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Linnean and Wallacean shortfalls in the knowledge of arthropod species in Chile: Challenges and implications for regional conservation

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ABSTRACT

Despite global efforts to identify and classify species to improve biodiversity baselines, there still remains large knowledge shortfalls that affect our understanding of the functioning of ecosystems and the design of effective conservation practices. Using the results of the first ongoing large-scale biodiversity inventory for Chile which has already recorded ca. 1,800 species and discovered 87 new species of arthropods, we explore and discuss taxonomy (Linnean) and distribution (Wallacean) shortfalls that preclude large-scale knowledge of arthropod biodiversity for one of the lesser studied groups in the world — the arthropods. Linnean shortfalls are mainly associated with the lack of funding of monitoring and inventory initiatives and the bias towards most charismatic or umbrella species, which in turn trigger effects on the experts' availability, recruitment of taxonomists in research centers, journal impact factors, as well as the availability of scientific collections of type specimens. Instead, Wallacean shortfalls are related to accessibility to remote areas, and the spatial and temporal resolution of sampling efforts. Based on our results and literature review, we discuss the findings and also propose a novel conceptual framework aimed to reduce data gaps and support biodiversity conservation policies, particularly in developing countries. The framework has three main components: (1) the ecosystems, their species, and the threats; (2) the key elements for a biodiversity assessment strategy, and (3) an action plan for protecting biodiversity.

1. Introduction

Although more than 20,000 new species are discovered every year, estimating the real number and composition of the global flora and fauna continues to be an elusive task (Ronquist et al., 2020). Taxonomy (Linnean) gaps or shortfalls refers to the discrepancy between formally described species and the number of species that actually exist (Lomolino, 2004). Estimating global biodiversity is particularly challenging because the number of unknown species still suffer from bias and large uncertainties. According to some estimates, the total number of species is approximately 8.7 million, of which only approximately 14 % have been described (Mora et al., 2011), however, the predicted number of species is highly sensitive to the estimation method and to the parameter values considered (Hortal et al., 2015). Besides these gaps, incomplete biodiversity distribution along spatial and temporal scales (Wallacean shortfalls) preclude a better understanding of ecosystems and their functioning, as well as developing more efficient conservation plans against drivers of biodiversity loss such as climate change (Troudet et al., 2017; Start and Gilbert, 2019).

In recent decades, integral species inventories and the monitoring of biodiversity status and trends has been one of the main approaches to assessing species, habitats, and communities to reduce knowledge and distribution gaps in many countries (Ferreira et al., 2011; Lobo et al., 2021). However, these inventories and international efforts have focused mostly on flora, vegetation types, and vertebrate animals (Start and Gilbert, 2019; Ryabov et al., 2021).

With the accelerated loss of biodiversity and the increase in anthropogenic pressures, generating a complete inventory of the biota is

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even more pressing (Rodman and Cody, 2003; Rodman, 2007; Johnson et al., 2017). Budget availability and our limited taxonomic knowledge of non-charismatic elements, such as arthropods, have been determining factors preventing us from having a more comprehensive view of global biodiversity and its role in ecosystem functioning (Ronquist et al., 2020). With close to 1.2 million arthropod species described and around 80 % of arthropods yet to be discovered (Stork, 2018), there are still huge gaps in our knowledge of the taxonomy and distribution of most arthropod species, whose ecosystem functions are not exactly known (Sheehan and Miller, 2021). For these reasons, when conducting specific works, complementary collection campaigns and many years of taxonomic and systematic reviews are needed to identify species and their functions in the ecosystem (Cardoso et al., 2020). Some advances in national inventories, such as the Swedish Malaise Trap Project (SMTP)—one of the most ambitious international insect inventories—have contributed to identifying close to a third of the undescribed country-level diversity, resulting in around 300 new species for science (Karlsson et al., 2020a, 2020b).

Arthropods continue to be the “hidden biodiversity” not only in tropical forests (Stork, 2018; Mesaglio et al., 2021), but also in subtropical arid, Mediterranean, and temperate environments of developing countries, where they have been historically ignored by conservation efforts in favor of vascular plants and vertebrate animals (Troudet et al., 2017; Pizarro-Araya et al., 2021). Studies show that the abundance and diversity of arthropods—the main and lesser-known component of global biodiversity—are diminishing in several regions of the world (Wagner, 2020; Wagner et al., 2021). The situation is even worse due to anthropogenic pressures that threaten to change ecosystem dynamics and distribution patterns of many species, including the risk of losing functions that are essential to the functioning of ecosystems, without us even knowing which species make those processes possible (Johnson et al., 2017).

Furthermore, the number of endangered and extinct species has been underestimated due to the rarity of many species, the lack of sufficient data, and the fact that many species remain undescribed (Stork, 2018). The problem is exacerbated by the sixth mass extinction currently underway, where the current biodiversity crisis might be associated with high and increasing rates of species extinction as a result of human actions (Cowie et al., 2022; Rull, 2022). If we consider that for every extinct or endangered species, there are other biota components that are affected by potential cascading effects, the extinction of arthropods is another sign of a global catastrophe (Chichorro et al., 2019).

Taking into account the Linnean and Wallacean shortfalls and the ecological importance of arthropods, as well as the need to improve our knowledge of the diversity, dynamics, and function of this taxonomic group (Hortal et al., 2015; Cardoso et al., 2020), we provide the first results of the national biodiversity inventory generated under the “Sistema Integrado de Monitoreo de Ecosistemas Forestales” (SIMEF [Integrated System for Monitoring Forest Ecosystems]) of Chile, a country with high levels of endemicity that is exposed to multiple anthropogenic threats, such as changes in land use, ecosystem degradation, and the effects of climate change (Boisier et al., 2018). The SIMEF began in 2015 as a project of the Global Environmental Fund (GEF) and is now a regular program of the Chilean state under the direction of the Ministry of Agriculture (simef.minagri.gob.cl). This system implemented a biophysical, socioeconomic, and biodiversity inventory for terrestrial ecosystems that includes xerophytic formations in arid and semiarid regions, the Mediterranean scrubland, the sclerophyllous forests, the Nordpatagonian forests, and the Valdivian rainforest. All of these areas as a whole are considered one of the 36 global hotspots of biodiversity (Arroyo et al., 2006; Mittermeier et al., 2011).

The main purpose of this biodiversity inventory is to collect data to establish a baseline for the study of the distribution and richness of the phyla Chordata and Arthropoda at regional and national scale. The taxonomic data are collected from a subset of samples taken from a national grid (5 × 7 km) with the purpose of assessing the biodiversity status and trends in the country's ecosystems. In this article we focus our analysis on arthropods—one of the most numerous components of biodiversity—as they are one of the lesser known and lesser studied groups at local and regional level.

In Chile, the number of total described species amounts to 35,116, of which around 47 % are arthropods (Jaksic and Mella, 2018). These figures are expected considering that, for example, the beetles alone account for about 25 % of all described species in the world (Stork et al., 2015). Despite arthropods being one of the most numerous taxa, conservation programs in Chile, as in many other countries, have focused mostly on vascular plants, mammals, birds, reptiles, and amphibians. Besides, most of the studied taxa are charismatic or umbrella species that are biologically known or essential to ecotourism (Jaksic and Mella, 2018). In this article (1) we explore the Linnean and Wallacean shortfalls of arthropod biodiversity analyzing the results of the ongoing Chile's first national biodiversity inventory, and (2) we examine the importance of expanding biodiversity knowledge by exploring potential policy strategies to face shortfalls and the current loss of biodiversity.

2. Methods

2.1. Spatial configuration of the study sites

For the estimation of biodiversity, the national area from Chile was divided into hexagonal units of 5 × 7 km. These units are appropriate for studying large geographic extensions without being affected by geometric distortions (Turner et al., 2012) and have been used by the Environmental Protection Agency (EPA) in its environmental monitoring and evaluation program (Spence and White, 1992). In this way, a total of 444 hexagonal units with a dimension of 262,500 ha per hexagon were obtained. Each hexagonal unit contains a total of 91 sampling units (study sites onwards) (Fig. 1). In this first stage, the terrestrial arthropod inventory has focused on a total of 142 study sites which were selected from areas of high conservation value, priority sites, and protected areas (public and private) subject to different levels of conservation or anthropogenic modification (Table A.1). Because the SIMEF project is still ongoing, the extreme north of the country and the strip between 35° and 50° south latitude were not sampled. The study sites were located in geographical areas with different native plant formations and climate conditions ranging from cold and hot desert in the extreme north, to cold semiarid in the center, and tundra and subpolar oceanic in the south (Fig. 2). The climate nomenclature is based on modified Köppen-Geiger system sensu Sarricolea et al. (2017).

2.2. Sampling method

The arthropod samplings were performed between 2017 and 2021. In each one of the study sites mentioned above we used a series of methods proposed sensu Vergara-Asenjo et al. (2021a) (Fig. 3). In each of the study sites, a reference point was defined in which the samplings were performed with the following sampling methodologies: A) For the collections of terrestrial arthropods in each of the study sites, four interception traps were installed (pitfall traps) 50 m away from the reference point following the cardinal points (i.e., N, S, E, W). Each trap consisted of a 250 ml plastic cup which was filled up to two thirds of its capacity with a mixture of water, household detergent and 70° alcohol. The traps were active for three nights (sensu Pizarro-Araya et al., 2021). B) For the collections of flying insects, 4 transects of 50 m were carried out in the direction of the cardinal points with a total of 200 m, timing ca 30 min, the collections were focused at 2 m wide through the transect and up to 3 m high using an entomological net to contribute to the collection of flying or jumping species. This sampling technique was repeated for 3 days. All captured material was mounted (e.g., Lepidoptera, Diptera) or fixed in 70 % alcohol (e.g., Diptera, Hymenoptera) (sensu Caldas and Robbins, 2003). C) For the sampling of scorpions (informative and representative group of the assemblage of terrestrial

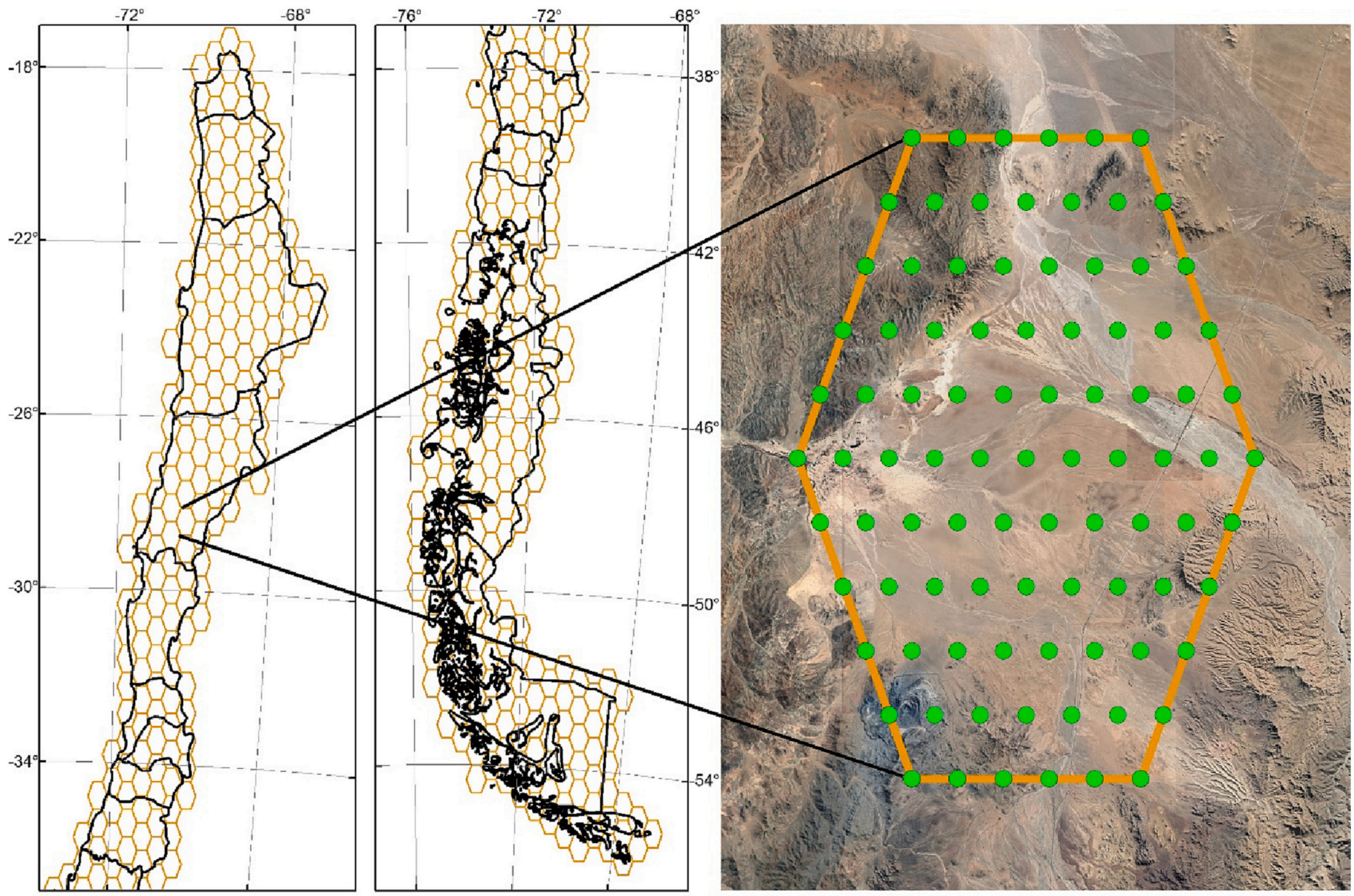

Fig. 1. Hexagonal grids with a detail of the systematic sampling units.

arthropods), manual sampling was carried out in four 50 m transects in the direction of the cardinal points with a total of 200 m, timing ca 30 min. Collections were focused 2 m wide across the transect using LED flashlights equipped with ultraviolet light (138 LED-UV) powered by a 12v battery. All the collected material was fixed in 80 % alcohol and 96 % alcohol. D) For the specific sampling of nocturnal flying arthropods (Coleoptera, Lepidoptera, Neuroptera, among others), eight 200-watt white lights were used on a 4 × 4 meter white sheet for 3–4 h. All the material attracted by artificial light was collected, fixed in alcohol and/or mounted depending on the taxon (Lepidoptera, Heterocera). The collected material has been deposited in the institutional collections of the Ecological Entomology Laboratory of the Universidad de La Serena (LEULS, La Serena, Chile, Jaime Pizarro-Araya), the Natural History National Museum (MNNC, Santiago, Chile, Mario Elgueta Donoso), and the Arachnology Division of the Bernardino Rivadavia Argentine Museum of Natural Sciences (MACN, Buenos Aires, Argentina, Martín J. Ramírez).

2.3. Classification of species and morphospecies

All collected specimens were taxonomically determined to the lowest possible level. When necessary, we reviewed primary (holotypes) and secondary (paratypes) type materials or material from reference collections identified by experts. In each case we selected the most up-to-date references or those representing the most stable classification for each group. Where taxonomic determination was difficult or in those groups where there were no formal taxonomic reviews, we used morphospecies as an alternative to taxonomic species. This has been proposed as an alternative identification method in studies with numerous invertebrate groups and in areas where taxonomic knowledge of these groups is limited (Derraik et al., 2010).

2.4. Biodiversity mapping

Biodiversity mapping has been proposed as a reliable tool for making decisions on land use (e.g., identification, selection, and design of conservation areas). In view of this, we plotted heat maps of richness, and new species or morphospecies, using the software QGIS to identify critical biodiversity spots in the country.

3. Results

3.1. Inventoried taxonomic groups

We collected a total of 49,151 individuals in the classes Arachnida, Diplopoda, Chilopoda, Insecta, and Malacostraca. There were 1,800 species recorded in 256 families and 33 orders, with 87 new species for the entire area under study, 15 % of which have already been described (Table A.2). The most represented taxa in terms of species richness were insects (70.6 % of the total) and arachnids (28.5 %) (Fig. 4). Coleoptera was the most diverse group, with new species recorded in northern Chile, including *Luispenaia paposo*, *Luispenaia atacamensis*, *Luispenaia paulseni* (Scarabaeidae), *Praocis* (*Mesopraocis*) *arenicola* (Tenebrionidae), and *Henicotherus francisca* (Chrysomelidae). Diptera and Acari were the most abundant groups in all the sites under study, but their taxonomic classification was difficult due to the poor or inexistent taxonomic knowledge of these groups in the country. In Arachnida, less diverse groups, but with newly recorded endemic species, included Scorpiones, Araneae, and Solifugae. Of special note were the descriptions of the scorpions *Brachistosternus philippii*, *Urophonius pehuenche*,

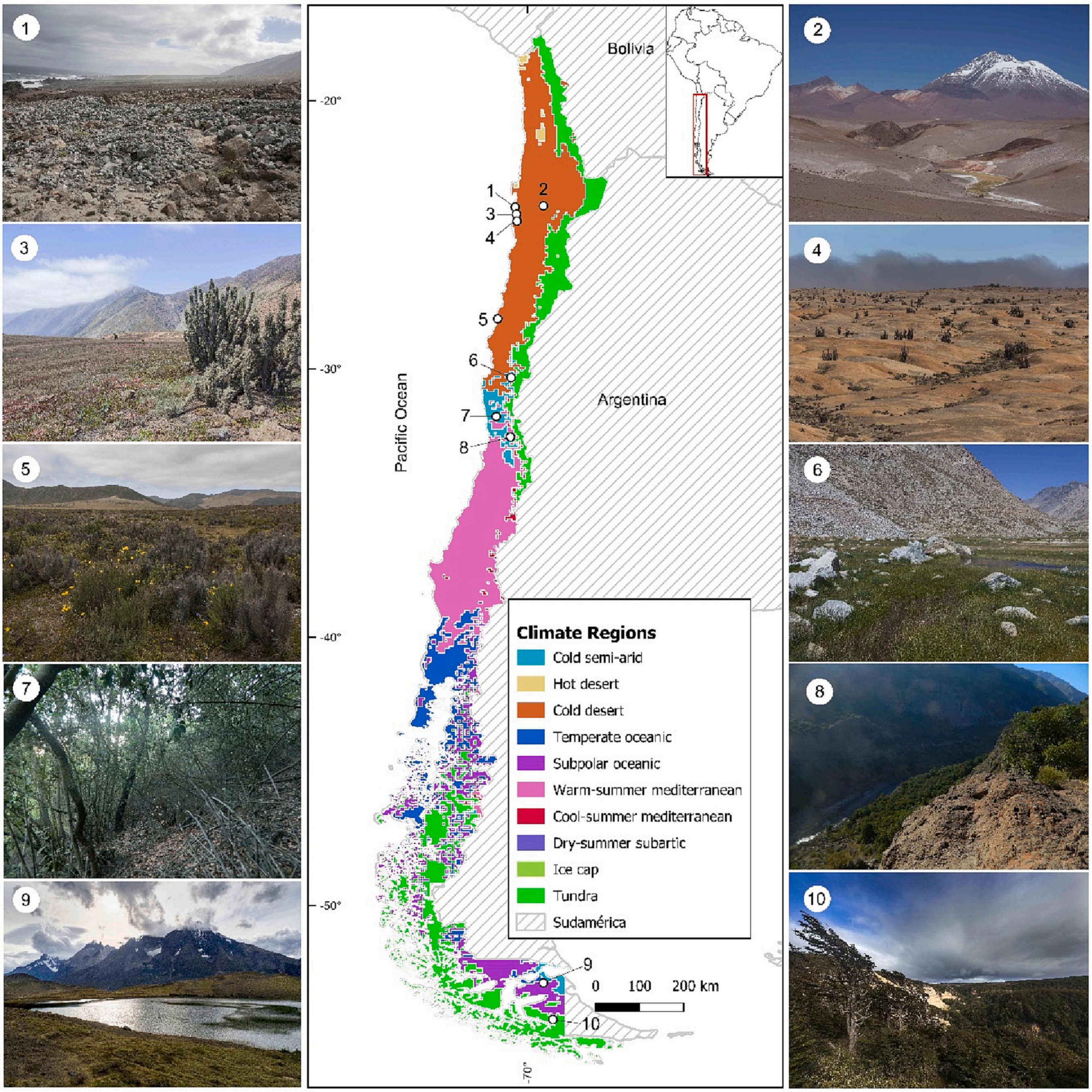

Fig. 2. View of some representative habitats studied in the SIMEF inventory in Chile. Protected and unprotected sampled areas along different climate regions are shown. (1) Paposo Norte Natural Monument, (2) Llullaillaco National Park, (3) Paposo Priority Site, (4) Pan de Azúcar National Park, (5) Llanos de Challe National Park, (6) Estero Derecho Private Protected Area and Natural Sanctuary , (7) La Campana National Park, (8) Río de Los Cipreses National Reserve, (9) Torres del Paine National Park, (10) Magallanes National Reserve.

Brachistosternus llullaillaco and *Bothriurus mistral* (Bothriuridae), and recently the spider *Tekellina araucana* (Synotaxidae) and *Osornolobus violetaparra* n. sp. (Orsolobidae) (Table A.2).

3.2. Spatial distribution of richness and new species

The geographical distribution of arthropod diversity revealed areas with different concentrations of species richness. In the south of the country, the areas with higher arthropod richness were native forests and Patagonian steppe environments (i.e., Torres del Paine National Park, TPNP), whereas in the north these were mostly protected wild areas, such as the Llullaillaco National Park, LlNP (Antofagasta Region), the Llanos de Challe National Park, LlChNP (Atacama Region), the Bosque Fray Jorge National Park (BFJNP), and the Chinchillas National Reserve (ChNR) both in Coquimbo Region (Fig. 5a). These protected areas have environments that are very different in terms of bioclimatic characteristics and have a wide variety of habitats. In northern Chile, most of the new species were recorded in extreme Andean (LlNP) and coastal desert (LlChNP) environments, whereas in the south most new species occurred in environments of the Magellanic forest located south of the TPNP (Fig. 5b). All the findings of new species occurred in 75 study sites, i.e., around 67 % of the environments sampled in this

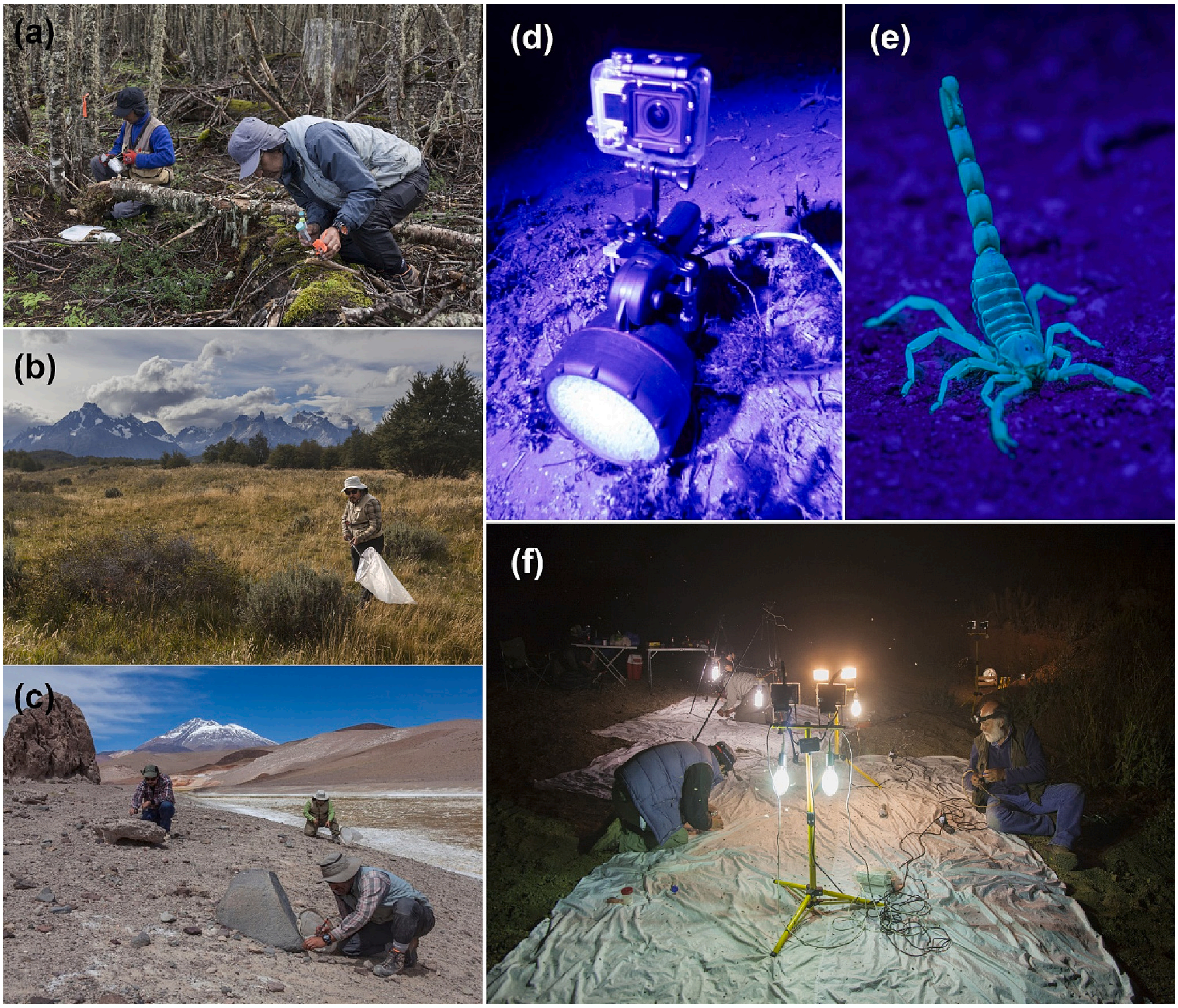

Fig. 3. Application of sampling methods in different areas of the country. (a) Transect sampling with pitfall traps in Torres del Paine National Park, (b) sweep net sampling in Torres del Paine National Park, (c) transect sampling with manual sampling in Llullaillaco National Park, (d) UV-light sampling in Llanos de Challe National Park, (e) nocturnal scorpion collection using UV light in Llanos de Challe National Park, (f) white-light sampling for nocturnal species in Paposo Priority Site.

inventory have one or more new species. Of the total number of new species registered in the inventory, about 39.1 % corresponded to mites (Acari), 16.1 % corresponded to camel spiders (Solifugae), and 13.8 % to spiders (Araneae). The rest was represented by diverse groups including Pseudoscorpiones (10.3 %), Coleoptera (6.9 %), Scorpiones (5.7 %), Orthoptera (3.4 %) and Hymenoptera and Chilopoda with 1.1 % each one.

3.3. Gaps, endemicity, and protected areas

This inventory is notable for its comprehensive sampling effort in a wide variety of protected and non-protected environments throughout Chile. Even though most study sites are protected areas, the vast majority of Chile's continental and insular environments and ecosystems have been poorly studied in terms of their diversity (Pizarro-Araya et al., 2021). The mapping of the arthropod diversity recorded in this inventory showed that the major information gaps involve habitats in the intermediate depression, central valleys, and high-altitude ecosystems located mostly in the north of the country. All the new species recorded in this inventory are endemic elements with restricted geographical distributions, making them even more difficult to preserve when there are potential threats to the species' habitats.

4. Discussion

While the data from the initial stages of this inventory have generated promising results for science and the natural heritage of the country, there are still important shortfalls that prevent us from having an adequate knowledge about arthropods and their distribution. Given human pressures on ecosystems and the rapid environmental changes produced by climate change, there is an urgency to generate information to support decision-making in conservation for vulnerable countries to the impacts of climate change on biodiversity e.g. current Chile's twelve-year megadrought (World Bank, 2021). Pushing the frontiers of our knowledge of biodiversity—particularly the exploration of new species—is key to better understanding ecosystem functioning, measuring extinction rates, or assessing the impact of threats such as climate change (Pecl et al., 2017).

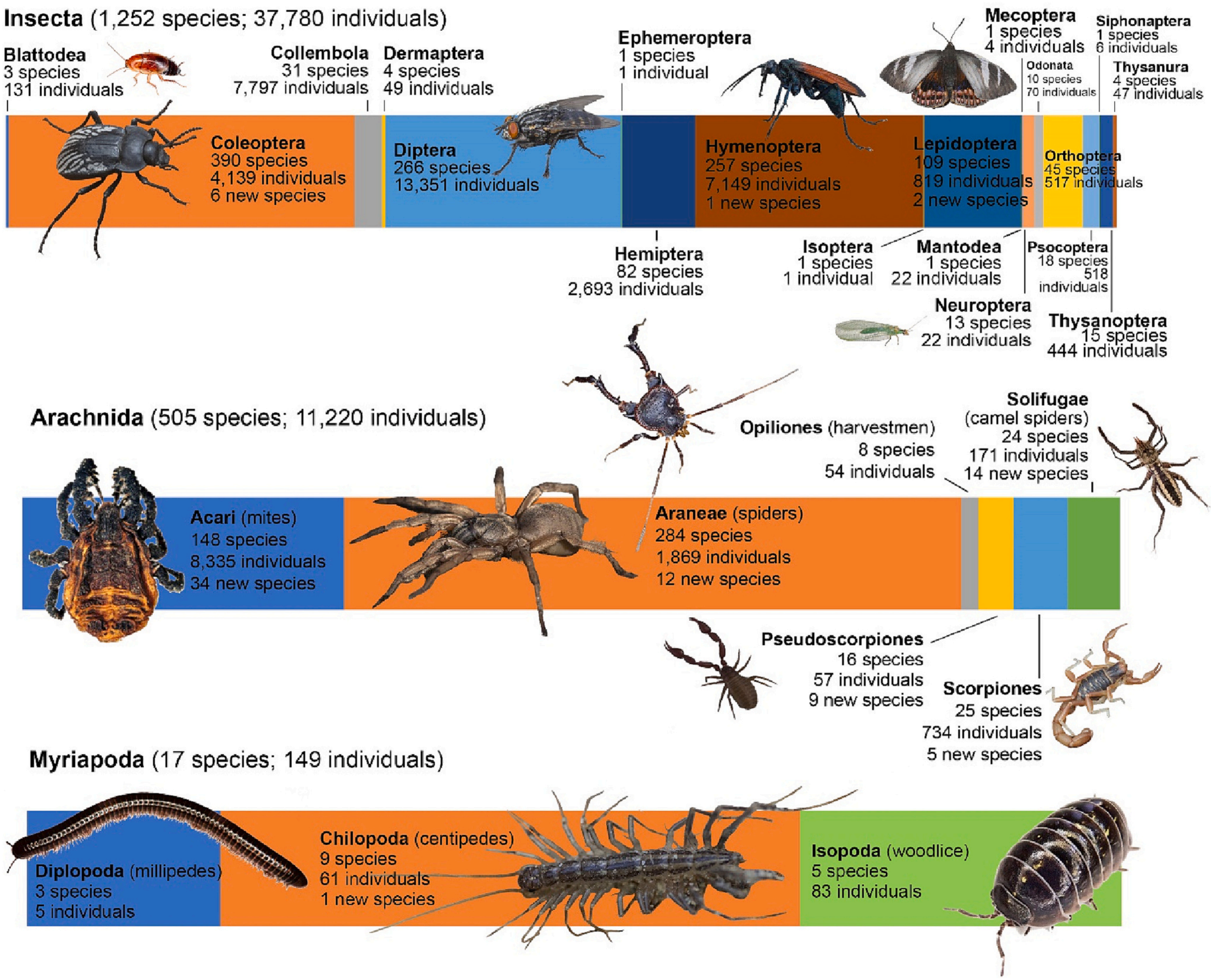

Fig. 4. Detail of the taxonomic composition of terrestrial arthropods registered in SIMEF inventory in Chile. Each fragment represents the species richness of the different groups (orders) of terrestrial arthropods.

Linnean and Wallacean shortfalls affect other aspects of biodiversity knowledge because they represent a lack of information about basic units of study in ecology (Hortal et al., 2015). New species of arthropods in this inventory revealed two distinct categories of Linnean shortfalls i) unsurveyed, understudied or remote areas to be sampled and ii) collected species to be described which require revisiting sampling areas to reach a minimum of specimens for taxonomic classification. On the other hand, the Wallacean shortfalls refers to the gaps in our understanding of species distributions (Hortal et al., 2015), a problem that worsens when there is difficult to access remote geographical areas, low spatial and temporal resolution of sampling efforts, and countries with reduced research capacities (Rodrigues et al., 2010). Linnean shortfalls are mainly associated with the lack of funding of monitoring and inventory initiatives and the bias towards most charismatic or umbrella species, which in turn trigger effects on the experts' availability, recruitment of taxonomists in research centers, journal impact factors, as well as the availability of scientific collections of type specimens. Waldron et al. (2013) carried out a global analysis of countries with inadequate financing for the study and effective conservation of biodiversity, among which Chile is in ninth place out of 199 countries. Although Chile has increased its total protected areas, the country currently has serious problems in the knowledge of various taxa, due to the serious deficit of taxonomists (and human capital training in disciplines such as taxonomy and systematics) and the scarcity of public and private funds for the study of a biota with high endemism.

Former initiatives of biodiversity data collection of countries like Canada, New Zealand, and the United States of America, among others, offered a path to generate taxonomy and distribution information of species under an integrative framework. Unfortunately, because collecting biodiversity data is time-consuming and expensive to maintain over time, few countries still maintain large scale efforts with public financing. In the recent years, a few countries have established collaborative platforms working with government institutions, universities, the private sector and non-government organizations to promote and visualize biodiversity data (i.e. the National Biodiversity Institute (INBio) of Costa Rica, the SIB of Colombia or the SNIB of Mexico) (INBio, 2022).

Large-scale studies and reviews of arthropod status and trends are scarce and plagued by Linnean and Wallacean shortfalls (Cardoso et al., 2019; Didham et al., 2020; Montgomery et al., 2020) with most literature dealing with areas of temperate climate (mainly Europe) and being highly focused on specific areas and selected taxa not representative of insects or even of insect subgroups (Miličić et al., 2021). Taxonomic bias often affects financing of biodiversity inventories and monitoring initiatives, which it is more evident for non-charismatic insects which receive little attention with a few exceptions, e.g., bees and butterflies (Mammola et al., 2020).

The challenge of generating taxonomic knowledge about the species

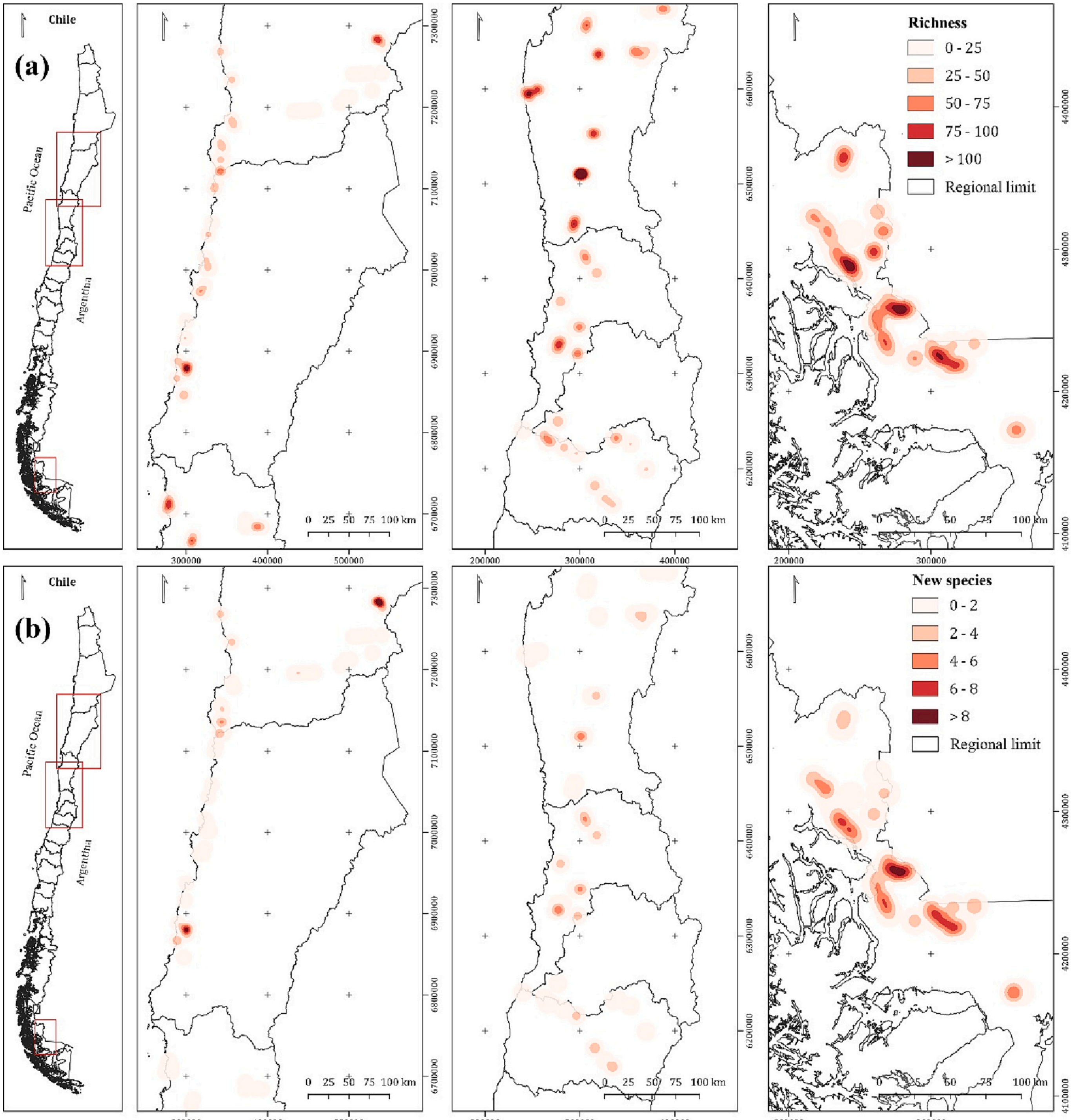

Fig. 5. Geographical distribution of terrestrial arthropods included in Chile's SIMEF inventory across the different sampling areas. (a) Species richness (number of species), (b) new species (described and undescribed). The spatial unit is a grid of 7 × 5 km^2.

is exacerbated with the increasing deficit of specialists able to tackle this effort. This is not a local problem only, as the development of taxonomy in many developing countries faces serious challenges due to the low number of specialists dedicated to identifying and classifying species (Engel et al., 2021). By contrast, the agreements adopted by the Global Taxonomy Initiative (GTI) of the Convention on Biological Diversity (CBD) seek to establish commitments to preserve global biodiversity and their associated ecological functions, especially the development of taxonomy as a discipline and the discovery of global biodiversity (Grieneisen et al., 2014).

The decreasing trend in the status of arthropods populations, as well as the key significance of insects and the numerous ecosystem services they provide, calls for global monitoring programs to reduce Linnean and Wallacean shortfalls, and identifying specialized conservation approaches for each particular case. Based on the above-mentioned reasons, we propose a conceptual framework aimed at reducing Linnean and Wallacean shortfalls and supporting biodiversity conservation policies—with a focus on arthropods. It comprises 3 main pillars: (1) the ecosystems, their species, and the threats that determine their integrity, dynamics, and functioning; (2) the key elements to include in a biodiversity assessment strategy and reduce Linnean and Wallacean shortfalls, and (3) an action plan for biodiversity conservation. We believe that these elements will foster the intersectoral links needed to develop strategies and action plans aimed at improving the monitoring and conservation of lesser known and lesser studied species (Fig. 6).

4.1. Ecosystems and the impact of anthropogenic threats

The accelerated changes in temperature and precipitation patterns associated with climate change pose new challenges for biodiversity as they interact or combine with the long-standing accumulated effects of other anthropogenic threats or stressors, such as deforestation and ecosystem degradation (Yang et al., 2021). These stressors may affect species dynamics and the integrity and functioning of ecosystems, with the potential to cause cascading effects on other elements of biodiversity (Kehoe et al., 2020). For example, studies on the impacts of climate change suggest that the arthropod populations—particularly of insects—will be positively or negatively affected for some species, with potential changes to their phenology and distribution (Halsch et al., 2020; Eggleton, 2020). Furthermore, climate change is affecting the survival and reproductive ability of plant-eating insects in many ecosystems of the world, creating suitable conditions for population outbreaks, such as those of the mountain pine beetle (*Dendroctonus ponderosae*) in North America (Hessburg et al., 2019) or the defoliator moth (*Ormiscodes amphimone*) in temperate forests from southern cone of South America (Estay et al., 2019). In view of this, identifying and monitoring species and its stressors is essential to understand their impacts as well as for effective design of conservation plans (Weisser et al., 2023).

4.2. Biodiversity assessment and monitoring

Constantly monitoring biological diversity and their stressors is essential to defining and adjusting conservation strategies as well as evaluating the status and trends of ecosystems, and their biological answers to environmental and policy change. In this regard, inventorying and monitoring a representative network of sampling sites will contribute with key information about the different components of biodiversity, its stressors and promote their inclusion in decision-making processes (Valdez et al., 2023). National networks of sampling sites at national levels should be maintained and strengthened over time (Vergara-Asenjo et al., 2021b; https://simef.minagri.gob.cl/).

Based on proposals such as those by Hochkirch et al. (2020) regarding to generate biodiversity information, we propose a seven-step strategy for monitoring ecosystems, their threats, and lesser-known taxa in particular, such as arthropods to reduce shortfall knowledge. This strategy consists of (1) promoting the valuation of biodiversity, (2) developing and funding monitoring programs, (3) conducting samplings at different spatial and temporal scales, (4) increasing efforts to promote the development of taxonomy, (5) combining efforts between institutions and other stakeholders, (6) systematizing information in geospatial databases, and (7) promoting science in communities, particularly through participatory monitoring.

4.3. Policy implications

Given the importance of knowing and monitoring lesser-known taxonomic groups, such as arthropods, in the face of anthropogenic threats and their potential effects on the functioning of ecosystems and the wellbeing of society, it is essential to reinforce national strategies through action plans for global diversity management and conservation. In this regard, the information gathered from biodiversity assessments should be used to (1) propose and update conservation red lists—such as IUCN list—using standardized criteria, (2) update management plans for the conservation of protected areas, including arthropod species, (3) include arthropod species as conservation targets, (4) promote basic research in arthropod taxonomy, (5) promote applied research on the effects of climate change on habitats, distribution, and population dynamics to develop accurate predictions about biological responses sensu Urban et al. (2016) and, (6) propose new public or private areas for conservation as well as actions for non-protected areas (Fig. 6). Generating information about the species, their stressors, and ecosystems in

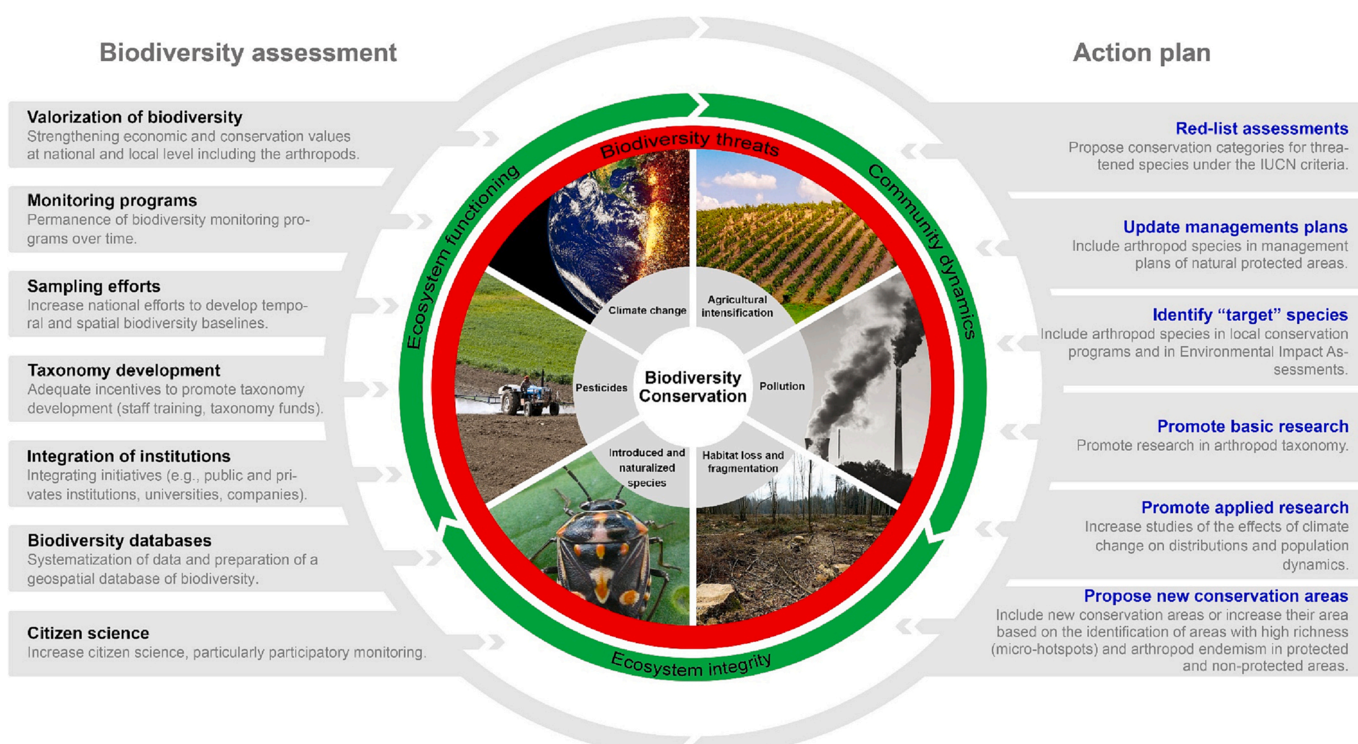

Fig. 6. A conceptual approach to reduce Linnean and Wallacean shortfalls with focus in arthropod species.

general will help reducing the shortfalls in our understanding of terrestrial biodiversity in the face of anthropogenic pressures and will ultimately contribute with conservation efforts in the coming decades.

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Integrated Forest Ecosystem Assessment and Monitoring System (SIMEF), INFOR.

CRediT authorship contribution statement

Gerardo Vergara-Asenjo: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration. **Fermín M. Alfaro:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Jaime Pizarro-Araya:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing, Funding acquisition, Project administration.

Declaration of competing interest

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

Data availability

Collected specimens have been deposited in the entomological collection of the Ecological Entomology Laboratory of the University of La Serena (LEULS) and in the Arachnology Division of the Bernardino Rivadavia Argentine Museum of Natural Sciences, Buenos Aires, Argentina (MACN). All published data are available upon formal request.

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Appendix A. Supplementary data

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