Discover Conservation

Perspective

Best practices for long-term monitoring of island arthropods: insights from the Azores Islands

Paulo A. V. Borges[1,2,3]

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Abstract
Long-term monitoring of biodiversity on island ecosystems is essential for understanding ecological trends, assessing anthropogenic impacts, and informing conservation strategies. Despite significant advancements, monitoring efforts are often fragmented, particularly for arthropods. Recent initiatives in the Azores Islands (Portugal, Macaronesia), have demonstrated the efficacy of standardized protocols and robust frameworks for long-term arthropod monitoring. These approaches enable consistent data collection, species identification, biodiversity assessments and indicators of change, critical for conservation and management policies.

Keywords Arthropod conservation · Island ecosystems · Multimetric biodiversity indices · Standardized sampling protocols

1 Introduction

Long-term monitoring of biodiversity is the systematic, repeated collection of data over extended periods, aimed at tracking changes in species composition, abundance, and ecosystem health, which is essential for understanding ecological trends, assessing the impact of human activities, and informing conservation efforts [1, 2]. Current monitoring faces fragmentation issues due to gaps in taxonomic coverage (birds are preferred), spatial consistency (focus on terrestrial habitats), and long-term data availability [3].

Recent efforts for the long-term ecological monitoring of arthropods resulted in the discovery of an unprecedented and rapid decline in insects and other arthropods abundance, diversity and biomass across the biosphere [4, 5], but the trends vary with habitat [6, 7].

Long-term ecological monitoring on islands is essential for understanding biodiversity patterns, ecosystem resilience, and responses to environmental change [8]. Islands often host unique assemblages of arthropods, making them critical sites for studying evolution, adaptation, and the impacts of isolation on species dynamics [9]. Arthropods, due to their diversity and ecological roles, serve as key bioindicators, offering insights into habitat health and shifts in environmental conditions [10].

✉ Paulo A. V. Borges, paulo.av.borges@uac.pt | [1]University of Azores, CE3C—Centre for Ecology, Evolution and Environmental Changes, Azorean Biodiversity Group, CHANGE—Global Change and Sustainability Institute, School of Agricultural and Environmental Sciences, University of Azores, Rua Capitão João d'Ávila, Pico da Urze, 9700-042 Angra Do Heroísmo, Azores, Portugal. [2]IUCN SSC Atlantic Islands Invertebrate Specialist Group, 9700-042 Angra Do Heroísmo, Azores, Portugal. [3]IUCN SSC Species Monitoring Specialist Group, 9700-042 Angra Do Heroísmo, Azores, Portugal.

Yet, there are very few cases on long-term monitoring of arthropods on islands [11, 12]. One challenge of long-term monitoring is the complexity of sustaining consistent data collection methods over extended periods [1, 13]. Recent initiatives on Azorean Islands have developed successful frameworks for monitoring that provide valuable data for both conservation and management [7, 14]. These projects contribute to broader conservation goals, enabling early detection of invasive species [15], shifts in community structure [7], and creation of indicators of forest conservation quality status [16].

2 Pipeline for arthropod long-term monitoring on islands towards conservation management policies

Projects like BALA (Biodiversity of Arthropods in the Azores) [14] and SLAM (Survey of Land Arthropods in the Azores) [7, 15, 16] serve as exemplary long-term monitoring initiatives, demonstrating effective strategies for data consistency and quality control over time. BALA was instrumental in establishing a baseline for arthropod biodiversity in Azores native forest [14], while SLAM expanded on this foundation with continuous sampling across diverse habitats [16, 17]. These initiatives have shown that the use of standardized protocols [8], alongside detailed data collection protocols, can yield robust datasets crucial for longitudinal studies.

The most recent proposed initiative for arthropod long-term monitoring was for Germany, "The German insect monitoring scheme (GIMS)" [18]. This initiative is quite ambitious and as a strategy covers the monitoring of common and rare species as separate modules, and includes a large number of taxonomic groups and habitats. However, most of the island territories will not have the resources for such tremendous investment.

In this perspective contribution I propose the following pipeline:

2.1 Use of a large-spectrum trap able to capture the maximum number of arthropods with a minimum sampling effort

The best option is clearly a Malaise Trap or the similar SLAM trap (Sea, Land and Air Malaise trap) (Fig. 1) used in the Azores Monitoring initiative [7, 15, 16]. The Swedish Malaise Trap Project (SMTP) initiative was also a very successful project [19] using Malaise Traps. These kinds of traps are easy to setup, can be in place in operation for long time periods and are quite resistant.

In the Azores SLAM experiment, native, wet, pristine forests across multiple islands were selected for study. To ensure adequate replication, ten 50 m × 50 m square plots were established per island [7, 15, 16], with efforts to maximize the distance between plots within the same mountain chain or continuous forest patch. Due to the logistical demands of sampling arthropods across numerous plots every three months over a twelve-year period, only one SLAM trap was placed in each plot (near the center). To evaluate whether this design adequately captured key community properties (e.g., species composition, abundance distributions), three SLAM traps were installed in 2015 within a single plot (Terra Brava Plot T18), spaced 30 m apart, and sampled monthly. Sensitivity analyses conducted by Matthews et al. [20] demonstrated that a single SLAM trap per plot was sufficient, as using three traps did not significantly alter the sampled communities based on various diversity metrics.

Based on our experience in Azores [7, 15–17, 20], the traps can survive at least three years in hyper-humid Azorean forests before needing to be replaced by a new one. In the Azores study the trap container was filled with propylene glycol (pure 1,2-Propanodiol) to kill the captured arthropods and conserve the sample between collections. The sites were visited every three months comprising the four main seasons in Temperate regions. The setup and maintenance of the traps can be done by Park-Rangers on different islands and the samples easily accommodated in, e.g., 96% ethanol-based fluids to be sent to the laboratory leading the monitoring study.

However, standardized time-based methodologies are also available for specific groups of arthropods, like the COBRA protocol for spiders [8] or pollinators.

Fig. 1 SLAM trap (Sea, Land and Air Malaise trap) (Credit: Paulo A. V. Borges)

2.2 Use a Rapid biodiversity assessment strategy for species identification

Sorting and identifying the sometimes-large samples originating from a Malaise or SLAM trap is a challenge. The workflow followed in the Azores initiative was as follows: (i) samples were sorted in the main orders by trained technicians or mostly students under ERASMUS traineeship programs: (ii) a reference collection of species and morphospecies for the target taxonomic groups was created, compiled an prepared by trained taxonomists; (iii) each sample was sorted into morphospecies by parataxonomists (students under ERASMUS traineeship programs); and (iv) a trained taxonomist always validates the identifications.

This pipeline can be challenging for hyper-diverse samples. However, for Temperate island forest communities this is a feasible effort as demonstrated by the Azores projects. Yet, morphospecies can overlook cryptic diversity and limit the resolution needed for phylogenetic or ecological analyses. For instance, Krell [21] discusses these trade-offs, underscoring the importance of complementing such approaches with molecular tools or targeted taxonomic identification to enhance data quality and utility.

2.3 Create databases in Darwin core

There is the need to set up a digital system for data entry, storage, and analysis, ensuring metadata collection for sample conditions, trap location, weather, and date. Data on species distribution and abundance needs to be properly stored in databases using the FAIR principle, i.e. a set of guidelines designed to ensure that data and digital resources are Findable, Accessible, Interoperable, and Reusable. Therefore, the Darwin Core standards (https://dwc.tdwg.org/terms/?utm_source=chatgpt.com) should be used for publishing and integrating biodiversity information [22] allowing the publication of data using the Toolkit of the Global Biodiversity Information Facility (GBIF IPT) [23]. As a best practices procedure, an Event Table should be created with the geographical and temporal data and an Occurrence Table with the species taxonomy and abundance data. An important follow-up will be the publication of such data as Data Papers (e.g. the AZORES BIOTA initiative [24]).

2.4 Create a Multicriteria index

Of critical importance for biodiversity conservation studies within the scope of long-term monitoring studies is the availability of indicators of change [25]. There are many biodiversity indices and indicators (species richness, diversity, dominance, evenness and rarity indexes), many of which are sensitive to sampling effort. The concept of 'biodiversity quality,' as discussed by Feest and colleagues [26, 27], emphasizes not only species richness but also the functional and conservation value of species within ecosystems. This paradigm has been applied to evaluate arthropod communities, including spiders in Portuguese protected areas [28], offering a multidimensional approach to biodiversity assessment. Moreover, the multimetric index proposed by Tsafack et al. [16] combines biogeographic and trophic parameters personalised to the Azorean Forest arthropod communities, serving as a prototype for developing similar arthropod-based indices in other island ecosystems, emphasizing endemic and introduced species dynamics.

The inclusion of biomass as a monitoring metric provides a multidimensional perspective on biodiversity changes, complementing species richness and diversity indices. Brush et al. [29] highlighted how shifts in biomass reflect underlying changes in community structure and ecosystem functioning, particularly in response to land use changes in Azores. The integration of biomass data into long-term monitoring protocols can provide actionable insights for conservation policies. As shown by Lhoumeau and Borges [15], tracking changes in biomass over time allows for early detection of declines and shifts in arthropod communities, facilitating timely interventions to protect native biodiversity and ecosystem functions.

2.5 Perform IUCN red listing assessments based on the long-term data

Concerning IUCN Red Listing, arthropods are underrepresented compared to vertebrates and plants. This is partly due to the limited focus on non-charismatic species like insects, arachnids, and crustaceans and possibly other reasons such as the imbalance in species numbers across groups. Therefore, it is critical to perform large-scale assessments of the conservation status of insect groups to define priority species, areas and issues, for example increase the number of insects with informative IUCN Red List assessments [30]. Many arthropod species lack sufficient ecological or distributional data to assess their conservation status. This results in a high proportion of species listed as "Data Deficient," limiting their inclusion in conservation priorities [31]. The way forward will be enforcing the acquisition of high-quality data that will be facilitated by the availability of long-term monitoring data on the abundance and distribution of arthropods.

2.6 Main limitations and alternatives

As mentioned above Malaise or SLAM traps (Sea, Land, and Air Malaise traps) are widely used for arthropod monitoring due to their efficiency and minimal field effort. However, they have some limitations. First, SLAM traps exhibit sampling bias, underrepresenting ground-dwelling and highly mobile arthropods like pollinators. Their effectiveness is also influenced by environmental conditions such as wind and rainfall, which can disrupt arthropod activity and trap performance. However, in dense forests the wind factor may not be a strong limitation. Furthermore, sorting and identifying large samples require significant taxonomic expertise, often relying on parataxonomists, which may introduce inconsistencies.

To address these limitations, several alternative methods can complement SLAM traps, like pitfall traps that are effective for sampling ground-dwelling arthropods. Light traps are valuable for nocturnal and phototactic species, and for instance the COBRA protocol [8] offers standardized sampling for specific groups, such as spiders. Advanced approaches like DNA metabarcoding provide efficient species identification without reliance on taxonomic experts but require laboratory facilities. Other targeted methods, such as hand-collection, sweep netting, or bait traps, can focus on specific taxa or behaviors. Additionally, emerging technologies like automated monitoring devices (e.g., camera traps and acoustic sensors) are being developed for specific arthropod groups e.g. [32, 33]. By integrating these complementary approaches, particularly the addition of pitfall traps, researchers can overcome SLAM trap limitations, ensuring more comprehensive arthropod community monitoring. However, pitfall traps are time-consuming in the field but, as suggested by the protocol GIMS for island forests [8], can be a solution to sample epigean rare arthropods every 10 years.

3 Conclusion

The role of arthropods in providing ecosystem services, such as pollination, decomposition, and pest control, is well-documented [34]. Integrating assessments of these services into monitoring programs can highlight the functional consequences of biodiversity declines, reinforcing their importance to ecosystem health and human well-being [30]. Moreover, linking biodiversity monitoring with policy and socioeconomic benefits is critical for justifying investment in long-term programs. Demonstrating the contribution of arthropod conservation to ecosystem resilience, agriculture, and tourism can strengthen support among stakeholders [30].

There is a clear lack of arthropod distribution and abundance data of high quality for island ecosystems [8]. Moreover, implementing long-term monitoring of arthropods on islands remains a challenge. These shortfalls imply that: (i) we lack proper IUCN Red Listing for island arthropods; (ii) conservation efforts may be misdirected or ineffective for the conservation of island arthropods; (iii) restoration efforts may not adequately address the needs of these communities; and (iv) the lack of data make it difficult to justify the need for conservation efforts focused on arthropods. In general, I recommend a pipeline that uses SLAM traps as a practical sampling method for a whole arthropod monitoring with minimal field effort. This strategy proved to be successful for the monitoring and conservation of Azorean arthropods [7, 15–17, 20].

Despite a wide taxonomic coverage of the proposed pipeline, taxonomic impediments will still pose significant challenges for its successful application on many islands worldwide. The emerging use of molecular approaches, particularly, *high throughput sequencing* (HTS), can greatly facilitate the inventory and monitoring of insular arthropod biodiversity [35]. However, even with such approaches, developing adequate indicators for monitoring forest ecosystem changes remains a major challenge.

While the Azores provide a valuable case study, tailoring monitoring protocols to other island systems with varying resources, biodiversity, and threats is essential [8]. Comparative studies across islands can yield insights into global patterns of biodiversity change and resilience.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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