylogenetic endemism, climate plays a significant role (Guo et al., 2023), implying that changes in climate conditions may disproportionately affect these species, potentially leading to their decline or extinction.
Adaptive capacity	***Functional redundancy:***	***Phylogenetic distinctiveness:***
	Definition - Functional redundancy of a given community reflects the tendency for the constituent species to perform similar functions (Mouillot et al., 2014).	*Definition* - Phylogenetic distinctiveness reflects the degree of isolation of a species or a group of species within a phylogenetic tree (Pavoine & Ricotta, 2021).
	Rationale - Functional redundancy has been theoretically and empirically linked to the concepts of resistance and resilience of ecosystem functioning to species loss (Biggs et al., 2020) via the insurance hypothesis (McCann, 2000). Hence, more functionally redundant systems should show greater resilience to perturbation (Mouillot et al., 2014) since when a species becomes extinct, its role can be fulfilled by functionally close species. This indirectly reflects the ability of the system to adapt to disturbances.	*Rationale* - Evolutionarily distinct species or group of species represent uniquely divergent genomes (Warren et al., 2008). Consequently, sets of evolutionarily distinct species are expected to encompass a large proportion of the parental clade's total phylogenetic diversity, which may play a crucial role in ensuring long-term stability and resilience (Cadotte et al., 2012). This implies that communities exhibiting higher phylogenetic distinctiveness are more likely to harbor increased evolutionary potential, enabling them to adapt.

288

289

290 *Step 3: Compute measures of vulnerability and its components*

Once all the markers are collected, the next step is to combine those markers to determine a composite vulnerability measure. Of the myriad of vulnerability assessments that already exist (e.g., correlative, trait-based, mechanistic), not all are equivalent in terms of data requirements and objectives (see Foden et al., 2019 for an extensive review on the topic), with the correlative approaches being the most frequently used. Despite the increasing availability of traits for birds, mammals, reptiles, and plants (Díaz et al., 2022; Faurby et al., 2018; Soria et al., 2021; Tobias et al., 2021), trait-based approaches have been barely applied to date. Among the trait-based approaches, most are criteria-based, in which biota are classified into categories of vulnerability from low to high when summing up the different components of vulnerability (hereby referred to as qualitative or semi-quantitative frameworks). To prevent the use of arbitrary thresholds, we propose a continuous quantitative framework where a multicriteria decision analysis can be applied (Leclerc, Courchamp, et al., 2020; Parravicini et al., 2014) and provide continuous values and a ranking of islands or archipelagos based on their vulnerability scores. This technique ranks alternatives according to their distance to positive (i.e., no vulnerability, where exposure and sensitivity are minimized and adaptive capacity is maximized) and negative ideal solutions (see (Leclerc, Courchamp, et al., 2020) for details). Note that alternative approaches exist for combining the three vulnerability components such as additive effect between components (Nyboer et al., 2021) or interacting effect between exposure and sensitivity for instance (Silva Rocha et al., 2024).

Step 4: From vulnerability assessment to policy relevant conservation actions

The vulnerability framework developed could be used to increase the fundamental knowledge on vulnerability (Step 1-3) but has also the potential to help implementing biodiversity policies (Step 4, Box 2). For instance, one of the targets of the Global Biodiversity Framework is to minimize the impact of climate change on biodiversity through (among

316 others) mitigation, adaptation and risk disaster reduction actions. Such aims require to use
317 different markers of adaptive capacity through multiple plausible scenarios (e.g., protected
318 areas, habitat intactness) to inform on how different management actions can impact the
319 overall vulnerability. Vulnerability assessments can help targeting the control and eradication
320 of invasive alien species in conservation priority sites such as islands (Target 6), but also
321 identifying the sites that need to be under protection (Target 3) to conserve biodiversity.
322 Effective conservation practice relies on understanding biodiversity's vulnerability through
323 multiple lenses. Where the exposure type is common across species (e.g., inundation, invasive
324 species), the threat itself may be managed through dedicated programs for, like mangrove
325 rehabilitation, or invasive species control (Jones et al., 2016). Finally, beyond its use in
326 current policies, our vulnerability framework could be useful in drafting new policies. Indeed,
327 to set relevant targets in the new policies being drafted (e.g., by [year], reduce by [number] %
328 the number of species threatened by [threat]), policy makers need to know (i) what is the
329 current situation and (ii) what could be the future situation under different scenarios. Our
330 vulnerability framework may provide both, and can contribute to the setting of policy targets
331 that are simultaneously ambitious and reachable for insular biodiversity.

332

333 **Concluding remarks**

334 Given the proliferation of threats that islands are facing, efforts must be made to study island
335 biota in the light of global change, and thus to embrace the whole of biodiversity, mainland
336 and insular, in current vulnerability assessments in international instance such as IPCC or
337 IPBES. Our comprehensive and detailed framework lays the foundations to understand and
338 predict island biodiversity vulnerability to global change. Yet, the outcomes of vulnerability
339 assessments will be challenged by missing data and, in the case of future assessments, by
340 uncertainties about the future trajectories of anthropogenic threats. In this context, it is crucial

to estimate the existing uncertainty as well as to communicate this uncertainty (e.g., (Hossain et al., 2019; Rocchini et al., 2011; Tessarolo et al., 2021; Thuiller et al., 2019)), which will ultimately help to identify future research priorities.

Glossary:

Adaptive capacity: the ability to adapt to changing conditions for an individual, population or a species; this may be via ecological (i.e., physiological and/or behavioural plasticity) or evolutionary adaptation (i.e., through natural selection acting on quantitative traits).

Adaptive radiation: the rapid diversification of a single evolutionary lineage into multiple ecologically or morphologically distinct species.

Exposure: the extent to which each species' physical environment changes due to global threats. It includes the intensity, magnitude and frequency of the threat(s).

Sensitivity: the intrinsic capacity of species to cope with threats, based on their life-history, ecology, morphology, or behavior.

Threats: external factors that have the potential to impact the viability, abundance, distribution, or behavior of an individual, species, community or an ecosystem.

Vulnerability: susceptibility of a system/species to a negative impact following a threat

Box 1 | The case of the Hawaiian honeycreepers

409 The Hawaiian Islands constitute an archipelago of eight larger and numerous smaller volcanic

islands in the North Pacific Ocean, in total about 16,644 km^2 in size, and about 3,200 km from

411 the nearest mainland. The islands in the northwest are older and typically smaller, due to

412 progressive erosion, while the islands in the southeast are larger and still volcanically active.

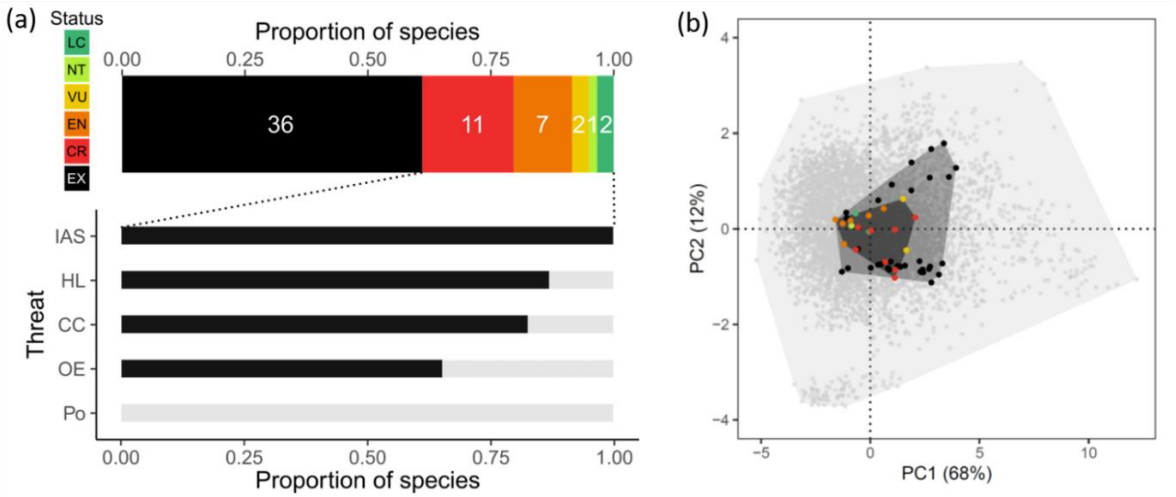
413 Thanks to the archipelago's extreme isolation and the islands' variation in size and

414 environmental conditions, Hawaii has been a hotspot of speciation and adaptive radiation

(Baldwin & Sanderson, 1998; Lerner et al., 2011; Price, 2004). The Hawaiian honeycreepers

(Fringillidae: Drepanidinae) represent one of the most iconic examples of adaptive radiation,

which has resulted in a striking variation in bill morphology (Lerner et al., 2011). This strong adaptive radiation, however, has also led to species with highly restricted ranges and naturally small population sizes. Hence, little is needed to push these species over the brink of



extinction and, to date, at least 36 of the 59 known species of honeycreepers are extinct (Figure 3a). Extinction has been non-random with respect to the functional trait space of the species, with extinct species generally larger in size (Figure 3b). The main drivers of past extinction, as well as current threats to the species, are the introduction of alien species and the loss of habitat due to conversion to agricultural land. Introduced species include predators of birds and eggs (rats, cats, dogs), herbivores that modify the habitat (for example, the extinction of Laysan Honeycreeper *Himatione fraithii* is ascribed to the introduction of rabbits, which eliminated virtually all vegetation cover from the Laysan islands), and vector species of infectious diseases, such as avian malaria (Benning et al., 2002). Habitat loss began with Polynesian colonists, who cleared much of the low-elevation and seasonally dry forest for agricultural purposes, and was continued by later European colonists, who additionally converted high-elevation forests for pasturage (Riper & Scott, 2017). Climatic factors contributed little to past extinctions but are a progressive threat to extant species, especially because it may lead to an upslope shift of infectious diseases (notably avian malaria) (Benning et al., 2002).

Figure 3: Conservation status, threats, and morphospace of Hawaiian Honeycreepers. (a) IUCN Red List threat status of 59 known species of honeycreeper (LC: least concern, NT: near threatened, VU: vulnerable, EN: endangered, CR: critically endangered, EX: extinct) and prevalence of threats among the 23 extant species (IAS: invasive alien species, HL: habitat loss, CC: climate change and extreme events, OE: over-exploitation, Po: pollution) (b) The morphospace compared between 19 extant honeycreepers (dark grey polygon), 54 extant and extinct honeycreepers (medium grey polygon), and 5,974 extant passerine birds globally (light grey polygon). The morphospaces for the extant species were obtained through a principal component analysis (PCA) based on the eight morphological traits available in AVONET (Tobias et al., 2021), namely bill length from tip to skull along the culmen, bill length to nostrils, bill width and depth to nostrils, tarsal, wing and tail length, and Kipp's distance. The same eight traits for the extinct honeycreepers were taken from (Matthews et al., 2023). The first two principal components explain 80% of the total morphological variance and are primarily associated with body size (PC1) and tarsus length versus Kipp's distance (PC2), respectively. The list of species was obtained from (Matthews et al., 2023; Ricklefs, 2017) and the IUCN Red List of Threatened Species v2023-1. Species names were harmonized and duplicates removed based on the taxonomic backbone used by the IUCN.

Box 2| A novel vulnerability framework fit for multiple policies

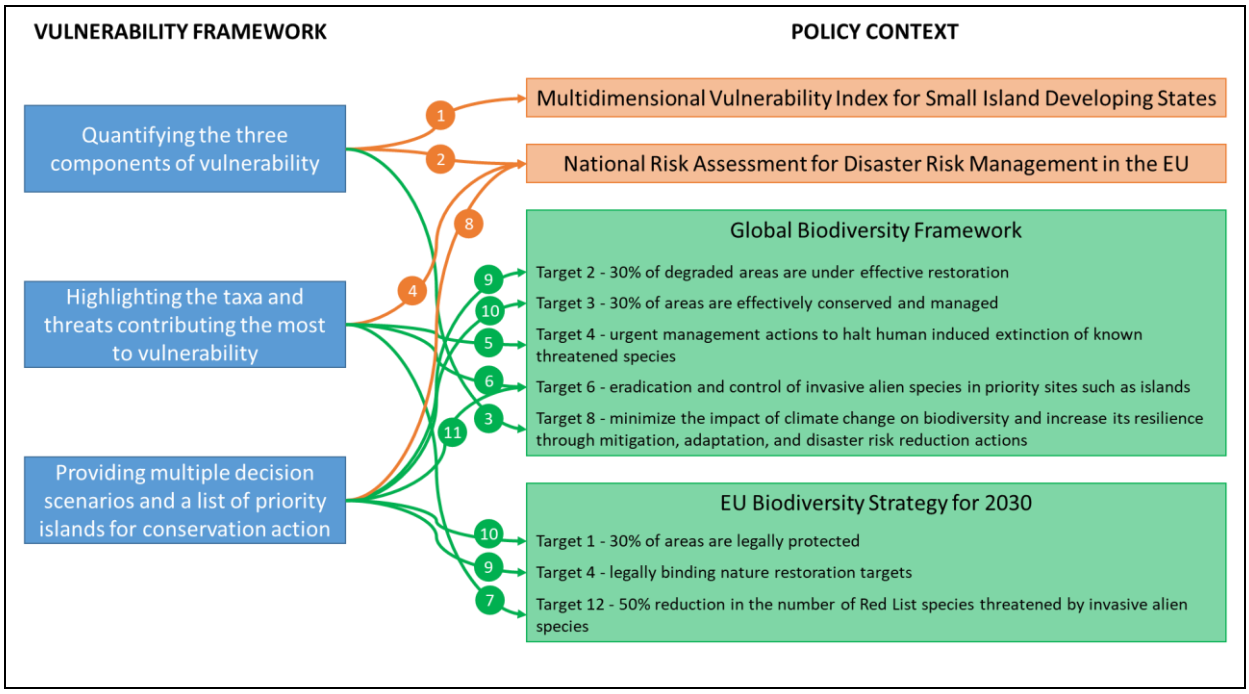
This novel vulnerability framework proposed for insular biodiversity is particularly relevant to inform various vulnerability policies (in orange) and biodiversity policies (in green) at both international and supranational levels such as the European Union (EU).

First, by quantifying the three components of island vulnerability, our framework can directly feed the currently missing biodiversity component of the Multidimensional Vulnerability Index (MVI). The MVI is developed by the Small Island Developing States (SIDS; https://www.un.org/ohrlls/mvi/) with the United Nations to characterise the financing help for sustainable development needed in the face of global change (1). The SIDS is a political coalition of 39 low-lying islands that are united by the threat posed by climate change to their survival. In climate change negotiations, they are a loud and powerful voice for upscaling climate action since they are disproportionally affected by climate change consequences. To understand and respond, several assessments of these islands' climate change vulnerability have been carried out (e.g. (UN High Level Panel, 2022; UNFCCC, 2007)), but none includes more than a broad mention of biodiversity impacts. A scientifically rigorous assessment of climate change vulnerability of island biodiversity is, therefore, both extremely important and critically urgent. Our framework can also help EU Member States, which are required to report to the European Commission on their disaster risk management activities, to identify which components of vulnerability they can act on (2). The risk of biodiversity loss has been recently included in the Recommendations for National Risk Assessment for Disaster Risk Management in the EU (Poljansek et al., 2021), but it does not cover specifically insular biodiversity. In that context, our framework can provide a real additional value for the EU Member States with insular territories. Our framework can also further help identifying whether mitigation strategies for islands to reach Target 8 of the Kunming-Montreal Global

Biodiversity Framework (hereafter, GBF) should focus on limiting territories' exposure or promoting the adaptive capacity of insular biota (3).

Second, our framework can help EU Member States with insular territories to identify and prioritise which species, sites and threats they should use to best mitigate their vulnerability in the context of their National Risk Assessment (4). Such actions can also contribute to (i) identifying the species, sites and to focus the management measures to reach Target 4 of the GBF (5), (ii) determining the most vulnerable islands to invasive alien species to reach Target 6 of the GBF (6), and helping EU Member States with insular territories to identify species threatened by invasive alien species on which to focus conservation actions to reach Target 12 of the EU Biodiversity Strategy for 2030 (EU BDS, 7).

Finally, by providing multiple scenarios of threats trajectories and a list of priority islands for conservation action, our framework can contribute to document the risk of biodiversity loss under different conservation scenarios to EU Member States with insular territories (8). The vulnerability framework could contribute to identifying priority islands for restoration (target 2 of the GBF and target 4 of the EU BDS (9)) and for protection (target 3 of the GBF and target 1 of the EU BDS (10)), as well as in determining which invasive alien species should be eradicated or controlled (target 6 of the GBF (11)).



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Supplementary material :

Supplementary appendix 1 :

Islands as past, current, and future epicentres of extinctions: The IUCN Red List documented nearly 1,000 species as globally extinct or extinct in the wild (IUCN Red list access 04/07/2023). Among the documented extinctions, the overwhelming majority occurred on oceanic or continental islands. Extinction hotspots are located in the Oceanic realm, followed by the Afrotropical realm (e.g., Madagascar) and the Nearctic. Among reported extinctions in the IUCN Red List, the large majority are represented by animal species (>80%), followed by plants. Most of these species have gone extinct because of invasive alien species, but a large number have also concurrently been harmed by wildlife exploitation and/or land use change due to cultivation (Leclerc et al., 2018; Maxwell et al., 2016). In fact, extinct species within insular regions have faced, on average, four threats (i.e., biological invasions, wildlife exploitation, cultivation, and habitat modifications), and the exposure to threats for birds, mammals, amphibians, reptiles, freshwater fish, plants, arthropods, and gastropods continue to increase, with an average of ten threats being faced by threatened species (Leclerc et al., 2018).

Moreover, because insular biota makes a disproportionate contribution to global biodiversity in relation to their surface area (Fernández-Palacios et al., 2021), the risk for future extinctions is high. The first extinction due to climate change already occurred on an island near Papua New Guinea (Fulton, 2017). In 2016, *Melomys rubicola* (also called the Bramble Cay melomys) became the very first documented extinction due to climate change (Waller et al., 2017). This small rodent was endemic to a low-island of Bramble Cay in Australia and was periodically recorded from 1978 to 2009. Seven years after its last observation in the field

and numerous efforts to trap the species the years after, the species was officially declared extinct. Although only symbolic, compared to a thousand of species already extinct since 1500, this is one of the first documented victims of climate change as a major factor of near-future extinctions in our contemporary history. Unfortunately, under future climate change, we can expect that islands will continue to contribute disproportionately to the loss of biodiversity, given that the overwhelming majority of critically endangered species are endemic to island systems, and their inherent characteristics make them extremely vulnerable to global change drivers

Table S1: Traits and characteristics from population to the community that may be included in the island biota vulnerability framework (IBVF) with examples of sources where to calculate or when directly available.

	Traits	Level	Availability
Population dynamic	Growth rate	population	Living planet database (vertebrates), FishGlob (fishes), German vegetation (plants)
	Population size	population	CoralTraits (corals), BIOTime (multiple taxa)
Reproduction	Reproductive strategies	species	GIFT (plants), COMPADRE, GARD (reptiles)
	Mating system	species	
	Clutch size	species	GARD (reptiles), AmphiBio (amphibians), COMBINE (mammals), AVONET (birds)
	Fecundity	species	GARD (reptiles), AmphiBio (amphibians)
	Temperature-dependent sex determination	species	
	Generation time	species	Amniote (vertebrates), CoralTraits (corals), COMPADRE (plants)
	Parental care (time)	species	Amniote (vertebrates)
Life-history	Life-cycle	species	TRY (plants), GIFT (plants)
	Life stage	population	FishBase (fishes), CoralTraits (corals), Amphibio (amphibians)
	Dependence on intraspecific interactions	species	CoralTraits (corals)
	Body dimension (mass/size?)	species	Amniote (vertebrates), TRY (Plants), GIFT (plants), COMBINE (mammals), AVONET (birds).
	Clonality	species	GIFT (plants), COMPADRE (plants)
Acclimatation or evolution	Phenotypic plasticity	population	Noble et al 2018 (reptiles)
	Genetic diversity	population	Miraldo et al. 2016 (mammals)
	Life span	species	AmphiBio (amphibians),
Ecological characteristics	Climatic niche breadth	species	GARD (reptiles), GBIF (plants), BIEN (plants)
	Endemicity	species	Global Species Database (vertebrates, invertebrates, plants)
	Habitat specialization	species	IUCN
	Habitat condition	species	IUCN
	Diet breadth	species	GARD (reptiles), AmphiBio (amphibians),
	Nocturnality	species	GARD (reptiles), Amphibio (amphibians)
	Dependence on water for reproduction, foraging, shelter	species	Amphibio (amphibians)

Movement and mobility	Competitive ability	species	
	Dispersal capacity	species	AVONET (birds), TRY (plants), GIFT (plants)
	Site fidelity	species	
	Migration frequency and distance	species	AVONET (birds)
	Flight efficiency	species	AVONET (birds)
Distribution	Number of insular populations	population	
	Home range	population	HomeRange (mammals)
	Geographic rarity	population	
	Low local abundance	island level	
	Range size	population	IUCN
Community properties	Level of disharmony	community	
	Functional redundancy	community	TRY and GIFT(plants)
	Phylogenetic diversity	community	GIFT, WCVP (plants)
	Richness	community	GIFT, WCVP (plants)
	Intactness	ecosystem	
	Phylogenetic endemism	community	Vertlife (vertebrates), PhylomeDB (plants), GIFT, WCVP (plants)
Inherent vulnerability	Behaviour (aggressiveness)	species	
	Dwarfism-gigantism	species	Meiri et al 2008 (mammals), Meiri 2007 (reptiles), Benítez-López et al. 2021, Rozzi et al. 2023 GIFT (plants)
	Vulnerability to diseases	species	GABiP (amphibians)
	Tolerance to drought		try-db.org (plants), Le Galliard et al. 2021 (reptiles)
	Tolerance to fire	species	try-db.org (plants)
	Endemism	community	GIFT and WCVP (plants)

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Table S2: An overview of studies assessing the vulnerability of species to climate change. This is a non-exhaustive summary that focuses on studies that have been conducted recently, use trait-based approaches, and include a full assessment of vulnerability with exposure, sensitivity, and adaptive capacity markers.

Study	Ecosystems	Spatial coverage	Taxa	n	Main findings
(Barry et al., 2023)	Freshwater	Ireland	Fish	32	All species were vulnerable to some effect of climate change with cold water species more vulnerable to climate change than warm water species.
(Boyce et al., 2022)	Marine	Global	Multiple groups (animals, plants, chromists, protozoans, and bacteria)	24,975	Almost 90% of all species are at high or critical risk under high emissions, with exploited species in low-income countries with heavy dependence on fisheries at greatest risk.
(Nyboer et al., 2021)	Freshwater / Marine	Global	Fish	415	Over 20% of recreationally fishes are vulnerable under a high emission scenario, with 72% of vulnerable freshwater fish and 33% of vulnerable diadromous fish being without conservation effort, compared to only 19% for vulnerable marine species.
(Vaz-Canosa et al., 2023)	Terrestrial	Uruguay	Amphibians Reptiles	112	14.6% of amphibians and 10.9% of reptiles were identified as highly vulnerable to climate change.
(Bueno-Pardo et al., 2021)	Marine	Portugal	Fish Invertebrates	74	Under the RCP 8.5 scenario, only two species were classified as at very high vulnerability. Overall vulnerability scores were low, likely due to the high adaptive capacity of species from temperate ecosystems.
(Leclerc et al., 2020)	Terrestrial – insular	Global	Mammals	873	All islands have some degree of vulnerability to future climate change, especially those in the Pacific Ocean. Among endemic mammals, those with long generation times and high food specialization are predicted to be most vulnerable to climate change.
(Ramírez-Bautista et al., 2020)	Terrestrial	Oaxaca State, Mexico	Rodents	55	Under the higher impact (MPI-RCP 8.5) climate scenarios, some level of threat was predicted for all species assessed, with 4 species predicted to be highly vulnerable.

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