

Research Article

The Brazilian Biological Invasion Platform: six years of lessons learned reporting non-native marine species

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Abstract

Considering the potential ecological, socioeconomic, and human health threats related to non-native species introduction, the management of biological invasions is a priority for biodiversity conservation and human welfare. Science-based databases that provide lists and records of non-native species are fundamental to supporting regional and local management actions and decision-making processes. When easily available and disseminated, they can also reach the broader public and foster societal engagement. Here, we describe our experience with the Brazilian Biological Invasion Platform, a portal launched in 2019 that compiles and reports records of estuarine and marine non-native species in Brazil. The system was developed by integrating the Application Programming Interface (API) from Google Maps. Data collation involves four steps: (i) taxon selection; (ii) searches for non-native species reported for Brazil in the scientific literature (including gray literature); (iii) data filtration and extraction to spreadsheets for each species—date, type of record, spatial coordinates, habitat, ecosystem, and source of information; and (iv) careful revision and data transfer to a general database. Finally, the records are uploaded to the platform. The website allows searches by species and by record, with different filters, which are displayed on a map. People and institutions can contribute recommendations, comments, and new records through an online form. The portal encompasses more than 188 non-native and 151 cryptogenic species, with over 6,200 georeferenced records of zoo- and phytoplankton, zoo- and phytobenthos, nekton, and bacteria. We discuss the decision-making process and lessons learned during the first years of the platform, highlighting its impact on management and science outreach, gaps, needs, and challenges, in addition to perspectives for the coming years. Sharing these experiences will contribute to other initiatives already in progress or under development, which constitute important tools to connect biological invasion science, policy, and social awareness.

Key words: georeferenced records, management of biological invasions, non-indigenous species list, online portal, science communication, societal engagement

Introduction

Biological invasions are one of the greatest threats to biodiversity and ecosystem integrity, potentially causing environmental, socioeconomic, and human health impacts. For this reason, all international conventions, treaties, and national public policies aiming to ensure biodiversity conservation have specific goals associated

with the prevention, monitoring, control, and eradication of invasive non-native species. The Convention on Biological Diversity (Convention on Biological Diversity 2020), the United Nations Sustainable Development Goals (United Nations 2015), and the National Biodiversity Policy (Brasil 2002) are examples that illustrate this concern about biological invasions.

In Brazil, the National Strategy for Invasive Non-Native Species (MMA 2018a) establishes specific goals to be achieved by 2030. There are also national plans launched to combat non-native species with a higher invasive potential, such as the National Plan for Prevention, Control, and Monitoring of the Sun Coral (MMA 2018b), which includes 59 actions within nine objectives. Moreover, the goals of the National Strategy for Invasive Non-Native Species and the objectives of national plans guide the development and implementation of management plans for invasive non-native species in specific territories (e.g., states) and protected areas. These plans include actions for preventing the arrival and establishment of new species, as well as surveying non-native species already present and controlling them. Given the limitation of human and financial resources, it is essential to prioritize non-native species to be controlled and eradicated (McGeoch et al. 2009). Thus, a key step in combating biological invasions is the elaboration of lists of non-native species and their categorization by status—whether the species is already present in the natural environment, whether its distribution is restricted or expanding, and whether negative impacts have already been described.

In this study, we use the criteria adopted by Lopes and colleagues (2009) for the classification of non-native species. First, we generally categorize species as either native, non-native, or cryptogenic. Native species are those that occur in their area of evolutionary or historical origin; non-native species are those that occur outside their natural geographic distribution range as a result of anthropogenic activities; and cryptogenic species are those with evolutionary and biogeographic origins poorly described or unknown, which cannot be distinguished as non-native or native (Carlton 1996). In turn, non-native species are classified as confined, detected, established, or invasive (Lopes et al. 2009). A non-native species is termed confined when it occurs only in controlled artificial environments, totally or partially isolated from the natural environment. Species termed “detected” are those recorded in the natural environment but without a subsequent increase in their abundance or dispersion. This category is also used for cases of isolated records. Established non-native species are those detected recurrently, with a complete life cycle in nature and signs of population growth over time in a restricted or broad region, but without presenting apparent ecological or socioeconomic impacts. Finally, invasive species are those established species whose abundance or geographic expansion interferes with the survival of other species or causes measurable impacts on socioeconomic activities or human health.

Lists of non-native species are prepared based on the best available knowledge at a given time. Over time, new scientific evidence regarding the occurrence, distribution, and taxonomy of non-native species accumulates—either due to the increase in the number of researchers and research groups studying the subject or due to the actual arrival or expansion of the distribution range of non-native species in the territory. Therefore, it is essential to constantly review the lists of non-native species, updating the status and area of occurrence of already known species and including new species when applicable (Teixeira and Creed 2020). Another important, and sometimes neglected, aspect is that non-native species lists

must be communicated to a diverse audience, including environmental managers, researchers, students, educators, nature observers, and others. Compared to terrestrial environments, species introductions in marine ecosystems are often more difficult to identify, detect, and monitor, considering uncertainty in taxonomic knowledge, the larger scale of dispersal, and fewer physical barriers and limitations that the marine environment offers to direct observation (Kinlan and Gaines 2003; Ojaveer et al. 2015). Yet global trade has been spreading marine species through biofouling on ship hulls and transportation within ballast water at ever-increasing rates that are predicted to rise even higher over the next few decades (Sardain et al. 2019). Aquaculture and the aquarium trade are other vectors that have contributed to the transport of non-native marine species worldwide. Therefore, databases that collate and make records of invasive non-native species available—especially marine and estuarine ones—and that are constantly maintained and updated are essential to support management actions and decision-making, as well as to bring society closer to the issue. Such databases should be freely accessible, user-friendly, and scientifically grounded.

Here, we detail the process of conception, development, structuring, and content of the Brazilian Biological Invasion Platform, highlighting its impacts on management and science outreach. We also discuss the identified knowledge gaps, needs, and challenges during this first implementation phase, as well as the perspectives for the coming years.

Building the platform

The Brazilian Biological Invasion Platform (*Bioinvasão Brasil*), a portal that compiles and reports records of estuarine and marine non-native species in Brazil, was launched in 2019 (Casares et al. 2025—<https://bioinvasaoBrasil.org.br/>). It was conceived as one of the objectives of a larger project carried out by the Brazilian Institute for Biodiversity (BrBio) and Universidade do Estado do Rio de Janeiro (UERJ): to transform the National Database of Records and Management of Sun Coral (created and maintained by the Sun Coral Project in 2013; see Creed et al. 2017) into an online platform. Originally, it was intended to include only the records of *Tubastraea coccinea* and *T. tagusensis*. However, given the structure already created for each species and the recent review of the list of non-native marine species in Brazil—prepared at that time by Dr. Larissa Pires-Teixeira (Teixeira and Creed 2020) from the Marine Benthic Ecology Laboratory at UERJ, the technical team responsible for database development—we took the opportunity to create a portal that encompassed all non-native marine and estuarine species. The Brazilian Biological Invasion Platform is a digital portal that aims to make records of non-native species in Brazil freely available, disseminate the issue of biological invasions to society, and provide information to support the management of invasive species.

System development

The platform was developed using a hybrid methodology of systems analysis, blending characteristics of the waterfall project model with a defined scope (a project with sequential steps carried out one after another) and agile methodologies (dividing product deliveries into short cycles to speed up project delivery). This approach focused on continuous collaboration through incremental

deliveries, incorporating constant suggestions and changes proposed by those involved—the system developer and project managers, who were researchers from the Laboratório de Ecologia Marinha Bêntica, UERJ, and the BrBio team. Systems analysis, together with product discovery techniques (methods used to understand a given problem or context, such as interviews), was fundamental to the platform’s development, helping us understand the users’ needs and requirements to create an effective and functional platform for the entire community. The process was divided into eight stages, detailed in Table 1.

To enhance the interaction and usability of the platform, the Google Maps Application Programming Interface (API) was used, enabling navigation of occurrence records of non-native species on maps. The displayed occurrence records are clickable, showing images and detailed data about the geographic location. All occurrence records and details are registered in an online administrative system integrated into the platform by the management team, with restricted access through user credentials and data encryption for security.

Database structure

The platform’s database contains two sets of information. The first set (Fig. 1) gathers important data about the species: the authorship of the species (author’s name and date of description), the type of organism, the year it was first recorded in Brazil as non-native or cryptogenic, its current situation or status (cryptogenic, confined, detected, established, or invasive), and whether the record of the species has been validated by external specialists. The names of the species entered into the database are always checked through the World Register of Marine Species platform (WoRMS—WoRMS Editorial Board 2025), ensuring alignment with the most recent taxonomic revisions and incorporating the best available scientific knowledge. Periodically, or when a publication is identified that modifies the name of a species already included in the system, a new consultation with WoRMS is conducted to check whether changes are necessary in the portal.

Table 1. Detailed description of the steps followed to develop the platform.

Step	Description
1. Identifying main objectives and problems to be solved	· Identification of the platform’s objectives and the opportunities it would offer for exploration. · Development of several interviews and questionnaires.
2. Determine requirements of platform	· Collection of details about the functional and non-functional requirements of the platform (characteristics the portal should have, how it should behave, and what constraints it should meet). · Documentation of these requirements as specifications that served as the basis for development.
3. Requirements modeling	· Creation of visual models or diagrams to represent the required system’s interaction flow (e.g., use case diagrams, process flows, and sequence diagrams).
4. Analysis and documentation	· Evaluation of the consistency, completeness, and feasibility of the required system. · Resolution of discrepancies or ambiguities and refinement of the requirements. · Documentation of all processes to serve as a reference throughout the development cycle.
5. System design	· Development of the system design, including architecture diagrams, user interface designs, and database designs.
6. Prototyping	· Development of parts of the system as prototypes using an iterative and incremental model for validation and refinement through user feedback.
7. Development	· Incremental programming based on prototyping, validating, and testing each development step and module until achieving a usable project in a production environment.
8. Deployment and Adjustments	· Official launch of the project at the URL, with cyclical and ongoing adjustments and optimizations made to improve performance and security.

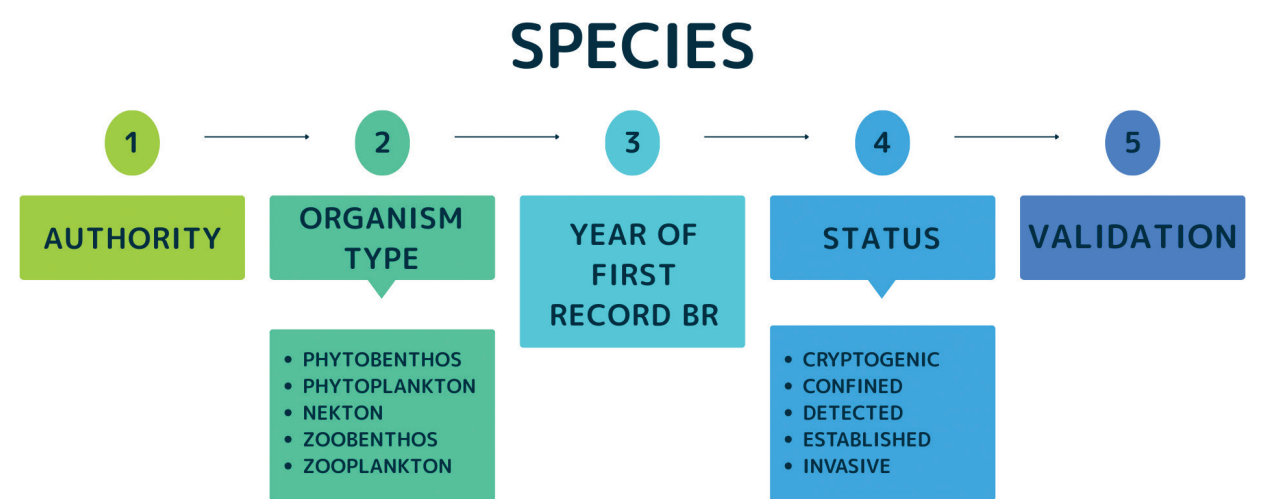


Figure 1. Representative scheme of the information associated with the species included in the database. BR = Brazil.

The second set of data includes information about the records (Fig. 2). Each record must be associated with a species, record type (e.g., presence record, absence, research, monitoring, or environmental education), a specific date, a pair of geographic coordinates, and a particular environment (artificial, natural, or urban, each with its subdivisions). Each record is also linked to a source of information. Therefore, we aimed to encompass the widest possible variety of record types, going beyond traditional presence records to include others, while always giving due credit to the source of information, which may be a scientific publication, report, or personal communication. For instance, absence records (when available) are important since they provide baseline data that may support valuable inferences, such as estimating the date of a species’ introduction at a given place, identifying potential biological resistance by native communities, or assessing effective management (for example, providing data on the success of

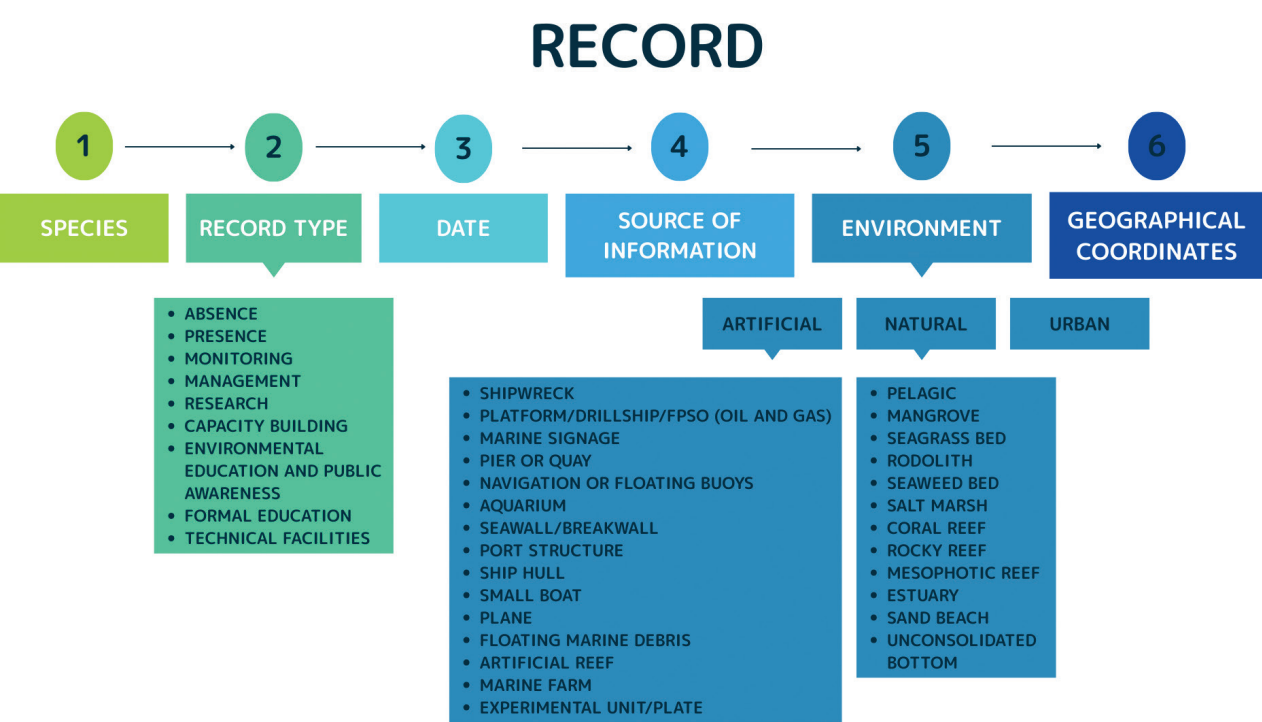


Figure 2. Representative scheme of the information associated with each record inserted into the database.

eradication strategies). For marine species, records associated with the urban environment may, for example, relate to areas where there are training activities, environmental education and public awareness initiatives, research, or expert availability. In contrast, records of presence, absence, management, and monitoring are always associated with natural or artificial environments and their corresponding subdivisions (Fig. 2).

Data gathering and upload

We started our species list with the non-native species compiled by Teixeira and Creed (2020) and species considered cryptogenic in Lopes et al. (2009) and Rocha et al. (2013). Following this preliminary species list, we proceeded to collate records for each species through a series of steps: (i) taxon selection; (ii) literature search; (iii) data filtration and extraction; and (iv) revision. The first step involves choosing a taxonomic group (phylum or class, usually) to direct the search effort. Then, we conduct a literature search to compile a list of all non-native species of the group listed in more specific studies (e.g., Ajala-Batista et al. 2020) and annotate those present in Brazil. The second step involves searching for records of non-native species in Brazil within the scientific literature, which includes articles published in national and international journals, doctoral theses, master's and graduate dissertations, technical reports, and books. For this, searches are conducted mainly on the Google Scholar portal (<https://scholar.google.com.br/>), using specific keyword combinations in English and Portuguese for better results, such as the taxonomic group name and species name followed by AND *exotic/exótica* or non-native/*não nativa* or non-indigenous/*não indígena* and AND Brazil/*Brasil*.

During the third step, the studies displayed in the search are then filtered to include only those referring to the occurrence of species in marine (including estuarine) environments in Brazil. An initial survey of the listed studies is carried out, and references of interest cited within them are also added to the list of publications of interest. The first two pieces of information to be found are the year of the species' first record in Brazil and its status. These pieces of information allow for the species' inclusion in the system via the "admin" mode. Each species is assigned an identification number (ID). Next, data associated with each species' records are obtained from the selected studies, such as location (geographic coordinates), record date, type of record, environment, habitat, and source of information. These data are stored in Excel spreadsheets created for each species, where each row represents a record with its respective information.

Only georeferenced records (with associated geographic coordinates) are included in the database. We use decimal degree coordinates, which must be converted if not available in this format in the referenced literature. In cases where the source of information contains only a map with sampling points or only the name of the species' location, or when the provided coordinates result in visibly incorrect locations, the coordinates are estimated using Google Earth (<https://earth.google.com/>). When the provided coordinates fall on terrestrial locations close to marine environments, new coordinates are estimated based on the closest body of water, as well as the description of the species' habitat of occurrence (if available) or species life-history characteristics. When references do not provide all the information about the species' occurrence, direct contact with the author(s) of the study or the person responsible for the biological or scientific collection is necessary—for example, in cases of specimen material from museum or herbarium collections—to obtain missing data. This email contact is made by

the person responsible for searching the records of the species of a given taxonomic group, usually an undergraduate or graduate biologist or oceanographer, who identifies himself or herself as part of the platform's team. Subsequently, the records for all species are entered into the main database and carefully reviewed by other members of the team, in this case postdoctoral researchers, to minimize errors (fourth step). Finally, the records are inserted into the platform via the “admin” mode. Each record is assigned an ID number to facilitate its identification, search, and potential editing. The species list has been updated until April 2025. Not all species have occurrence records included in the platform yet.

The platform

General interface

The portal features an interface that provides information about the platform's objectives and origin, criteria for species status categorization, how the platform works, search options (by species and by records), data summaries (graphs summarizing part of the data), how to collaborate (via an electronic form), credits, and how to cite the obtained information (Fig. 3).

There are two search possibilities: by species and by records. When the *species* topic is selected from the search menu (*Busca*), a search box opens and allows the user to filter by species name, common name, status, or type of organism (e.g., phytobenthos). At the same time, the system displays a table with an alphabetical list of all the species (taxa) included on the platform. Each species is listed with an ID number, common name, status, type of organism, validation status, date of first record in Brazil, and the total number of records for that species on the platform. The data can be consulted by sorting each column in ascending/descending or alphabetical/reverse-alphabetical order.

Similarly, when the “*record*” item is selected from the search menu (*Busca*), a search tool appears. This tool allows users to search using combinations of filters, such as species, type of organism, environment, record dates, status, record type, and habitat. It is also possible to select the order of the search results by species, type of organism, record date, record type, environment, or habitat. Search results are displayed on the map as points, and the records are listed below in a table.



Figure 3. Interface of the Brazilian Biological Invasion Platform showing the main menu.

Selecting a point on the map opens an information box about the record. We are currently working on a search tutorial that will soon be displayed on the portal.

Part of the data included in the portal is summarized as graphs and tables in the section of the menu labeled *Números*, which means “Numbers.” This section provides information on the proportion of species by status category, by type of organism, number of records per year, number of records per type of organism, and number of presence records in natural and artificial environments per type of organism.

The platform includes an online form for users willing to collaborate. People may send comments, criticisms, compliments, questions, and suggestions regarding the platform, as well as records and photographs of non-native species. When someone expresses interest in submitting records, we send them a more detailed spreadsheet via email to collect additional information related to the record in question. The information, along with photographic evidence, is analyzed, and if validated, the record is included in the system. Moreover, an email address is provided for further contact or inquiries.

Content

The platform currently includes 339 marine species found in Brazil (April 2025). Among them, 151 are considered cryptogenic, 13 confined, 62 detected, 87 established, and 26 invasive (Fig. 4A). Of the 339 species, there are seven phytoplanktonic species included (Fig. 4B): one invasive diatom (*Coscinodiscus wailesii*), five dinoflagellates (three cryptogenic and two invasive—*Alexandrium tamarense* and *Gymnodinium catenatum*), and one cryptogenic microalga. The portal includes 17 zooplankton species (Fig. 4B), of which two are cryptogenic, four confined, three detected, and eight established. Twenty-one of the species belong to the phyto-benthos (Fig. 4B), of which four are cryptogenic, six confined, four detected, six established, and one invasive (*Caulerpa scalpelliformis*). The group with the largest number of species included in the platform is the zoobenthos (Fig. 4B). The system includes 275 species, of which 139 are cryptogenic, two are confined, 44 are detected, 69 are established, and 21 are invasive. The nektonic organisms comprise 19 species (Fig. 4B), of which one is cryptogenic, two are confined, 11 are detected, four are established, and one is invasive (lionfish—*Pterois volitans*).

The platform has a total of 6,191 records (April 2025) and is currently in the phase of data collection, review, and inclusion, species by species. Most of the included records refer to zoobenthic species (5,543), mainly due to records related to sun coral species *Tubastraea coccinea* and *T. tagusensis* (4,823). This predominance results from the first major effort to systematize and include data—based on the database of the Sun Coral Project—and the considerable research effort devoted to these species (Dutra et al. 2023).

In addition to the records of sun coral, the platform has already collated and included records for one species of diatom (25 records), 15 species of mollusks (490 records), one species of cladoceran crustacean (9 records), two species of echinoderms (193 records), one species of hydrozoan (37 records), and 17 species of non-native fish (614 records). Many other records (more than 7,000) related to dozens of species have already been compiled and are under review to be subsequently uploaded to the system, such as anthozoan cnidarians (1,398 records from 16 species), scyphozoan cnidarians (25 records from two species), hydrozoan

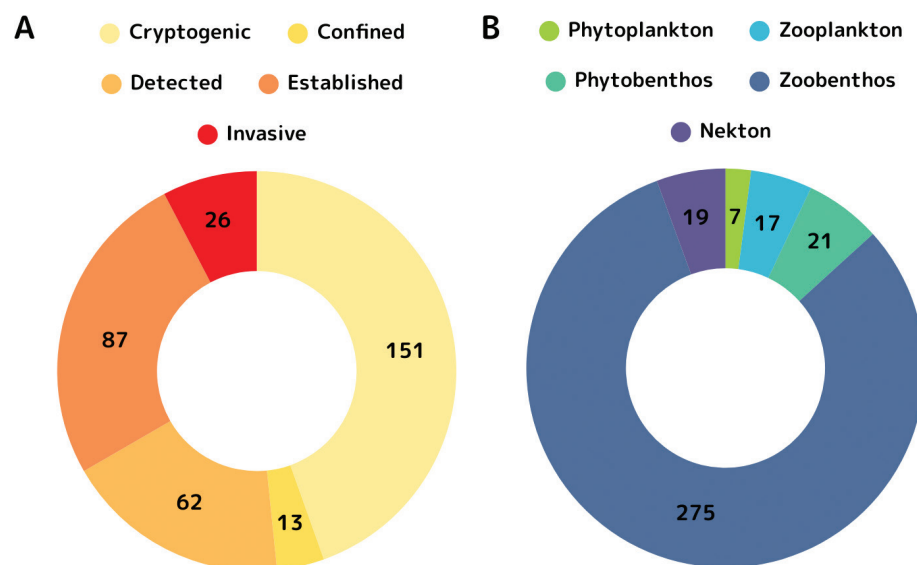


Figure 4. Number of species included in the platform per category. **A.** status; **B.** type of organism/functional group.

cnidarians (899 records from 23 species), polychaetes (710 records from 17 species), decapod crustaceans (151 records from six species), non-decapod crustaceans (866 records from 23 species), bryozoans (665 records from 32 species), one species of echinoderm (*Tropiometra carinata*—184 records), ascidians (2,404 records from 42 species), and fish (196 records from 27 species). There are also records currently being compiled, such as those associated with species of sponges and macroalgae.

Finally, there are groups for which searches for records need to be further refined, such as non-decapod crustaceans, or have not yet begun, such as the remaining microalgae. Considering that biological invasion is a highly dynamic process, the data mentioned here will be continuously updated as more records are added to the database, uploaded to the portal, and received from contributors, and as scientific knowledge advances.

User profile

To understand the profile of the portal users, we use the Google Analytics 4 platform. Through this tool, we can obtain information on the number of users and visitors during a determined period of time, as well as more detailed information such as users' country and state of origin, session duration, and whether they are new or returning users. This informs us about the platform's public outreach, and the results help guide necessary actions to improve its impact.

According to the report obtained from the Google Analytics platform from April 2024 to April 2025, *Bioinvasão Brasil* attained 1,224 users (almost all new), who spent nearly 2,000 sessions on the portal. In Google Analytics 4, a session is a group of user interactions (events) with a website or app within a specific time frame. A new session begins when a user opens the app or views a page and ends after a period of inactivity (defaulting to 30 minutes or at midnight). One user can have multiple sessions, and each session includes all the actions taken during that visit, such as page views, events, or transactions. Most users were from Brazil ($n = 813$), as expected. Nonetheless, there were users and visitors from other countries, including the United States, France, China, the United Kingdom, and the

Netherlands. Brazilian visitors accessed the portal mainly from the states of Rio de Janeiro, São Paulo, Bahia, Paraná, Ceará, Rio Grande do Sul, Minas Gerais, and Santa Catarina. The mean duration of each session was approximately 3.5 minutes.

Impacts and accomplishments

Advances in non-native species lists and records

During these first years, we have gathered, processed, and systematized a large amount of scientific and technical information on marine and estuarine non-native species in Brazil. Our distinction lies in going beyond a simple list of non-native species by providing georeferenced records for each taxon. This focus has fostered a detailed and careful review of nearly all records of non-native species for each group analyzed so far. We have compiled more than 10,000 records of non-native species. This represents an important advance in our knowledge of marine biological invasions in Brazil, South America, and the southwestern Atlantic Ocean—information that would otherwise remain fragmented without this effort.

Support for local, regional, and national biological invasion management

By compiling records of non-native invasive species along the 8,000 km Brazilian coast—often scattered across various types of publications—and making them freely available and searchable, the platform contributes to management and supports informed decision-making. Local, regional, and national environmental managers benefit from the available information to understand changes in non-native species occurrence and distribution through time and space, as well as to plan strategies and actions to prevent the introduction of new species and to control those already present.

Science outreach and societal engagement

The portal represents a powerful tool for communicating information on biological invasions and fostering societal engagement in combating this challenge. In this regard, *Bioinvasão Brasil* unites science, awareness, and decision-making processes. The platform allows for societal contributions, as anyone who finds a species they believe to be non-native can contact us and submit their record, provided it is georeferenced and preferably accompanied by a photograph. We receive external contributions mainly from divers who have observed non-native species in natural environments and from researchers who provide information after publishing records in scientific articles. Environmental consultants have also contributed data, as there is a recent requirement that companies conducting environmental monitoring in areas influenced by potentially polluting enterprises submit records of non-native species to publicly accessible platforms. This requirement is part of the Invasive Alien Species Prevention and Control Project (*Projeto de Prevenção e Controle de Espécies Exóticas Invasoras* – PPCEX), established by the Brazilian Institute of Environment and Renewable Natural Resources (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis* – IBAMA), and is applied as compensation for damage caused during

the exploitation and production of oil and gas, which are potentially polluting activities. This regulation enables the publication of records that would otherwise remain confined to reports. Furthermore, the platform has become a kind of clearinghouse, as some specific management projects use its online form for user contributions as a third-party mechanism for receiving information.

Human resource development and multidisciplinary

The platform also serves as an important means of developing human resources with expertise in biological invasions and data organization and technology. This has been achieved by including scholarship holders and undergraduate volunteers from the biology and oceanography programs at the Universidade do Estado do Rio de Janeiro on the team. Since 2019, ten undergraduate students have interned with the platform and presented posters at local conferences. Another noteworthy feature of the platform is the collaborative involvement of professionals from the biological sciences, information technology, and design. This interdisciplinary approach enables us to achieve better results, effectively address emerging challenges, and continuously improve the portal's features. As a result, we are able to deliver an attractive, functional, and user-friendly experience for our users and visitors.

Partnerships

Partnerships have played an important role in the portal's success. The solid collaboration among UERJ, BrBio, and Promodigital has been fundamental in developing and improving the platform through fundraising and technical cooperation. The recent partnership established with the Instituto Nacional de Ciência e Tecnologia Biodiversidade da Amazônia Azul, funded by Brazil's Conselho Nacional de Desenvolvimento Científico e Tecnológico, has brought additional financial and technical support, as well as opportunities for material exchange and dissemination. Finally, partnerships continue to enhance the platform's outreach and impact.

Knowledge gaps, needs, and challenges

Keeping a platform that provides records of non-native species active and up-to-date involves a series of challenges and constant, meticulous work. Here, we discuss the most important difficulties faced during the first six years of *Bioinvasão Brasil*, together with the major accomplishments achieved and perspectives for the forthcoming years (Fig. 5).

General challenges

Compiling non-native species records has involved detailed, time-consuming work, especially to develop and complete the first version of the database, which is still being carried out by our team. Although we had the opportunity to start from the species list prepared by Teixeira and Creed (2020), we needed to update the list and search for distribution records for all species within the marine and estuarine environments of Brazil. This is an ongoing effort that must be continually maintained due to newly reported non-native species, new occurrences of already listed species, changes in species status, and taxonomic updates.

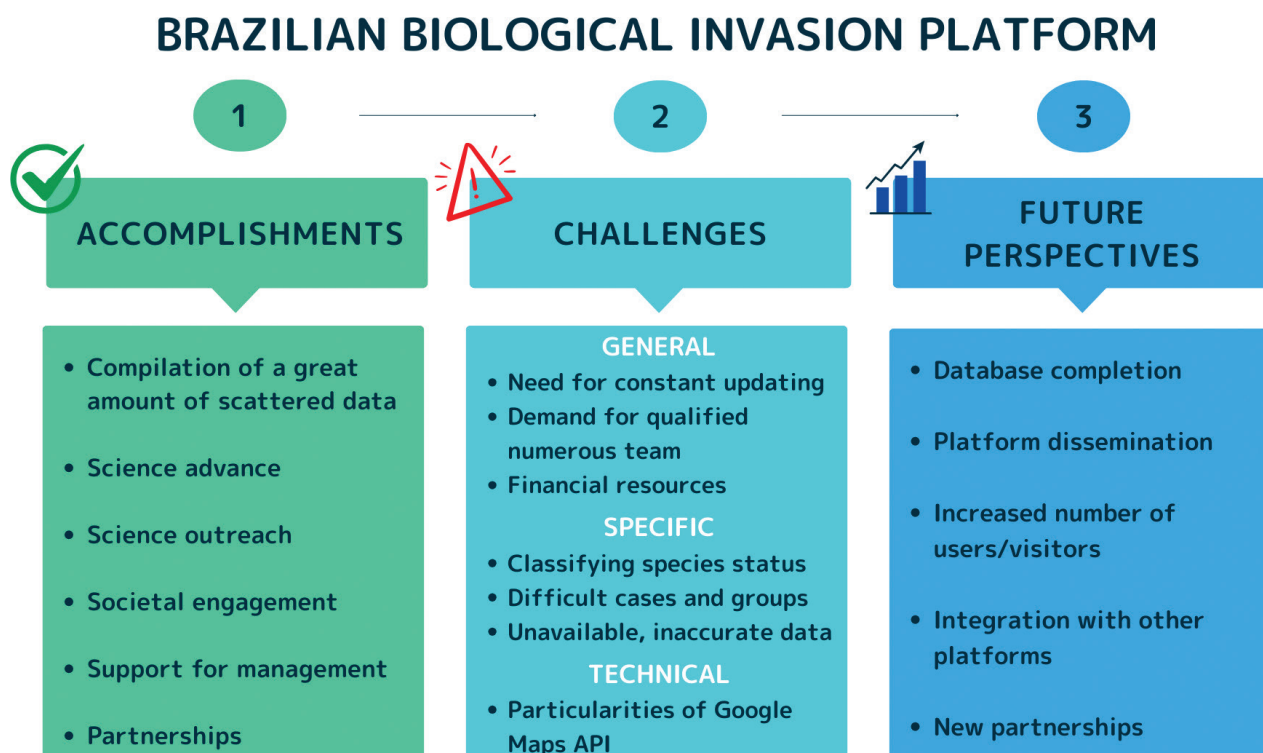


Figure 5. Scheme summarizing the many accomplishments achieved, the main challenges faced, and the future perspectives of the Brazilian Biological Invasion Platform.

The so-called “hidden invasion records” (Carlton and Schwindt 2024) are other important sources of “new” non-native or cryptogenic species. Such records can remain “hidden” as a result of reports published in global taxonomic and invasion literature that have gone unnoticed by local researchers (Carlton and Schwindt 2024). Therefore, bibliographic searches must be broad enough to capture both local and global taxonomic and invasion literature, and—perhaps just as important—the filtration process must be careful enough to detect publications that mention or suggest the possibility of a given species having been introduced in the study area. In our case, searches for species names (both current and former) AND Brazil, coupled with a meticulous filtering process, have been an important way of detecting references from the taxonomic literature. The need for native species reassessments, also highlighted by Carlton and Schwindt (2024), is an additional challenge that can increase the number of non-native marine and estuarine species in Brazil and in our list. However, it is more difficult to overcome, since it requires a large collaborative effort involving taxonomists and ecologists.

Thus, it is essential for information to be constantly updated in the system to ensure data reliability, based on the best available scientific knowledge. This is a long-term task that requires time, as well as human and financial resources, not only for building the database and integrating it into the system but also for maintaining the portal. It represents intensive work that demands a dedicated team with well-defined roles and continuous internal communication. However, obtaining funding for human resources has been challenging. Up to now, we have been able to maintain the portal with existing funds related to an ongoing project of our laboratory and by obtaining scholarships from university outreach grants, as well as from national science support agencies that fund projects of partner institutions. Much of the human resources come from academic research staff not specifically

dedicated or paid to work on the platform, which is not ideal. Therefore, the establishment of partnerships is fundamental and mutually beneficial.

Developing a working plan with clear and objective goals to be accomplished is important for task organization and division. For us, the decision to complete the database taxon by taxon has worked well, considering that the overwhelming amount of information being published every month could otherwise hinder the progress of our work.

Specific challenges in data gathering

Apart from the more general challenges, the elaboration of non-native species lists and the compilation of records involve more specific difficulties. For example, classifying species status is not always an easy task. There are complex cases where conflicting information exists about the same species and where studies diverge on its status. Moreover, just as aquatic species can differ across watersheds, the same marine species may be classified as non-native in one region of Brazil and native or cryptogenic in another, especially in the case of estuaries. There are also peculiarities, such as the “Amazon barrier,” that create complex Caribbean–Brazil biogeographical distribution scenarios in the flora and fauna, which may be interpreted in different ways (single native range with an Amazon break, introduction into Brazil, or cryptogenic). Such cases demand deeper and more careful research into the species’ biogeography and introduction history, as well as assistance from taxonomic specialists.

Other complicated cases are those related to nektonic species that can swim long distances, sometimes called vagrants (i.e., “species that are occasionally seen outside their normal geographic range, but without establishing viable populations in the new area”; Joyeux et al. 2001), essentially freshwater species that can occasionally be found in estuaries or even the sea (e.g., Franco et al. 2023), and those belonging to taxonomically complex or understudied taxa. Due to these complexities and our commitment to scientific rigor, we decided to invite taxonomic specialists to collaborate with us and validate species status classification for each taxon being completed.

In addition to the problems in determining species status, we also face difficulties related to the accessibility and quality of data for compiling records of each non-native species. Many studies are old and difficult to find, while others are not freely accessible. Many references lack the necessary data on species occurrence, making it challenging to fill gaps in the records. The broader the distribution of a species within the country, the greater the likelihood of data gaps—and the more time-consuming it becomes to complete missing information. Some references mention specimens that are part of university or museum collections across Brazil, requiring communication with the curators responsible for these collections to obtain missing data. In other cases, direct communication with the author of the study is necessary. The systematization and online availability of collection material data for consultation would be highly beneficial in such cases. Some of the material from Brazilian museum collections is now starting to be included in online biodiversity repositories, for example, the “Sistema de Informação sobre a Biodiversidade Brasileira”, an information system on Brazilian biodiversity (SIBBR; <https://www.sibbr.gov.br/>). Yet, the system is far from complete. This slows down searches, sometimes without yielding the desired data, and personal requests for such information often go unanswered.

Another frequent challenge is related to the geographical coordinates of species records. Many studies simply cite the locality name, such as the beach where the

species was found. There are also instances where incorrect coordinates are provided, placing the occurrence location, for example, in the middle of a city or a terrestrial ecosystem. In such cases, approximate coordinates are determined using Google Earth, based on the location name and relevant reference data, such as maps of collection points and substrate type, when available.

Technological difficulties

Since the beginning of the portal, we have faced an important difficulty related to a limitation of the Google Maps API, which does not allow more than one record from the same pair of geographical coordinates to be displayed as different points on the map. The initial alternative to overcome this issue was to slightly change the coordinates. Considering our platform deals with marine records, we had to do this manually, since inserting an algorithm could, by chance, place a point on land. This involved additional work and time. Fortunately, we recently implemented an add-on script to the Google Maps API to solve this issue by creating clusters of markers that display larger pins for clusters and, when clicked, expand into a spider-like graphic showing the different markers at the same position. Another technical improvement recently implemented was the capacity to upload data in batches to the system, which will also save time for our team, who previously had to manually upload records one at a time.

Future perspectives

In the short term, the focus of the work will be to complete the searches and enter all records of non-native species from the remaining taxonomic groups, as well as to submit the status of the species included in the system for validation by specialists. This will take into account new publications, as it is estimated that between two and eight new marine non-native species are recorded per year in Brazil (Teixeira and Creed 2020). In this regard, strengthening collaboration with researchers to promote the standardized use of specific terminology or keywords in studies reporting new occurrences of marine and estuarine non-native species based on field surveys would substantially enhance the efficiency of literature searches used to feed the platform. The list of taxonomic experts and contributors to the platform will be added to the site. In the midterm, we will devote additional effort to publicizing the platform. Through a planned communication strategy supported by informative and attractive audiovisual materials, we aim to increase the number of collaborators and users of the portal, thereby increasing the platform's impact. The goal is to establish loyal users who regularly search the platform and contribute records, while also attracting new users who become engaged with the portal. To achieve this, frequent outreach efforts must be made, including participation in academic events and the production of content for audiovisual materials and social media posts targeting different societal segments that the platform aims to reach. Specifically, we hope to better engage academics, environmental consultants, environmental managers, and citizen scientists.

There is also the possibility of integrating the platform with other search portals and databases containing lists and records of non-native species and marine biodiversity, both nationally and internationally, thereby combining

efforts and increasing its reach. This would be particularly valuable at regional and continental scales, especially along the southwest Atlantic with Venezuela, the Guianas, Uruguay, and Argentina, and between the Caribbean and southwest Atlantic on the South American continent, where collaboration is still considered lacking (Schwindt and Bortolus 2017; Schwindt et al. 2022). In this respect, the Coastal Ocean Marine Biosecurity International Network of the Americas and the Caribbean (<https://stri.si.edu/story/comбина>) is compiling existing resources and working to build new tools, including non-native species databases and information resources, so our experience here may provide useful insights regionally. The platform holds immense potential and, in the future, could include species from terrestrial and freshwater ecosystems. To achieve this, it will be necessary to expand the team responsible for data acquisition, filtering, review, and integration into the system.

Conclusion

Beyond the various existing challenges and the intensive work involved, the platform is a powerful tool for supporting management actions against biological invasions, gathering the best scientific knowledge available on the subject, making it freely accessible to society, and providing support for better decision-making. The portal's format allows for interaction and contributions from anyone, bringing the general public closer to the issue of biological invasions. The platform offers several opportunities for information sharing, social engagement, education, and support for local and regional public policies.

In these early years of the platform, efforts have primarily focused on gathering and including data in the system. We are still completing this phase. However, in the coming years, greater emphasis will be placed on dissemination strategies and partnerships to further expand the use of the portal. The platform holds potential for growth through increased partnerships and integration with other biodiversity and non-native species databases. Maintaining the platform is a continuous process that involves the technical and practical challenges previously described, a dedicated multidisciplinary team, and, above all, significant importance for science, outreach, the management of biological invasions, and the conservation of Brazilian biodiversity. We hope that by sharing these experiences, we will contribute to other similar initiatives already in progress or yet to be developed.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

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Author contributions

FAC conceptualized the study, carried out the formal analysis, was responsible for visualization, and wrote the original draft of the manuscript. VRM contributed to visualization and reviewed and edited the manuscript. ML contributed with software and reviewed and edited the manuscript. LMPT reviewed and edited the manuscript. SSOP aided in conceptualization, acquired funding, and reviewed and edited the manuscript. EP contributed with software and reviewed and edited the manuscript. JCC conceptualized, supervised, acquired funding, and reviewed and edited the manuscript.

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Data availability

All of the data that support the findings of this study are available in the main text.

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