












Essays and Perspectives



## Pivotal steps to consistently advance invasion science in a megadiverse country

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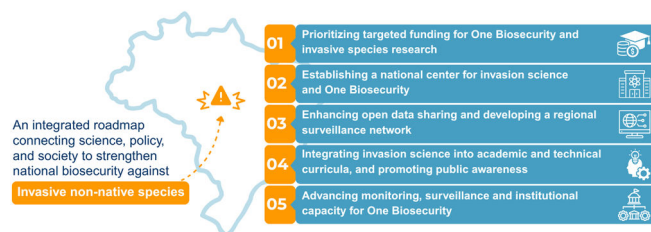
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### HIGHLIGHTS

- Advance in invasion science is needed considering the mounting cross-cutting impacts
- Aligning with global frameworks would foster coordinated national response
- A national center would bridge science, policy, and management gaps
- Open data sharing and early detection are critical to reduce response delays
- Education and public engagement are key to long-term biosecurity capacity

### GRAPHICAL ABSTRACT

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## ABSTRACT

Non-native invasive species pose an escalating threat to Brazil's rich biodiversity and ecosystem services, yet their management remains limited to fragmented efforts, underfunded research, and a lack of institutional coordination. This paper outlines pivotal steps to advance invasion science in Brazil through an integrated framework that bridges science, policy, and society. Invasive species are still often promoted for economic or aesthetic reasons, and conflicting interests and insufficient scientific integration hinder their regulation. We highlight five strategic areas for action: (1) establishing targeted funding lines for invasive species research and management, aligned with One Biosecurity principles; (2) creating a national center for invasion science to coordinate efforts and promote innovation; (3) enhancing open data sharing and integrating Brazil's databases with international platforms to strengthen surveillance networks; (4) incorporating invasion science into academic and technical curricula to build a skilled and responsive workforce; and (5) integrating biosecurity into broader policy agendas following One Biosecurity principles. We recommend an alignment of local and national biosecurity efforts with regional and global surveillance systems, particularly at transboundary ecosystems vulnerable to new introductions. Drawing on international best practices and local case studies, this framework provides a roadmap to make biosecurity a national priority in Brazil. By fostering collaboration among researchers, managers, educators, and policymakers, Brazil can develop a more resilient and evidence-based response to biological invasions, protecting not only biodiversity but also the socioeconomic and cultural foundations that depend on healthy ecosystems.

**Introduction**

Invasion science is a relatively young discipline, even though the human-mediated introduction of species has accompanied human migrations and activities throughout history (Hulme, 2021). References to the effects of novel species can be found in Darwin's writings, but the field was truly consolidated with the publication of Charles S. Elton's seminal book, *"The Ecology of Invasions by Animals and Plants"* in 1958. In Brazil, the discipline arose considerably later, with early studies dating back to the 1990s (Frehse et al., 2016) and a surge in publications beginning in the 2000s (Campbell and Simberloff, 2022).

Despite these scientific advances, there is a knowledge gap in public awareness as well as in the implementation of public policies focused on invasive non-native species in Brazil (Dechoum et al., 2024). Mechanisms that explain invasion success or failure and the potential future distribution of non-native species have not received sufficient attention, and effective management strategies are also lacking (BPBES, 2024; Seebens et al., 2025). This gap is further compounded by regional disparities in research efforts, with a concentration of studies in the south and southeastern regions (BPBES, 2024). Other areas, such as in northern Brazil, remain substantially understudied regarding biological invasions, despite their ecological relevance and vulnerability (e.g., Elmoor-Loureiro et al., 2023; Franco et al., 2024). Besides, many invasive species continue to be shielded (i.e., legislation or projects that actively shield them from control measures) or even promoted (i.e., initiatives or policies that encourage their use, often due to economic or aesthetic value) through numerous bills and projects, exacerbating the problem of invasions (Pelicice et al., 2023). The fact is that environmental issues behind biological invasions often remain invisible to the public.

The urgency of addressing invasive species in Brazil is underscored by national commitments to international environmental agreements (e.g., Ziller et al., 2024) that call for proactive management and monitoring of biological invasions. However, persistent challenges — such as gaps in taxonomic knowledge for certain groups, limited access to updated and integrated biodiversity data (especially regarding species distribution at the country level), and a lack of coordinated efforts across institutions — continue to hinder the understanding and management of invasive species. The entanglement of socio-ecological systems, whereby invasive species are tied to economic activities (e.g., agriculture, forestry, aquaculture, ornamental plants) or cultural practices (e.g., medicinal plants), further complicates efforts to prevent new introductions and control established populations.

In many cases, the financial benefits derived from production

systems involving invasive species are concentrated in specific economic sectors, while the environmental and social costs are widely distributed across society and the public sector (i.e., externality of negative impacts; Hulme et al., 2023). For instance, although introduced trees widely used for silviculture may generate positive economic impacts, they can negatively affect biodiversity, ecosystem services and the livelihood of local communities when they invade adjacent ecosystems and impact biodiversity and functioning (Souza et al., 2018; Linders et al., 2020). These tensions, coupled with conflicting interests between development goals and biodiversity conservation, hinder the implementation of effective measures to reduce species introductions, limit spread, and mitigate the ecological impacts of invasive species. Rather than a simple disconnection between science and policy, the situation reflects deeper social and structural conflicts that affect how scientific knowledge provides a basis for regulatory frameworks: while the negative effects of invasive species are clearly addressed by science, the use of the same species is widely promoted by different actors, counteracting attempts to control invasions and reduce their impacts.

Without addressing these systemic issues, Brazil will remain vulnerable to socio-ecological risks, including biodiversity loss, habitat degradation, the disruption of ecosystem services, and the emergence of increasing costs. Given these challenges, a transformative approach is required to advance invasion science and address the threats posed by invasive species in Brazil, aligning national actions with global frameworks such as One Biosecurity. Recently proposed by Hulme (2020) and expanded by Hulme et al. (2025), One Biosecurity represents a comprehensive, interdisciplinary framework that bridges human, animal, plant, and ecosystem health to prevent and mitigate biological invasions. It builds on the complementarity link between One Health and biosecurity, promoting cross-sectoral coordination from pre-border risk assessment to post-border management. Strengthening One Biosecurity funding in Brazil would therefore enable more integrated and preventive strategies against biological invasions, while enhancing coherence with international biodiversity and health agendas. The following sections highlight essential topics to be urgently addressed by authorities, researchers and research institutions that work in the field to contribute to effectively safeguard biodiversity and increase resilience against the growing threat of invasive species in Brazil, considering biodiversity, human dimensions, and ecosystem health in a holistic approach.

*Prioritizing targeted funding for One Biosecurity and invasive species research*

Investments in scientific projects in Brazil are predominantly

facilitated through general funding calls from federal and state agencies (e.g., National Council for Scientific and Technological Development - CNPq, state's Research Support Foundations - FAPs), and private institutions (e.g., Brazilian Biodiversity Fund - FUNBIO, Serrapilheira Institute). However, these calls are often broad and rarely focused on biological invasions. This aspect can hinder the development of consistent research in different regions of the country. In contrast, targeted and regular funding calls, particularly those related to long-term projects (e.g., Long-Term Ecological Research Programs - PELDs), have proven to be more effective in promoting applied research and collaboration between academia and technical management (Tabarelli et al., 2013). One example is the CNPq/IBAMA-PREVFogo 33/2018 call, which supported projects exclusively focused on fire management in priority ecosystems. This initiative not only resulted in scientific publications but also fostered dialogue between researchers and institutions, leading to the development of practical tools and solutions. Specific federal funding is also crucial to decreasing subnational disparities.

To strengthen efforts in prevention, early detection, control, and mitigation of invasive species impacts, it is essential to implement grants that prioritise biosecurity aligned with One Biosecurity principles. These thematic calls could support the development and application of innovative technologies for invasive species control, impact mitigation, management, and restoration of invaded ecosystems, while recognizing that some control methods still require further validation in real-world settings. Funding priorities should result from collaborative efforts between researchers and managers at the regional, state, and national levels, and could be further enhanced by partnerships with industry and other stakeholders, ensuring that resources are directed to the most urgent challenges. By designing funding focused on invasive species, Brazil could promote frameworks and technology (e.g., genome-informed control strategies and monitoring tools) to integrate cutting-edge scientific knowledge with on-the-ground management efforts, resulting in more effective action towards invasions. For instance, the Great Lakes Fishery Commission (Canada–USA) coordinates invasive species surveillance and control, including a binational program on Asian carp that employs eDNA as a monitoring tool, supported by dedicated funds from Canadian and US programs (Jerde et al., 2013; Nathan et al., 2015; Reid et al., 2021). Strengthening One Biosecurity funding in Brazil would enable a structured, innovative, and unified approach for invasion science, creating a more responsive and well-supported research landscape that may foster proactive policy alignment and coordinated actions that better safeguard human health, production systems and the natural environment (Hulme et al., 2025).

In addition, given the multiple borders and mobility connections with other countries, joint calls with international funding agencies should tackle specific issues arising from those relationships. An important model for applying such a measure is the Amazon+10 Initiative, which promotes joint calls from state and federal agencies in Brazil with international partners to foster scientific expeditions in the Brazilian Amazon. These integrated regional calls can increase the representation of local researchers and be more context-specific, thereby promoting more effective actions to address local issues.

#### *Establishing a national center for invasion science and One Biosecurity*

Environmental governmental institutions in Brazil, burdened with broader concerns (e.g., mining, hunting, deforestation), may not have the budget or personnel to address the specific issue of invasive species, despite their profound ecological, public health, and economic consequences, a scenario that has worsened, particularly, in the last six years (Silva Junior et al., 2021; Azevedo-Santos et al., 2023). Although there is a specific coordination unit within the national federal agency dedicated to invasive species, the Coordenação de Manejo de Espécies Exóticas Invasoras (CMEEI) from the Instituto Chico Mendes de Conservação da Biodiversidade (ICMBio), Brazil still lacks a centralized and multidisciplinary center with broader operational and strategic reach and with the

capability to address early detected biological invasions as environmental emergencies. Besides, such an institution (which does not need to be a physical center but rather a permanent working group or knowledge hub operating at the national level) is also important to analyse and understand previous invasion processes, to start collaborative research, to update nomenclature, and to enhance better understanding and adherence to global frameworks (e.g., Soto et al., 2024).

Establishing such a center, similar to Australia's Centre for Invasive Species Solutions, or the Center for Invasion Biology in South Africa, could bridge this gap, providing a hub for research, policy development, and public engagement efforts (Pyšek et al., 2020). It would facilitate collaboration with universities and research institutions, and streamline efforts in early detection, rapid response, and evidence-based policy-making. Moreover, the center could promote cross-disciplinary training, foster the development of novel tools (ranging from genetic methods to socio-economic impact assessment), and build capacity by equipping professionals with the skills necessary to address invasive species threats comprehensively. The center could also connect researchers, public institutions, and policymakers in more effective ways, supporting legislation and initiatives directed to address the use and control of invasive organisms.

#### *Enhancing open data sharing and developing a regional surveillance network*

In Brazil, there is a considerable volume of occurrence and distribution data on non-native species that remains unpublished or siloed within academic research groups and environmental consulting firms. Despite the existence of platforms such as the Global Register of Introduced and Invasive Species (GRIIS; <https://griis.org>), the Horus Institute database (<https://bd.institutohorus.org.br/>), and Global Biodiversity Information Facility (GBIF; <https://www.gbif.org>), much of the country's detailed spatial data — particularly regarding newly detected populations — is not systematically made public or integrated. This results in serious knowledge gaps in the invasion map of Brazil and hinders the development of effective early detection and rapid response strategies. The Horus Institute has played an important role in consolidating open-access occurrence records of non-native invasive species over the past two decades. Since 2019, the database is able to receive real-time observations through a cell phone application (Invasoras BR), and in 2025 it implemented an early detection system that sends automated email alerts about new occurrences to registered users linked to protected areas, species, states, or municipalities. However, the database is not automatically updated, besides it does have serious gaps in terms of species distribution (Sühs et al., 2025), since this requires that occurrence data be made openly accessible in the first place. The challenge, therefore, lies not only in technological capacity but in the relatively low level of data sharing and openness by researchers and professionals working in restoration and field activities. With data openly available, it is possible to periodically update the national database and then maintain it integrated with global platforms, such as GBIF and iNaturalist (<https://www.inaturalist.org>). Such integration would significantly enhance Brazil's biosecurity capacity (Pyšek et al., 2020; Pockock et al., 2024).

It is also crucial to recognize the economic dimension of biological invasions. Management costs rise exponentially as invasions spread and establish. Delays in data sharing and weak coordination translate directly into higher long-term costs for agriculture, public health, and biodiversity conservation. For example, invasive species such as the Mediterranean fruit fly *Ceratitis capitata* and the dengue mosquito *Aedes aegypti* have become significant economic burdens (Adelino et al., 2021; Oliveira et al., 2013), illustrating how the failure to act early results in severe financial and ecological consequences. Investments in pre-invasion actions towards minimizing risks of spread and impacts are much less costly than control measures and mitigations of the damages of invasive species (Cuthbert et al., 2022; Bradshaw et al., 2024).

Public agencies and research funders have a key role to play in advancing open science. They should strongly encourage researchers and environmental consultants to share their data on non-native and invasive species—especially novel occurrences or newly detected foci—with public agencies immediately, rather than waiting for formal scientific publication. Delayed reporting compromises conservation efforts by missing critical windows for eradication. Reporting invasive species detections must be part of the conditions tied to research permits, environmental monitoring programs, or natural resource exploitation licenses, to enable timely governmental action and maximize eradication opportunities at early invasion stages. Data sharing is essential to build effective environmental policy, and work in this direction is already underway. For instance, the national environmental agency (IBAMA) has recently issued an ordinance (Portaria IBAMA 104/2005) determining that all the raw biodiversity data obtained in environmental impact assessments must be entered in the SISBIA, a data storage and management system for environmental impact assessment data produced during environmental licensing processes. Integration of SISBIA with a dedicated invasive species database would certainly increase the amount of invasive species records, expand and refine their geographic coverage, and enhance early detection capacity. Support for the national repository system focused on invasive species records that already exist in Brazil would increase its reach and possibility of becoming more robust and being continuously updated and improved.

Effective management of biological invasions requires tighter collaboration between researchers, land managers (e.g., protected area staff), and policymakers. For instance, protected areas in Brazil managed by ICMBio, state and municipal environmental agencies have faced growing impacts from invasive species and often lack access to the best available knowledge or technical solutions. Many managers are also unable to generate sufficient research demand for species that are already impacting local ecosystems. Stronger cooperation and transparent data flows between scientists and field practitioners are essential to close this gap and to align local management practices with the latest science (Sprague et al., 2022; Hulme, 2015). Finally, although national, regional, and international networks for invasive species data already exist and provide important information-sharing platforms, there are no early detection and rapid response programs established and environmental agencies are scarcely prepared to respond or act upon existing information. A regional surveillance network focused on transboundary ecosystems is urgently needed, particularly between border nations and also between Brazilian states. Such a system should be supported by a central coordinating body within the Ministry of Environment and complemented by engagement from the Ministry of Foreign Affairs to strengthen cross-border cooperation. Without this level of coordination, Brazil risks continuing with a fragmented approach that undermines its capacity to respond effectively to biological invasions. Similar initiatives must be encouraged at the local level with a focus on areas of high value for biodiversity, and especially for areas of occurrence of endangered, endemic, or rare species.

#### *Integrating invasion science into academic and technical curricula, and promoting public awareness*

Despite its critical importance, invasion science remains largely absent from the Brazilian formal education system, even within Biology, Ecology, Agronomy, Animal Production Science and Architecture courses. Explicitly incorporating invasion science into undergraduate and graduate curricula across biological, agricultural and technical sciences is essential to build a workforce equipped to detect, monitor, and manage invasive species and to promote the use of alternatives in production systems (Azevedo-Santos et al., 2015). Educational programs should address interdisciplinary topics, including risk analyses, genetic monitoring, impact assessment, monitoring approaches, and management techniques—blending theoretical foundations with practical experience (Zhang et al., 2019; Haubrock et al., 2024).

Although costly, tools such as environmental DNA (eDNA) analysis, whole genome resequencing (WGR), artificial intelligence algorithms and remote sensing can promote an integration between disciplines and assist in early detection, mapping, and monitoring of invasive species (Sankaran et al., 2023). Integrating these technologies into academic and technical curricula can empower professionals and communities alike to contribute actively to biosecurity efforts. Investment in training and capacity-building across different technological levels—ranging from molecular tools to citizen science applications—is fundamental to enhancing Brazil's biosecurity. These actions would allow more responsive interventions and broader participation in surveillance and management of invasive species (Dechoum et al., 2019; Tabashnik et al., 2021; Stuart et al., 2022).

In addition, we advocate for the explicit inclusion of biological invasions and biosecurity within the Brazilian National Common Core Curriculum (BNCC, “Base Nacional Comum Curricular”), which defines the national baseline content in basic education. While the BNCC already refers to sustainability and general ecological concepts, it omits direct references to invasive species. This omission limits the ability of state governments and basic education institutions to emphasize this topic in their educational planning. Including biological invasions alongside climate change and habitat degradation, and restoration would ensure early engagement with the issue and higher public awareness. Training biology teachers to include these topics in their classes is also crucial. This could be addressed through extension projects organized by the proposed national center in association with state governments and universities, focusing on areas with a high level of invasion and located within the most susceptible ecosystems. It would foster a generation of informed citizens and professionals prepared to address the complex challenges posed by invasive species. An educational reform is probably the most solid action to strengthen Brazil's long-term biosecurity and promote an environmentally responsible society.

In addition to formal education, increasing public awareness about the problem posed by biological invasions requires a large improvement in the communication between invasion scientists and society. Although the negative impacts of invasive species have been increasingly present in the traditional media, many of those species have positive effects in local communities or for specific societal segments, for example, as a source of income or multiple uses, so that management actions may be perceived negatively (Novoa et al., 2018). Invasive species that have an economic value (e.g., aquaculture of tilapias) or are charismatic (e.g., *Callithrix* marmosets) feed political and societal movements toward their protection, highlighting the dissonance between scientific evidence and public perception (Pelicice et al., 2023). To counteract this problem, communication strategies are needed to inform society of the ecological and economic risks these species pose, as recommended in the recent Thematic Report on Invasive Alien Species, Biodiversity and Ecosystem Services (Dechoum et al., 2024). Public engagement, when well-structured, can still mobilize society and policymakers to adopt and enforce biosecurity measures, creating a more inclusive approach to invasive species management (Novoa et al., 2018). In some cases, it might even foster citizen science models that contribute to early detection surveillance efforts (Gallo and Waitt, 2011). Platforms like iNaturalist and Invasoras BR enable large-scale data collection through citizen science and can significantly enhance detection capacity when used strategically, also incorporating data validation procedures to enhance robustness (Encarnação et al., 2021; Pocock et al., 2024). Smartphone-based data collection, image recognition, and acoustic sensors have shown promise in monitoring invasive species (Encarnação et al., 2021).

#### *Advancing monitoring, surveillance and institutional capacity for One Biosecurity*

Brazil has made important advances in non-native species

management, including the development of risk analysis protocols, early detection and rapid response protocols and guidance, and management guidelines for protected areas (BPBES, 2024). However, implementation remains a major bottleneck. Bureaucratic hurdles, limited technical staff, and the low prioritization of biological invasions in environmental and political agendas have impeded the full application of existing tools. Often treated as a sectoral concern, biosecurity is rarely integrated into broader policy frameworks that deal with water resources, public health, poverty alleviation, or sustainable development. To overcome these limitations, Brazil must invest in a unified institutional framework with clear roles, standardized protocols, and dedicated funding to support enforcement and inter-agency collaboration.

The successful experience of other countries—such as South Africa, where invasive species control is linked to water security and job opportunities—demonstrates the importance of aligning invasive species management with broader societal goals. Similar approaches in Brazil could increase political interest and funding, while delivering multiple co-benefits. To that end, policies should strengthen and promote One Biosecurity, especially regarding import and export regulations, management of protected areas, and the regulation of high-risk species currently promoted for economic use (e.g., tilapia, African grasses, ornamental plants, aquarium fishes). Strengthening legal and institutional support in line with scientific evidence is key to reducing the growing environmental, social, and economic impacts of biological invasions (Early et al., 2016; Pysek et al., 2020; Ahmed et al., 2023; Faria et al., 2023).

## Conclusions

To effectively address the pervasive and complex threat of invasive species in Brazil, it is not sufficient to rely on limited research, fragmented efforts and reactive measures (instead of coordinated and proactive action). As a megadiverse and continental-scale country, Brazil faces unique challenges and responsibilities in advancing invasion science. Although important protocols and knowledge exist, their implementation is hindered by bureaucratic inertia, lack of funding, limited expertise, conflicts of interest with economic sectors, and political negligence regarding the topic. Invasion science must be recognized not as an isolated issue, but as inherently linked to broader agendas, such as water security, food production, public health, education, and sustainable development (i.e., One Biosecurity; Hulme, 2020; Hulme et al., 2025).

This paper outlines pivotal steps needed to continue improving the research, management and communication of invasive species in Brazil. Targeted funding and institutional coordination are essential to support prevention, early detection and long-term control. A national center for invasion science can centralize actions and foster intersectoral collaboration. Open data policies and regional surveillance networks can close critical information gaps. Adjustments in the educational curricula and promotion of public engagement can help prepare a new generation of scientists, managers, and citizens to respond to this growing threat. Furthermore, mainstreaming biosecurity across policy sectors and aligning it with socioeconomic goals, as demonstrated in international experiences, would create synergies that increase political and financial support. In summary, advancing invasion science in Brazil requires a coordinated, science-informed, and socially engaged approach that is proactive rather than reactive. By seizing this opportunity, Brazil can lead the way in biodiversity protection while strengthening its ecological resilience and societal well-being.

## ORCID iD authorship contribution statement

**Ana Clara Sampaio Franco:** Conceptualization, Writing - original draft, Writing - review & editing **Fernando Gertum Becker:** Writing - review & editing **Marcelo Fulgêncio Guedes Brito:** Writing - review & editing **Alessandra Fidelis:** Writing - review & editing **Ana Clara**

**Guido:** Writing - review & editing **Rafael Lacerda Macêdo:** Writing - review & editing **Thaisa Sala Michelan:** Writing - review & editing **Gerhard Ernst Overbeck:** Project administration, Writing - review & editing **Fernando Mayer Pelicice:** Conceptualization, Writing - review & editing **Bruno Eleres Soares:** Writing - review & editing **Brisa Marciniak de Souza:** Visualization, Writing - review & editing **Helena Streit:** Writing - review & editing **Jean Ricardo Simões Vitule:** Conceptualization, Writing - review & editing **Rafael de Oliveira Xavier:** Writing - review & editing **Juliano Zardetto:** Writing - review & editing **Sílvia R. Ziller:** Writing - review & editing **Michele S. Dechoum:** Supervision, Project administration, Writing - review & editing.

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## 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.

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