Seed Science Research

cambridge.org/ssr

Overcoming major barriers in seed ecology research in developing countries

Fernando A. O. Silveira[1], Lisieux Fuzessy[2], Shyam S. Phartyal[3], Roberta L. C. Dayrell[4], Filip Vandelook[5], Jerónimo Vázquez-Ramírez[6,7], Çağatay Tavşanoğlu[8], Mehdi Abedi[9], Sershen Naidoo[10], Diana C. Acosta-Rojas[11], Si-Chong Chen[12], Diana M. Cruz-Tejada[13], Gehan Jayasuryia[14], Carlos A. Ordóñez-Parra[1] and Arne Saatkamp[15]

[1]Centre for Ecological Synthesis and Conservation, Federal University of Minas Gerais, Belo Horizonte, Brazil; [2]CREAF, Science building, Campus UAB, Bellaterra (Cerdanyola del Vallès), 08193 Barcelona, Catalonia, Spain; [3]School of Ecology and Environment Studies, Nalanda University, Rajgir, India; [4]Royal Botanic Gardens, Kew, Wakehurst, Ardingly, Haywards Heath, West Sussex, UK; [5]Meise Botanic Garde, Meise, Belgium; [6]School of Life and Environmental Sciences, Deakin University, Melbourne, Australia; [7]Pronatura Veracruz A.C., Coatepec, Mexico; [8]Division of Ecology, Department of Biology, Hacettepe University, Ankara, Turkey; [9]Department of Range Management, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Noor, Mazandaran Province, Iran; [10]Department of Biodiversity and Conservation Biology, University of the Western Cape, Bellville, South Africa; [11]Senckenberg Biodiversity and Climate Research Centre, Frankfurt, Germany; [12]Wuhan Botanical Garden, Chinese Academy of Sciences, Wuhan, Hubei Province, China; [13]University of Pisa, Pisa, Italy; [14]University of Peradeniya, Peradeniya, Sri Lanka and [15]IMBE, Aix Marseille Université, CNRS, IRD, Université d'Avignon, Marseille cedex, France

Abstract

Scientists are becoming increasingly aware that disparities in opportunities for conducting and publishing research among scientists living under different socio-economic contexts have created pervasive biases and long-lasting impacts on our views of the natural world. These disparities are challenging the establishment of a global research agenda for a variety of disciplines, including seed ecology. Seed ecology has progressed enormously recently, but multiple barriers have hindered progress in the Global South where biodiversity and environmental complexity are highest. Here, we identify ten major challenges that seed ecologists from developing countries face in relation to planning, designing, conducting and publishing their research. We also propose several measures to overcome these challenges: (1) closing biodiversity knowledge shortfalls, (2) enhancing and creating long-term seed ecological networks, (3) supporting better infrastructure, (4) making fieldwork easier and safer, (5) unlocking funding opportunities, (6) promoting inclusive scientific meetings, (7) alleviating language barriers, (8) improving education, (9) shifting the notion of novelty and relevance and (10) supporting native seed markets. The authors recommend that the proposed solutions can be implemented by seed ecologists and the broader scientific community including funding agencies, research directors, journal editors and the academic publishing industry. Solutions can help mitigate multiple challenges simultaneously, thus offering a relatively inexpensive, fast and productive pathway for the development of seed ecology into a truly global research discipline that benefits scientists irrespective of their geographic location and background.

Introduction

Seed ecology is a complex, exciting and growing subdiscipline of seed science. Seed ecology addresses processes, patterns, mechanisms and environmental challenges ranging from seed production to seedling establishment and ecosystem restoration across a wide diversity of ecological scales. Seed ecology is interdisciplinary in nature and often intersects with knowledge stemming from a broad range of subdisciplines in ecology, plant science, genetics and conservation biology, as well as in applied fields such as agriculture, forestry and restoration ecology (Saatkamp et al 2019). Since the publication of Fenner's (1985) seminal book on the ecology of seeds, followed by the first edition of the classic book by Baskin and Baskin (1998) *Seeds: Ecology, Biogeography, and Evolution of Dormancy and Germination*, the discipline has undoubtedly expanded and brought a wealth of knowledge about how seeds interact with their mother plants (Wang et al 2022) and the subsequent environments (Donohue et al 2010), shape a wide diversity of associated organisms (Chen et al 2017), contribute to community assembly (Larson and Funk 2016), cascade into manifold processes at biogeographical and macroecological scales (Chen et al 2019) and contribute to ecosystem restoration (Dalziell et al 2022). Several studies have emphasized the paucity of solid information of seed ecology as a limitation to understanding plant responses at different geographic scales. However, the

Research Opinion

Cite this article: Silveira FAO *et al* (2023). Overcoming major barriers in seed ecology research in developing countries. *Seed Science Research* **33**, 172–181. https://doi.org/10.1017/S0960258523000181

Received: 6 July 2023
Revised: 4 September 2023
Accepted: 6 September 2023

Keywords:
equity; geographic biases; inclusion; international collaboration; language barriers; seed ecology

Corresponding author:
Fernando A. O. Silveira;
Email: faosilveira@gmail.com

development of novel and automatic approaches to data compilation for the study of seed ecology now include big data (Chen et al 2020; Carta et al 2022), functional perspectives (Saatkamp et al 2019), molecular ecology (Footitt et al 2020), global-scale analyses (Rubio de Casas et al 2017) and automated trait data acquisition (Dayrell et al 2023).

The wider application of seed ecology and subsequent growing seed ecology databases has enriched our understanding of the ecology of seeds of native, crop and invasive species over the last two decades (Fernández-Pascual et al 2023). However, the contribution of scientists and data to the development, management and use of the analytical tools that have enabled this progress is not globally representative. This is largely because, as in many biodiversity-oriented fields, sampling efforts and available data on the ecology of seeds are both concentrated in developed countries (*sensu* United Nations 2014), whereas developing countries are underrepresented in the scientific literature, with a few exceptions such as China (Marks et al 2023). Research on seed ecology is hindered by insufficient human and financial resources, limited long-term and monitoring data, and a lack of recognition of seed ecological knowledge by decision-makers in the environmental sector. These factors hinder novel research questions requiring long-term data, challenging ecological patterns at various scales or in modelling studies. Consequently, the generation of novel information through basic research is crucial to enable testing of more advanced hypotheses. Unfortunately, this need has received limited investment and garnered little recognition from the forefront of the broader scientific community (Geldmann et al 2020).

Ecologists have recently begun to acknowledge that disparities between developing and developed countries have profound, long-lasting effects on how we understand, manage, protect and restore our natural world (Culumber et al 2019). Geographical biases significantly impact the planning and implementation of seed-based conservation and restoration programmes (Godefroid et al 2013; Ribeiro et al 2016). Given the unprecedented levels of biodiversity loss in the tropics, where many developing countries are located, there is a pressing need for ecologists to bridge the gap between the science of restoration and its practical implementation (Dalziell et al 2022). Additionally, climate change has unequivocally demonstrated that environmental challenges do not adhere to national borders, emphasizing the imperative for a collective global effort to mitigate environmental problems and combat the alarming rate of species extinction. Therefore, identifying the factors contributing to these disparities and designing solutions to alleviate them should be prioritized by the scientific community.

Here, we provide a list of ten barriers that seed ecologists from developing countries are facing and possible solutions to alleviate them. The solutions proposed here stem from a shared responsibility and collaborative efforts required from all countries to effectively address global environmental challenges. We acknowledge the importance of the debate on underrepresented groups in science, including those based on gender, race or sexual orientation; however, we do not address these issues, given they have been discussed elsewhere. Nevertheless, we have tried to accommodate a diversity of opinions, perceptions and experiences from developing countries' seed ecologists by assembling a list of authors that either work in or hail from countries where these barriers are present. Researching seed ecology in developing countries presents significant challenges due to the high biodiversity prevalent in many of these regions, as well as the complex logistical, social and economic contexts within which the research is conducted. We recognize that our list is not exhaustive, but rather represents initial steps towards a broader discussion that the seed ecology community needs to engage in (Table 1).

Closing biodiversity knowledge shortfalls

Seed ecology studies require data of distinct natures, which are often lacking for species from developing countries (Fernández-Pascual

Table 1. Summary of the proposed solutions to overcome barriers in seed ecology research in developing countries

Barrier	Summary of the proposed solutions
Persistent biodiversity knowledge shortfalls	Prioritize data-deficient areas, building seed trait databases, using modern technology to accelerate extraction of seed traits
Lack of long-term seed ecological networks across multiple scales	Implement networks microclimate sensors and long-term vegetation data
Poor infra-structure	Establishing meaningful and collaborative partnerships between developed and developing countries
Unsafe fieldwork	Building partnerships with local individuals, communities, organisations, or governments, and creating protocols to improve safety
Limited funding opportunities	Strengthening international collaboration, developing strategies for alleviating barriers imposed by article processing charges
Exclusive scientific meetings	Organizing in-person meetings on different continents, informing decisions on abstract acceptance in advance, considering the schedule of developing countries when defining deadlines, and promoting hybrid meetings to decrease the travelling and accommodation costs
Language barriers	Multiple solutions are suggested, but supporting English translation and polishing services is particularly encouraged
Poor education	Creating international and field-based seed ecology courses
Biased notion of novelty and relevance	Implementing double-blinded review, recruiting international reviewers, diversifying journal editorial boards, personalize the review process with sensitivity to international authors with English as an additional language, emphasize and value low-cost methods
Underdeveloped native seed markets	Easing the laboratory accreditation process for native seed and relaxing the level of the international and national limitations over seed transport

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

et al 2023). More specifically, in such countries, there are clear knowledge gaps for species taxonomy, distribution, abundance, phylogenetic relationship, niche breadth, species traits and biotic interactions (the so-called biodiversity knowledge shortfalls; Hortal et al 2015). In many cases, community-level studies in developing countries lack species-level identification, so data for unidentified species need to be removed. Due to the colonial science culture of the past, research infrastructure in many developing countries has begun to thrive only in the last few decades (Marks et al 2023). The absence of a robust foundation in seed data restricts seed ecologists from developing countries in their ability to test more elaborated hypotheses or use modelling approaches that require sophisticated climatic, edaphic and biological data. Consequently, seed ecologists from developing countries face the necessity of gathering new baseline data in their early-career stages. Gathering new data over large, unexplored areas is time-consuming and often prohibitively costly. Furthermore, investment in collecting such data is often limited given that local-scale field studies are undervalued by international journals (Geldmann et al 2020). Consequently, fewer studies are published, fewer data are made publicly available and papers are often published in local journals. For example, seed trait and seed germination data of Mediterranean Basin plants are significantly biased towards the northern parts of the Basin where developed countries are located, whereas seed trait data in the Mediterranean parts of northern African countries are underrepresented (Tavşanoğlu and Pausas 2018). Both funders and international journals should recognize and support these priorities by introducing grants targeting baseline studies in data-deficient areas (see Section 'Unlocking funding opportunities') and welcoming the publication of their results (see Section 'Shifting the notion of novelty and relevance').

Alternative initiatives help accelerating trait data compilation and acquisition in developing countries, as exemplified by the Seed Information Database (https://ser-sid.org/). First, data papers and meta-analyses can be a useful way of mobilizing and consolidating data published in local languages and data stored in the so-called gray literature. By compiling, standardizing, harmonizing and checking the quality of unpublished data stored in theses, reports, papers published in non-indexed journals and ongoing experiments, seed ecologists can amplify the data use, reuse and rescue (Fernández-Pascual et al 2023). Such databases are rare but are starting to emerge in developing countries (Ordóñez-Parra et al 2023). Nevertheless, increased and targeted funding is needed to support data curation, management and archiving future efforts. Identifying data-deficient countries can inform prioritization for closing knowledge gaps.

Furthermore, emerging high-throughput methods of seed trait extraction from images offer a powerful and efficient approach to rapidly increase seed ecology knowledge and support seed identification initiatives (Dayrell et al 2023). Finally, additional strategies include the production of curated field guides (https://fieldguides.fieldmuseum.org/; Acosta-Rojas et al 2021), building of interactive keys (i.e. https://seedidguide.idseed.org/), creating plant taxonomy networks based on seed traits and partnering with local seed collector networks.

Enhancing and creating long-term seed ecological networks across multiple scales

The global coverage of vegetation (Bruelheide et al 2019), species abundance (Dornelas et al 2018) and trait data (Kattge et al 2020) is biased towards Western Europe, North America and Australia, reflecting unequal sampling efforts across the globe. These biases prevent studies addressing long-term land-use changes, and specifically restrict seed ecologists from developed countries to test ecological hypotheses spanning large spatial and temporal dimensions across multiple scales.

Likewise, existing microclimatic data (i.e. environmental conditions experienced by seeds), as exemplified by *in situ* measurements of soil temperature, are also biased towards developed countries (Lembrechts et al 2022). Under these conditions, seed ecologists should rely on biased global models (not suitably calibrated for their local conditions), national meteorological data (which are less useful for seed ecology) or whenever possible, invest time and money on generating the necessary microclimate data.

Implementing long-term environmental and biological data gathering is becoming increasingly important in some developing countries (Wohner et al 2021). However, environmental data and technology-sharing agreements underpin and help sustain research networks, but are virtually non-existent in the seed ecology community. For such data to become meaningful in seed ecology, environmental data gathering should operate at the microclimatic level. For instance, novel soil temperature and moisture sensor technologies are available at relatively low cost (Lembrechts et al 2022). Another powerful way of advancing seed ecology in developing countries is the establishment of globally distributed research networks, which need not be prohibitively expensive or time-consuming on a *per capita* basis and are not limited to senior scientists or countries where science is well-funded (Borer et al 2014).

Supporting better infrastructure

New techniques such as omics and molecular ecology are being used to analyse how genes modulate seed interactions with the environment (Colville et al 2022; Simonin et al 2022). However, molecular seed ecology is rare in developing countries owing to a lack of basic equipment like incubators, stable power supplies to conduct germination experiments under controlled conditions and bureaucratic reagent importing. Indeed, many seed ecologists from developing countries have experienced multiple collapses of germination chambers due to unpredictable power failures. Laboratory infrastructure and equipment in developing countries are also often obsolete. For example, owing to different equipment precision settings, measuring the seed carbon and nitrogen content in a developing country may require 12 g, whereas the same chemical analysis in a European laboratory requires only 0.05 g of dry seeds (Acosta-Rojas, personal communication). Given the limited funding available for field studies in developing countries (see Section 'Unlocking funding opportunities'), waste of time and resources is likely if sampling additional material is needed to achieve the required seed material.

Another pervasive issue is infrastructure needed for the *ex situ* seed conservation in developing countries. Many tropical species have recalcitrant seeds (Wyse and Dickie 2017), and conservation of such genetic material requires expensive infrastructure and complex processing techniques such as *in vitro* preservation or cryopreservation (Pence et al 2022). Despite the high prevalence of recalcitrant species in tropical and subtropical biomes, there are few national facilities and research programmes focused on germplasm conservation. A few developing countries have national seed gene bank facilities for agricultural crops or their

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

wild relatives, but native and threatened seeds are not on their priority list for gene banking (Teixido et al 2017; ICAR-NBPGR 2023).

It is clear that disparities among countries in access to novel methods, and cutting-edge techniques largely affect researcher's capacity to produce, publish and receive credit for their research (Culley et al 2021). Solving these issues is not trivial, but a major step forward is the establishment of meaningful and collaborative partnerships between developed and developing countries (Armenteras 2021). The key is to include researchers from developing countries from the start in setting up the project goals and design. Crucial for a healthy 'global science' community is that individuals and institutions in developing countries acquire, improve and retain skills, knowledge, equipment and resources (Haelewaters et al 2021). Whenever possible and appropriate, allocation of financial resources to the purchase, installation or maintenance of infrastructure of research labs in developing countries can boost future research. Using local infrastructure to keep samples, data and results on site can be useful if samples are temperature- or time-sensitive, and especially important if samples were extracted from protected species or sites. This is overall good practice and a good way to implement the Nagoya Protocol by recognizing the sovereign rights of nations over their own genetic resources and preventing biopiracy.

Making fieldwork easier and safer

Seed collection in developing countries is often characterized by large territories that require travelling over long distances, with limited resources, poor logistics, bureaucratic restrictions and safety issues. Logistics and lack of funding restrict seed collection close to research institutions (Ribeiro et al 2016), thus resulting in widespread geographic, ecological and taxonomic biases. In addition, tropical seed ecologists are faced with markedly asynchronous fruit production (Connell and Green 2000), which implies multiple field excursions year-round to monitor fruiting phenology and collect a minimum number of seeds from different individual plants. Seed collection in tropical rainforest trees growing up to 60–70 m high requires appropriate, often expensive equipment (Lowman et al 1993).

Many developing countries have international or domestic military conflicts (Rodriguez et al 2020) making seed collections from the field harder and unsafe. In such regions, a major limitation is gaining access to the field due to military or governmental restrictions, while personal safety is commonly the major issue. Even in areas free of conflict, it may be unsafe for conducting fieldwork alone and for underrepresented groups (Pettorelli et al 2019), which can be another shortcoming for collecting seeds from wild species in the field.

An essential step in making fieldwork easier and safer is to build partnerships with local individuals, communities, organizations or governments. Partnerships can act as a support network and allow researchers to gain valuable information and a better understanding of local dynamics, which can ultimately make fieldwork safer and easier. Involving local stakeholders can also increase the relevance of research, improve knowledge sharing and lead to greater conservation success (Kainer et al 2009). Importantly, with appropriate training, local partners can participate in the research process (e.g. monitoring reproductive phenology or collecting seeds in remote areas), allowing researchers to use funds more efficiently. Securing assistance from local guides during fieldwork will not only enhance safety but also reduce the time spent travelling in the field, as they could provide shortcuts and recommend better routes. In parallel, establishing long-term phenological databases to help predicting and identifying fruiting stages of habitats would enable better planning of fieldwork and avoid wasting resources (Chapman et al 2018).

In addition, researchers in developing countries with violent conflict need to develop and follow a comprehensive fieldwork strategy to ensure their safety (some useful guidelines: Daniels and Lavallee 2014; Rudizki et al 2022). This strategy should address critical aspects, such as (i) conducting a risk assessment and formulating a safety plan to mitigate hazards; (ii) establishing emergency protocols to deal with unexpected circumstances; (iii) implementing effective communication strategies with local partners and universities and (iv) receiving adequate training in first aid, conflict resolution, personal safety and awareness, among others. The preparation and implementation of this programme involves costs that ultimately reduce the direct investment in research activities. International collaborators are encouraged that those costs in their projects.

Unlocking funding opportunities

Sustained funding is needed to support fieldwork, maintain equipment, acquire reagents, and, above all, cover scholarships and salaries. Limited resources for research prevent seed ecologists from being at the forefront of science. For example, annual research output, measured in terms of the total number of indexed papers across all fields of science, is <100 for many developing countries (van Noorden 2014). When resources are available, they are largely concentrated on model study species (e.g. *Arabidopsis thaliana*), crop species (Marks et al 2023) or are allocated based on priorities determined by researchers in developed countries (Asase et al 2022).

In terms of publication, many developing countries cannot pay subscription fees to allow access to paywall-protected scientific articles written by their own scientific communities. Therefore, many seed ecologists from developing countries are often left with few options, but to request PDFs directly from authors or use alternative methods to gain access to full texts (Bohannon 2016). Moreover, open-access policies of leading publishing companies based on article processing charges (APCs) are a growing concern for scientists in developing countries. Some scientific journals waive APC for low-income developing countries, but other developing countries remain excluded. Consequently, they are excluded from publishing in leading journals with broader scientific scope, reducing the exposure and attention of their research.

Strengthening international collaboration can also be a powerful way of overcoming limited funding. Higher investments in research and development do not necessarily lead to high-impact publishing. Nevertheless, countries with low investments can choose alternative paths, including enhancing international collaboration leading to greater impact and recognition of the research in the country (McManus et al 2023). When properly incorporated, capacity building and student exchange, international partnerships benefit researchers from both developing and developed countries (Haelewaters et al 2021). Given similar challenges, we encourage international collaboration among developing countries. Finally, one unorthodox strategy is to financially reward reviewers from developing countries in fully OA journals. This would be a more just and effective way of using APCs. In summary, establishing meaningful and more fruitful

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

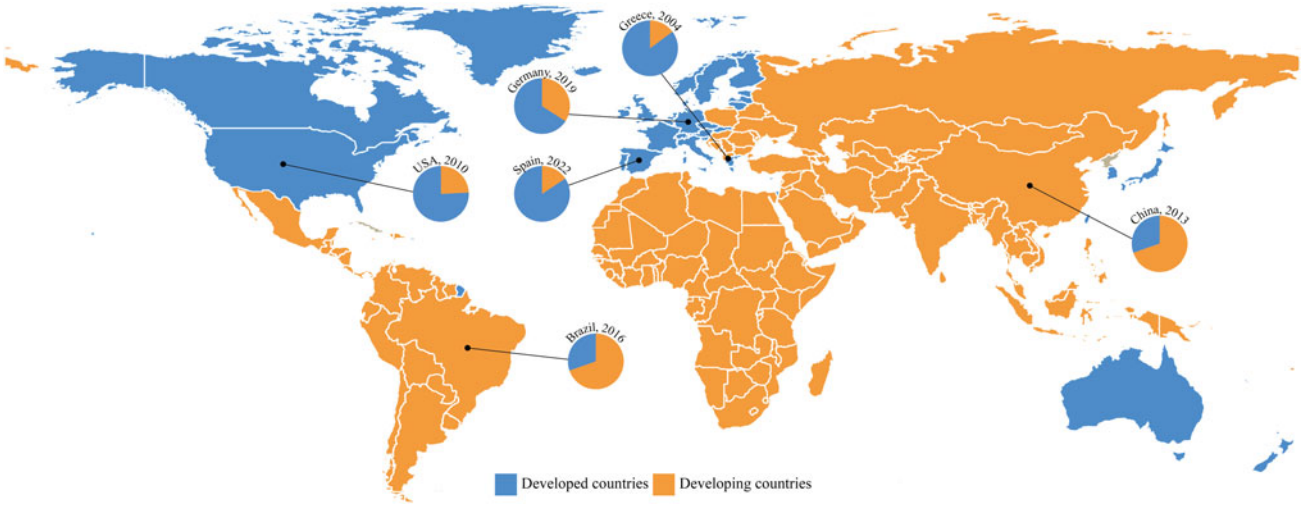

Fig. 1. Percentage of attendees from developing and developed countries in Seed Ecology Meetings since 2004. Data for Seed Ecology Meeting II in Australia, 2007 was not available.

collaboration is a win-win game with positive outcomes for all involved partners (Armenteras 2021).

Promoting inclusive scientific meetings

A good conference experience can make a difference in the professional development of the attendees and create long-lasting collaborations and opportunities (Joo et al 2022). The number of conference attendees from developing countries is less than 15% across Seed Ecology Meetings, but when the conference venue was held in a developing country the percentage of attendees from developing countries increased up to 70% (Fig. 1). High travelling costs, visa requirements, unrealistic deadlines (those ignoring long visa requirements and those coinciding with vacation time in the southern hemisphere), language barriers and cultural contrasts constitute possible reasons for the underrepresentation of seed ecologists from developing countries.

Practical solutions to increase attendance by seed ecologists from developing countries include organizing in-person meetings on different continents, informing decisions on abstract acceptance in advance to allow visa requirements, considering the schedule of developing countries when defining deadlines and promoting hybrid meetings to decrease the travelling and accommodation costs (Joo et al 2022). Developing open and inclusive meetings means working harder to support people from underrepresented regions of the world as attendees, but also developing local research networks in these regions to better connect seed ecologists.

A positive initiative is the recent implementation of membership waiving fees by the International Society for Seed Science (ISSS) for residents in low and lower-middle-income countries (https://seedscisoc.org/register/individual-resident-in-low-and-lower-middle-income-country/), meaning that high membership costs of international societies no longer discourages early-career seed ecologists to engage with their peers. An additional approach to addressing this issue could involve implementing a differential pricing system, where registration fees are reduced for participants from developing countries, with a particular focus on student delegates. This strategy would significantly alleviate the financial burden on young seed ecologists attendance. Furthermore, expanding the availability of conference scholarships specifically targeted towards students from these regions could provide an invaluable opportunity for their professional growth and engagement within the global seed ecology community.

We call for Seed Ecology Meetings to be a place for interdisciplinary research paradigms, integrating insights and methods from related disciplines to address complex research questions. This collaborative approach must bring together experts from multiple fields to create a more comprehensive understanding of seed ecology. This paradigm will benefit from researchers coming from different disciplines, different backgrounds and different places of the world.

Alleviating language barriers

Language barriers still hinder access to scientific knowledge during the training of students, but also during the research and publication processes. Currently, 98% of publications in science are written in English, including researchers from English as foreign language countries, which also results in increased costs for translation (Ramírez-Castañeda 2020). Using a large, randomized trial with real manuscript submissions to evaluate the various consequences of shifting to double-blind peer review, Fox et al (2023) provide strong evidence that authors from higher income and/or English-speaking countries receive significant benefits (a large positive bias) to being identified to reviewers during the peer-review process.

While the use of automatic translation and artificial intelligence apps may help alleviate these problems, student training crucially depends on resources in native, local languages (Steigerwald et al 2022). Scientific papers published in English that are relevant to local communities and decision-makers may remain inaccessible, hence non-English-language articles play an important role in improving the understanding of biodiversity and its conservation in developing countries, which in turn, may be inaccessible to readers screening the literature using English keywords (Chowdhury et al 2022; Amano et al 2023).

Language barriers can be alleviated by publishing in local languages. Some journals encourage publications to include non-English abstracts and summaries especially when research has consequences for local communities, decision-makers and

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

practitioners, thus extending the scientific impact beyond the restricted scientific community. In developing countries, many journals are published in national languages other than English. Despite the fact that our current academic promotion systems may not reward such efforts, one can submit a translated version of the manuscript in the Supplementary material. This would foster engagement with researchers and stakeholders who may not have a strong understanding of English.

Recently, Amano et al (2021) proposed ten tips for overcoming language barriers in science, which we endorse. The list includes dissemination of research in multiple languages, sourcing knowledge from multiple languages, increasing the visibility of non-English-language science, translating scientific terms, providing genuine support to non-native speakers, distinguishing language skills from scientific quality, considering language balance in scientific activities, acknowledging efforts to overcome language barriers and make use of existing resources and opportunities. In addition to this list, providing English translation and polishing services at no additional charge for seed ecologists in developing countries may benefit the whole scientific community with better quality science available (Ramírez-Castañeda 2020).

Altogether, this set of actions is expected to result in better outcomes not only for researchers in developing countries but also for peers in developed nations. English-speaking scholars would have access to global knowledge and contribute to making science more inclusive (Nolde-Lopez et al 2023). An excellent example of recent access to non-English literature is the impressive effort by Rosbakh et al (2020) to translate and digitize a huge data set on seed dormancy and germination from Nikolaeva et al (1985) originally published in Russian and previously mostly inaccessible to the vast majority of seed ecologists.

Another type of language barrier is the thousands of indigenous languages that are still spoken in developing countries. Translators are often required in order to communicate with communities in remote areas to ask their permission to collect seeds/plants on their land. Finding creative ways to communicate seed ecology knowledge to local communities remains a challenge.

Improving education

Training the next generation of seed ecologists is a multi-step challenge, but primarily requires enrolment in specific courses. However, seed ecology is hardly touched upon in ecology courses, and even more so in developing countries. Most plant science courses offered by universities in developing countries consist of limited lectures on seed germination and dormancy. In contrast, many agriculture universities offer full course training in seed technology with a prime focus on producing and sustaining the supply of quality crop seeds.

Dedicated training on seed ecology may alleviate several key challenges in seed ecological research in developing countries. First, the plant science course curriculum is recommended to cover all aspects of seed ecology, from seed production to dispersal to seedling establishment (Fenner 1985). Applied courses could include contemporary topics such as climate change, defaunation, biodiversity conservation and restoration, preferably using interdisciplinary approaches. We encourage seed ecologists from developed countries to engage in teaching courses in developing countries.

Both theoretical and practical field courses hold a large potential to improve education. Plant Functional Traits Courses are becoming common in many places offering hands-on training in applications of plant functional trait ecology within a real-life field research project setting in different parts of the world including developing countries (https://plantfunctionaltraitscourses.w.uib.no/). A similar successful example of a theoretical course is the Winter School on Functional Seed Ecology at the University of Pavia, Italy (http://seedschool.unipv.it/). Such online courses are offered at low costs to early-career researchers from developing countries, providing world-class lectures to the next generation of seed ecologists. Future international courses are expected to provide additional training to researchers to help building a more representative global network of seed ecologists.

Field courses have long been powerful and transformative in the tropics (https://tropicalstudies.org/). Intensive field-based programmes help students develop basic research abilities and create/extend a network of early-career colleagues. Field-based courses span all steps of the scientific process from the definition of hypotheses, developing and implementing sampling, analysing data, rehearsing formal oral presentations and preparing complete manuscript drafts. In many cases, such courses result in publications that can benefit both participants and instructors alike (Putz and Ruslandi 2018). To date, we are unaware of field courses entirely focused on seed ecology, but we encourage local courses to be developed given the low cost:benefit ratio of such activities.

Shifting the notion of novelty and relevance

Acceptance of scientific papers is largely determined by assessments of novelty and relevance by journal editors and reviewers. Editors have the responsibility of evaluating whether submitted papers have enough novelty and are relevant enough before deciding to invite reviewers that will provide recommendations that ultimately determine manuscript fate. A profound geographical mismatch exists among editors of leading ecological and conservation science journals, with journals having few or sometimes no editors from many of the most biodiverse, developing countries (Espin et al 2017). This geographic bias strongly influences acceptance rates and shapes the scientific publishing landscape, with detrimental consequences for scientists in developing countries who have their papers deemed as 'of local relevance' (Geldmann et al 2020). Recently, Smith et al (2023) found notably worse review outcomes for authors whose institutional affiliations were in Asia, for authors whose country's primary language is not English and based in countries with relatively low Human Development Indices. As a result, there are substantial biases in the geographic representation in the ecological and plant science literature (Marks et al 2023), with some developing countries being underrepresented, despite being home to the world's most diverse floras.

There are multiple ways in which the community of seed ecologists can address the underrepresentation of developing countries in both plant science and ecological literature. The emphasis on novelty is at the odds of replication of studies suggesting the process of getting new field data that are otherwise important to support quantitative syntheses and meta-analyses is disfavoured. A number of concrete actions by journal editors includes encouraging submissions from all countries, reaching out to international authors, recruiting international reviewers, publishing more open-access papers and diversifying journal editorial boards to represent our global audience (only two editors of SSR are currently affiliated with institutions in developing countries), personalize the review process with sensitivity to international authors with English as an additional language, emphasize and value low-cost methods, and waive APCs for developing countries (Culley et al 2021; Smith et al 2021). In

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

addition to that, compulsory anonymization of author identities (e.g. double-blind review) can help mitigating biases in the peer-review process (Fox et al 2023).

Given the paucity of basic data on the ecology of seeds in developing countries, creating manuscript categories dedicated to seed ecology data from data-deficient regions in international journals would incentivize the filling of knowledge gaps and provide recognition to researchers dedicated to these areas. A few journals (e.g. *Journal of Ecology*, *Biotropica* and *Ecology*) have recently created a manuscript category of 'Natural History' to accommodate studies showing the wonders of our natural world (e.g. Suetsugu and Hashiwaki 2023). We suggest that including Research Notes into the scope of *Seed Science Research* would reinvigorate the role of natural history and basic native seed biology as powerful knowledge-building methods. Studies focusing on natural history and basic seed ecology should, however, emphasize relevance beyond the local scales to attract the attention of a broad audience.

Supporting native seed markets

As signatories of the UN Convention on Biological Diversity, most developing countries operate under very strict biodiversity acts and laws, some of which hamper the exchange and transport of biological material overseas. Frequently, local legislation hampers the use of native species seeds that could be otherwise used to train students, generate knowledge and restore degraded ecosystems (Urzedo et al 2019). The national application of the Nagoya protocol is a great challenge for biodiversity research and especially for seed ecology, given that seeds consistently fall under this protocol (Prathapan et al 2018). While far-reaching exceptions in the Nagoya protocol enable an agro-industrial exploitation of biological resources across national borders, the application of rules suggested in Nagoya makes it very difficult for both local research teams as well as international consortia to work on seed ecology.

Native seed supply for restoration is essentially a community-based activity that faces broad barriers to operating within regulations because of requirements for excessive and costly technical documentation, scarcity of seed laboratories and lack of instructions for native seed quality testing. Therefore, easing the laboratory accreditation process for native seed quality assurance is recommended (Urzedo et al 2019). Future regulations should facilitate the exchange of seed material for seed ecological research not addressing genetic issues through simplified authorization procedures, pending the public availability of research results and following open standards on storage and further use of seeds. Relaxing the level of the international and national limitations over seed transport may also enhance banking threatened species in *ex situ* collections (Teixido et al 2017).

Conclusions

Seed ecology is a flourishing discipline that has been expanding its scope, breadth and approaches. Here, we discussed how overcoming long-standing barriers for seed ecologists in developing countries can contribute to accelerating the development of the discipline and extend progress to regions where biodiversity is highest and where research is more needed. The challenges outlined here are complex, multidimensional and not easily fixed. However, overcoming these barriers (and others not addressed here) is likely to provide long-term benefits to the whole community of seed ecologists. For example, increasing the availability of seed trait data for underrepresented regions and lineages will improve our understanding of seed-environmental relationships at global scales. Establishing meaningful collaboration is not necessarily costly and impractical, and has the potential to overcome multiple barriers simultaneously. We envision a new era of seed ecology when research done in developing countries is safer, inclusive, more valued, well-funded and benefits the whole community of scientists attempting to revealing the mysteries hidden within seeds.

Acknowledgements. This manuscript is a tribute to all seed ecologists who have been conducting extensive fieldwork and meticulous laboratory studies to deepen our understanding of seed production, dispersal, dormancy, persistence and germination, and their crucial role in maintaining biodiversity and sustaining our natural ecosystems. CAOP receives a scholarship from CAPES.

Conflict of interest. FAOS and FV are on the Editorial Board of Seed Science Research.

References

Acosta-Rojas D, Barczyk M, Espinosa C, Gusmán J, Peña J, Neuschulz E, Schleuning M and Homeier J (2021) *Field Guide of Animal-Dispersed Plants: Fruits and Seeds in and around Podocarpus National Park*. Quito: INABIO. https://doi.org/10.5678/vnkb-t219

Amano T, Berdejo-Espinola V, Christie AP, Willott K, Akasaka M, Báldi A, Berthinussen A, Bertolino S, Bladon AJ, Chen M, Choi C-Y, Kharrat MBD, de Oliveira LG, Farhat P, Golivets M, Aranzamendi NH, Jantke K, Kajzer-Bonk J, Aytekin MÇK, Khorozyan I, Kito K, Konno K, Lin D-L, Littlewood N, Liu Y, Liu Y, Loretto M-C, Marconi V, Martin PA, Morgan WH, Narváez-Gómez JP, Negret PJ, Nourani E, Quintero JMO, Ockendon N, Ying Oh RR, Petrovan SO, Piovezan-Borges AC, Pollet IL, Ramos DL, Segovia ALR, Rivera-Villanueva AN, Rocha R, Rouyer M-M, Sainsbury KA, Schuster R, Schwab D, Şekercioğlu ÇH, Seo H-M, Shackelford G, Shinoda Y, Smith RK, Tao S-d, Tsai M-s, Tyler EHM, Vajna F, Valdebenito JO, Vozykova S, Waryszak P, Zamora-Gutierrez V, Zenni RD, Zhou W and Sutherland WJ (2021) Tapping into non-English-language science for the conservation of global biodiversity. *PLoS Biology* **19**, e3001296. https://doi.org/10.1371/journal.pbio.3001296

Amano T, Berdejo-Espinola V, Akasaka M, de Andrade Junior MAU, Blaise N, Checco J, Çilingir FG, Citegetse G, Tor MC, Drobniak SM, Giakoumi S, Golivets M, Ion MC, Jara-Díaz JP, Katayose R, Lasmana FPS, Lin H-Y, Lopez E, Mikula P, Morales-Barquero L, Mupepele A-C, Narváez-Gómez JP, Nguyen TH, Lisboa SN, Nuñez MA, Pavón-Jordán D, Pottier P, Prescott GW, Samad F, Šćiban M, Seo H-M, Shinoda Y, Vajna F, Vozykova S, Walsh JC, Wee AKS, Xiao H and Zamora-Gutierrez V (2023) The role of non-English-language science in informing national biodiversity assessments. *Nature Sustainability* **6**, 845–854. https://doi.org/10.1038/s41893-023-01087-8

Armenteras D (2021) Guidelines for healthy global scientific collaborations. *Nature Ecology & Evolution* **5**, 1193–1194. https://doi.org/10.1038/s41559-021-01496-y

Asase A, Mzumara-Gawa T, Owino JO, Peterson AT and Saupe E (2022) Replacing "parachute science" with "global science" in ecology and conservation biology. *Conservation Science and Practice* **4**, e517. https://doi.org/10.1111/csp2.517

Baskin CC and Baskin JM (1998) *Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination*. San Diego: Academic Press.

Bohannon J (2016) Who's downloading pirated papers? Everyone. *Science* **352**, 508–512. https://doi.org/10.1126/science.352.6285.508

Borer ET, Harpole WS, Adler PB, Lind EM, Orrock JL, Seabloom EW and Smith MD (2014) Finding generality in ecology: a model for globally distributed experiments. *Methods in Ecology and Evolution* **5**, 65–73. https://doi.org/10.1111/2041-210X.12125

Bruelheide H, Dengler J, Jiménez-Alfaro B, Purschke O, Hennekens SM, Chytrý M, Pillar VD, Jansen F, Kattge J, Sandel B, Aubin I, Biurrun I, Field R, Haider S, Jandt U, Lenoir J, Peet RK, Peyre G, Sabatini FM,

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

Schmidt M, Schrodt F, Winter M, Aćić S, Agrillo E, Alvarez M, Ambarlı D, Angelini P, Apostolova I, Arfin Khan MAS, Arnst E, Attorre F, Baraloto C, Beckmann M, Berg C, Bergeron Y, Bergmeier E, Bjorkman AD, Bondareva V, Borchardt P, Botta-Dukát Z, Boyle B, Breen A, Brisse H, Byun C, Cabido MR, Casella L, Cayuela L, Černý T, Chepinoga V, Csiky J, Curran M, Ćušterevska R, Dajić Stevanović Z, De Bie E, De Ruffray P, De Sanctis M, Dimopoulos P, Dressler S, Ejrnæs R, El-Sheikh MAEM, Enquist B, Ewald J, Fagúndez J, Finckh M, Font X, Forey E, Fotiadis G, García-Mijangos I, de Gasper AL, Golub V, Gutierrez AG, Hatim MZ, He T, Higuchi P, Holubová D, Hölzel N, Homeier J, Indreica A, Işık Gürsoy D, Jansen S, Janssen J, Jedrzejek B, Jiroušek M, Jürgens N, Kącki Z, Kavgacı A, Kearsley E, Kessler M, Knollová I, Kolomiychuk V, Korolyuk A, Kozhevnikova M, Kozub Ł, Krstonošić D, Kühl H, Kühn I, Kuzemko A, Küzmič F, Landucci F, Lee MT, Levesley A, Li C-F, Liu H, Lopez-Gonzalez G, Lysenko T, Macanović A, Mahdavi P, Manning P, Marcenò C, Martynenko V, Mencuccini M, Minden V, Moeslund JE, Moretti M, Müller JV, Munzinger J, Niinemets Ü, Nobis M, Noroozi J, Nowak A, Onyshchenko V, Overbeck GE, Ozinga WA, Pauchard A, Pedashenko H, Peñuelas J, Pérez-Haase A, Peterka T, Petřík P, Phillips OL, Prokhorov V, Rašomavičius V, Revermann R, Rodwell J, Ruprecht E, Rūsiņa S, Samimi C, Schaminée JHJ, Schmiedel U, Šibík J, Šilc U, Škvorc Ž, Smyth A, Sop T, Sopotlieva D, Sparrow B, Stančić Z, Svenning J-C, Swacha G and Tang Z (2019) sPlot – a new tool for global vegetation analyses. *Journal of Vegetation Science* **30**, 161–186. https://doi.org/10.1111/jvs.12710

Carta A, Fernández-Pascual E, Gioria M, Müller JV, Rivière S, Rosbakh S, Saatkamp A, Vandelook F and Mattana E (2022) Climate shapes the seed germination niche of temperate flowering plants: a meta-analysis of European seed conservation data. *Annals of Botany* **129**, 775–786. https://doi.org/10.1093/aob/mcac037

Chapman CA, Valenta K, Bonnell TR, Brown KA and Chapman LJ (2018) Solar radiation and ENSO predict fruiting phenology patterns in a 15-year record from Kibale National Park, Uganda. *Biotropica* **50**, 384–395. https://doi.org/10.1111/btp.12559

Chen SC, Hemmings FA, Chen F and Moles AT (2017) Plants do not suffer greater losses to seed predation towards the tropics. *Global Ecology and Biogeography* **26**, 1283–1291. https://doi.org/10.1111/geb.12636

Chen SC, Tamme R, Thomson FJ and Moles AT (2019) Seeds tend to disperse further in the tropics. *Ecology Letters* **22**, 954–961. https://doi.org/10.1111/ele.13255

Chen SC, Poschlod P, Antonelli A, Liu U and Dickie JB (2020) Trade-off between seed dispersal in space and time. *Ecology Letters* **23**, 1635–1642. https://doi.org/10.1111/ele.13595

Chowdhury S, Gonzalez K, Aytekin ÇK, Baek S-Y, Bertolino S, Duijns S, Han Y, Jantke K, Katayose R, Lin M-M, Nourani E, Ramos DL, Rouyer M-M, Sidemo-Holm W, Vozykova S, Zamora-Gutierrez V and Amano T (2022) Growth of non-English-language literature on biodiversity conservation. *Conservation Biology* **36**, e3883. https://doi.org/10.1111/cobi.13883

Colville L, Hilhorst HW and Pritchard HW (2022) Editorial to the special issue on Seed Innovation Systems for the 21st Century. *Seed Science Research* **32**, 115–117. https://doi.org/10.1017/S0960258522000241

Connell JH and Green PT (2000) Seedling dynamics over thirty-two years in a tropical rain forest tree. *Ecology* **81**, 568–584. https://doi.org/10.1890/0012-9658(2000)081[0568:SDOTTY]2.0.CO;2

Culley TM, Philpott M, Tunison R, Merritt BJ, Barreiro-Sanchez JM, Wafer A and Holdren R (2021) Research inequity in the plant sciences. *Applications in Plant Sciences* **9**, e11417. https://doi.org/10.1002/aps3.11417

Culumber ZW, Anaya-Rojas JM, Booker WW, Hooks AP, Lange EC, Pluer B, Ramírez-Bullón N and Travis N (2019) Widespread biases in ecological and evolutionary studies. *BioScience* **69**, 631–640. https://doi.org/10.1093/biosci/biz063

Dalziell E, Lewandrowski W, Commander L, Elliott C, Erickson T, Tudor E, Turner SR and Merritt DJ (2022) Seed traits inform the germination niche for biodiverse ecological restoration. *Seed Science Technology* **50**, 103–124. https://doi.org/10.15258/sst.2022.50.1.s.06

Daniels LD and Lavallee S (2014) Better safe than sorry: planning for safe and successful fieldwork. *Bulletin of Ecological Society of America* **95**, 264–273.

Dayrell RLC, Ott T, Horrocks T and Poschlod P (2023) Automated extraction of seed morphological traits from images. *Methods in Ecology and Evolution* **14**, 1708–1718. https://doi.org/10.1111/2041-210X.14127

Donohue K, Rubio de Casas R, Burghardt L, Kovach K and Willis CG (2010) Germination, postgermination adaptation, and species ecological ranges. *Annual Review of Ecology, Evolution, and Systematics* **41**, 293–319. https://doi.org/10.1146/annurev-ecolsys-102209-144715

Dornelas M, Antao LH, Moyes F, Bates AE, Magurran AE, Adam D, Akhmetzhanova AA, Appeltans W, Arcos JM, Arnold H, Ayyappan N, Badihi G, Baird AH, Barbosa M, Barreto TE, Bässler C, Bellgrove A, Belmaker J, Benedetti-Cecchi L, Bett BJ, Bjorkman AD, Błażewicz M, Blowes SA, Bloch CP, Bonebrake TC, Boyd S, Bradford M, Brooks AJ, Brown JH, Bruelheide H, Budy P, Carvalho F, Castañeda-Moya E, Chen CA, Chamblee JF, Chase TJ, Siegwart Collier L, Collinge SK, Condit R, Cooper EJ, Cornelissen JHC, Cotano U, Crow SK, Damasceno G, Davies CH, Davis RA, Day FP, Degraer S, Doherty TS, Dunn TE, Durigan G, Duffy JE, Edelist D, Edgar GJ, Elahi R, Elmendorf SC, Enemar A, Morgan Ernest SK, Escribano R, Estiarte M, Evans BS, Fan T-Y, Farah FT, Fernandes LL, Farneda FZ, Fidelis A, Fitt R, Fosaa AM, Franco GADC, Frank GE, Fraser WR, García H, Gatti RC, Givan O, Gorgone-Barbosa E, Gould WA, Gries C, Grossman GD, Gutierréz JR, Hale S, Harmon ME, Harte J, Haskins G, Henshaw DL, Hermanutz L, Hidalgo P, Higuchi P, Hoey A, Van Hoey G, Hofgaard A, Holeck K, Hollister RD, Holmes R, Hoogenboom M, Hsieh C-h, Hubbell SP, Huettmann F, Huffard CL, Hurlbert AH, Ivanauskas NM, Janík D, Jandt U, Jażdżewska A, Johannessen T, Johnstone J, Jones J, Jones FAM, Kang J, Kartawijaya T, Keeley EC, Kelt DA, Kinnear R, Klanderud K, Knutsen H, Koenig CC, Kortz AR, Král K, Kuhnz LA, Kuo C-Y, Kushner DJ, Laguionie-Marchais C, Lancaster LT, Min Lee C, Lefcheck JS, Lévesque E, Lightfoot D, Lloret F, Lloyd JD, López-Baucells A, Louzao M, Madin JS, Magnússon B, Malamud S, Matthews I, McFarland KP, McGill B, McKnight D, McLarney WO, Meador J, Meserve PL, Metcalfe DJ, Meyer CFJ, Michelsen A, Milchakova N, Moens T, Moland E, Moore J, Mathias Moreira C, Müller J and Murphy G (2018) BioTIME: a database of biodiversity time series for the Anthropocene. *Global Ecology and Biogeography* **27**, 760–786. https://doi.org/10.1111/geb.12729

Espin J, Palmas S, Carrasco-Rueda F, Riemer K, Allen PE, Berkebile N, Kastner-Wilcox HKAK and Núñez-Regueiro MM (2017) A persistent lack of international representation on editorial boards in environmental biology. *PLoS Biology* **15**, e2002760.

Fenner M (1985) *Seed Ecology*. London: Chapman and Hall.

Fernández-Pascual E, Carta A, Rosbakh S, Guja L, Phartyal SS, Silveira FAO, Chen S-C, Larson JE and Jiménez-Alfaro B (2023) SeedArc, a global archive of primary seed germination data. *New Phytologist* **240**, 466–470.

Footitt S, Walley PG, Lynn JR, Hambidge AJ, Penfield S and Finch-Savage WE (2020) Trait analysis reveals DOG1 determines initial depth of seed dormancy, but not changes during dormancy cycling that result in seedling emergence timing. *New Phytologist* **225**, 2035–2047.

Fox CW, Meyer J and Aimé E (2023) Double-blind peer review affects reviewer ratings and editor decisions at an ecology journal. *Functional Ecology* **37**, 1144–1157. https://doi.org/10.1111/1365-2435.14259

Geldmann J, Alves-Pinto H, Amano T, Bartlett H, Christie AP, Collas L, Cooke SC, Correa R, Cripps I, Doherty A, Finch T, Garnett EE, Hua F, Jones JPG, Kasoar T, MacFarlane D, Martin PA, Mukherjee N, Mumby HS, Payne C, Petrovan SO, Rocha R, Russell K, Simmons BI, Wauchope HS, Worthington TA, Trevelyan R, Green R and Balmford A (2020) Insights from two decades of the student conference on conservation science. *Biological Conservation* **243**, 108478. https://doi.org/10.1016/j.biocon.2020.108478

Godefroid S, Van de Vyver A, Lebrun J, Kalenga WM, Minengo GH, Rose C, Luhembwe MN, Vanderborght T and Mahy G (2013) Germination capacity and seed storage behaviour of threatened metallophytes from the Katanga copper belt (D. R. Congo): implications for *ex situ* conservation. *Plant Ecology and Evolution* **146**, 183–192. https://doi.org/10.5091/plecevo.2013.745

Haelewaters D, Hofmann TA and Romero-Olivares AL (2021) Ten simple rules for Global North researchers to stop perpetuating helicopter research

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

in the Global South. *PLoS Computational Biology* **17**, e1009277. https://doi.org/10.1371/journal.pcbi.1009277

Hortal J, de Bello F, Diniz-Filho JAF, Lewinsohn TM, Lobo JM and Ladle RJ (2015) Seven shortfalls that beset large-scale knowledge of biodiversity. *Annual Review of Ecology, Evolution, and Systematics* **46**, 523–549. https://doi.org/10.1146/annurev-ecolsys-112414-054400

ICAR-NBPGR (2023) *ICAR-National Bureau of Plant Genetic Resources*. New Delhi: Indian Council of Agricultural Research. http://www.nbpgr.ernet.in/About_NBPGR/Mandate.aspx

Joo R, Sánchez-Tapia A, Mortara S, Bellini Saibene Y, Turner H, Hug Peter D, Morandeira NS, Bannert M, Almazrouq B, Hare E, Ación L, Narváez-Gómez JP, Alfaro Córdoba M, Marini F, Giordano R, Canelón S, Ebou A, Upadhya AR, Chávez J and Ravi J (2022) Ten simple rules to host an inclusive conference. *PLoS Biology* **18**, e1010164. https://doi.org/10.1371/journal.pcbi.1010164

Kainer KA, DiGiano ML, Duchell AE, Wadt LHO, Bruna E and Dain JL (2009) Partnering for greater success: local stakeholders and research in tropical biology and conservation. *Biotropica* **41**, 555–562. https://doi.org/10.1111/j.1744-7429.2009.00560.x

Kattge J, *et al.* (2020) TRY plant trait database – enhanced coverage and open access. *Global Change Biology* **26**, 119–188. https://doi.org/10.1111/gcb.14904

Larson JE and Funk JL (2016) Regeneration: an overlooked aspect of trait-based plant community assembly models. *Journal of Ecology* **104**, 1284–1298. https://doi.org/10.1111/1365-2745.12613

Lembrechts JJ, *et al.* (2022) Global maps of soil temperature. *Global Change Biology* **26**, 119–188. https://doi.org/10.1111/gcb.v28.9

Lowman M, Moffett M and Rinker HB (1993) A new technique for taxonomic and ecological sampling in rain forest canopies. *Selbyana* **14**, 75–79.

Marks R, Amézquita EJ, Percival S, Rougon-Cardoso A, Chibici-Revneanu C, Tebele SM, Farrant JM, Chitwood DH and vanBuren R (2023) A critical analysis of plant science literature reveals ongoing inequities. *Proceedings of the National Academy of Sciences* **120**, e2217564120. doi:10.1073/pnas.221756412

McManus C, Baeta Neves AB, Diniz-Filho JAF and Pimentel F (2023) Funding as a determinant of Citation Impact in Scientific Papers in different countries. *Anais da Academia Brasileira de Ciências* **95**, e20220515. https://doi.org/10.1590/0001-3765202320220515

Nikolaeva MG, Razumova MV and Gladkova VN (1985) In Danilova MF (ed.), *Spravochnik po prorashchivaniyu pokoyashchikhsya semyan*. Leningrad, Russia: Nauka.

Nolde-Lopez B, Bundus J, Arenas-Castro H, Román D, Chowdhury S, Amano T, Berdejo-Espinola V and Wadgymar SM (2023) Language barriers in organismal biology: what can journals do better? *Integrative Organismal Biology* **5**, obad003. https://doi.org/10.1093/iob/obad003

Ordóñez-Parra CA, Dayrell RLC, Negreiros D, Andrade ACS, Andrade LG, Antonini Y, Barreto LC, de V. Barros F, da Cruz Carvalho V, Corredor BAD, Davide AC, Duarte AA, Feitosa SDS, Fernandes AF, Fernandes GW, Figueiredo MA, Fidelis A, Garcia LC, Garcia QS, Giorni VT, Gomes VGN, Gonçalves-Magalhães C, Kozovits AR, Lemos-Filho JP, Le Stradic S, Machado IC, Maia FR, Marques AR, Mendes-Rodrigues C, Messias MCTB, Morellato LPC, de Moraes MG, Moreira B, Nunes FP, Oliveira AKM, Oki Y, Rodrigues ARP, Pietczak C, Pina JC, Ramos SJ, Ranal MA, Ribeiro-Oliveira JP, Rodrigues FH, Santana DG, Santos FMG, Senhuk APMS, Silveira RA, Soares NC, Tonetti OAO, da Silveira Vieira VA, de Sena Viana LC, Zanetti M, Zirondi HL and Silveira FAO (2023) Rock n' Seeds: a database of seed functional traits and germination experiments from Brazilian rock outcrop vegetation. *Ecology* **104**, e3852. https://doi.org/10.1002/ecy.3852

Pence VC, Meyer A, Linsky J, Gratzfeld J, Pritchard HW, Westwood M and Bruns EB (2022) Defining exceptional species — a conceptual framework to expand and advance *ex situ* conservation of plant diversity beyond conventional seed banking. *Biological Conservation* **266**, 109440. https://doi.org/10.1016/j.biocon.2021.109440

Pettorelli N, Barlow J, Cadotte MW, Lucas K, Newton E, Nuñez MA and Stephens PA (2019) Applied ecologists in a landscape of fear. *Journal of Applied Ecology* **56**, 1034–1039. https://doi.org/10.1111/1365-2664.13382

Prathapan KD, Pethiyagoda R, Bawa KS, Raven PH, Rajan PD and 172 co-signatories from 35 countries (2018) When the cure kills—CBD limits biodiversity research. *Science* **360**, 1405–1406. https://doi.org/10.1126/science.aat9844

Putz FE and Ruslandi RA (2018) An experiential, adaptive, inexpensive, and opportunistic approach to research capacity building in the tropics. *Biotropica* **50**, 555–558. https://doi.org/10.1111/btp.12566

Ramírez-Castañeda V (2020) Disadvantages in preparing and publishing scientific papers caused by the dominance of the English language in science: the case of Colombian researchers in biological sciences. *PLoS ONE* **15**, e0238372. https://doi.org/10.1371/journal.pone.0238372

Ribeiro GVT, Teixido AL, Barbosa N and Silveira FAO (2016) Assessing bias and knowledge gaps on seed ecology research: implications for conservation agenda and policy. *Ecological Applications* **26**, 2033–2043. https://doi.org/10.1890/15-1852.1

Rodriguez ACT, Binda E, Quintero JMO, Garcia H, Gómez B, Soto C, Martínez S and Clerici N (2020) Answering the right questions. Addressing biodiversity conservation in post-conflict Colombia. *Environmental Science & Policy* **104**, 82–87.

Rosbakh S, Baskin CC and Baskin JM (2020) Nikolaeva *et al.*'s reference book on seed dormancy and germination. *Ecology* **101**, e03049. https://doi.org/10.1002/ecy.3049

Rubio de Casas R, Willis CG, Pearse WD, Baskin CC, Baskin JM and Cavender-Bares J (2017) Global biogeography of seed dormancy is determined by seasonality and seed size: a case study in the legumes. *New Phytologist* **214**, 1527–1536. https://doi.org/10.1111/nph.14498

Rudzki EN, Kuebbing SE, Clark DR, Gharaibeh B, Janecka MJ, Kramp R, Kohl KD, Mastalski T, Ohmer MEB, Turcotte MM and Richards-Zawacki CL (2022) A guide for developing a field research safety manual that explicitly considers risks for marginalized identities in the sciences. *Methods in Ecology and Evolution* **13**, 2318–2330. https://doi.org/10.1111/2041-210X.13970

Saatkamp A, Cochrane A, Commander L, Guja LK, Jimenez-Alfaro B, Larson J, Nicotra A, Poschlod P, Silveira FAO, Cross AT, Dalziell EL, Dickie J, Erickson TE, Fidelis A, Fuchs A, Golos PJ, Hope M, Lewandrowski W, Merritt DJ, Miller BP, Miller RG, Offord CA, Ooi MKJ, Satyanti A, Sommerville KD, Tangney R, Tomlinson S, Turner S and Walck JL (2019) A research agenda for seed-trait functional ecology. *New Phytologist* **221**, 1764–1775. https://doi.org/10.1111/nph.15502

Simonin M, Briand M, Chesneau G, Rochefort A, Marais C, Sarniguet A and Barret M (2022) Seed microbiota revealed by a large-scale meta-analysis including 50 plant species. *New Phytologist* **234**, 1448–1463. https://doi.org/10.1111/nph.18037

Smith AC, Merz L, Borden JB, Gulick CK, Kshirsagar AR and Bruna EM (2021) Assessing the effect of article processing charges on the geographic diversity of authors using Elsevier's "Mirror Journal" system. *Quantitative Science Studies* **2**, 1123–1143. https://doi.org/10.1162/qss_a_00157

Smith OM, Davis KL, Pizza RB, Waterman R, Dobson KC, Foster B, Jarvey JC, Jones LN, Leuenberger W, Nourn N, Conway EE, Fiser CM, Hansen ZA, Hristova A, Mack C, Saunders AN, Utley OJ, Young ML and Davis CL (2023) Peer review perpetuates barriers for historically excluded groups. *Nature Ecology and Evolution* **7**, 512–523. https://doi.org/10.1038/s41559-023-01999-w

Steigerwald E, Ramírez-Castañeda V, Brandt DY, Báldi A, Shapiro JT, Bowker L and Tarvin RD (2022) Overcoming language barriers in academia: machine translation tools and a vision for a multilingual future. *BioScience* **72**, 988–998. https://doi.org/10.1093/biosci/biac062

Suetsugu K and Hashiwaki H (2023) A non-photosynthetic plant provides the endangered Amami rabbit with vegetative tissues as a reward for seed dispersal. *Ecology* **104**, e3972. https://doi.org/10.1002/ecy.3972

Tavşanoğlu Ç and Pausas JG (2018) A functional trait database for Mediterranean Basin plants. *Scientific Data* **5**, 1–18. https://doi.org/10.1038/sdata.2018.135

Teixido AL, Toorop PE, Liu U, Ribeiro GVT, Fuzessy LF, Guerra TJ and Silveira FAO (2017) Gaps in seed banking are compromising the GSPC's Target 8 in a megadiverse country. *Biodiversity and Conservation* **26**, 703–716. https://doi.org/10.1007/s10531-016-1267-7

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press

United Nations Report (2014) https://www.un.org/en/development/desa/policy/wesp/wesp_current/2014wesp_country_classification.pdf

Urzedo DI, Fisher R, Piña-Rodrigues FCM, Freire JM and Junqueira RGP (2019) How policies constrain native seed supply for restoration in Brazil. *Restoration Ecology* **27**, 768–774. https://doi.org/10.1111/rec.12936

van Noorden R (2014) The impact gap: South America by the numbers. *Nature* **510**, 202–203. https://doi.org/10.1038/510202a

Wang Z, Baskin JM, Baskin CC, Yang X, Liu G, Ye X and Cornelissen JH (2022) Great granny still ruling from the grave: phenotypical response of plant performance and seed functional traits to salt stress affects multiple generations of a halophyte. *Journal of Ecology* **110**, 117–128. https://doi.org/10.1111/1365-2745.13789

Wohner C, Ohnemus T, Zacharias SMollenhauer H, Ellis EC, Klug H, Shibata H and Mirtl M (2021) Assessing the biogeographical and socio-ecological representativeness of the ILTER site network. *Ecological Indicators* **127**, 107785. https://doi.org/10.1016/j.ecolind.2021.107785

Wyse SV and Dickie JB (2017) Predicting the global incidence of seed desiccation sensitivity. *Journal of Ecology* **105**, 1082–1093. https://doi.org/10.1111/1365-2745.12725

https://doi.org/10.1017/S0960258523000181 Published online by Cambridge University Press