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Discussion Paper

TRACKS: Six good practices for Non-Indigenous Species research and their SWOT evaluation

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Abstract

Addressing the challenges posed by Non-Indigenous Species (NIS) demands coordinated efforts across terrestrial, freshwater and marine ecosystems. In this study, we engaged a diverse group of 90 Italian researchers operating within these three domains to identify and assess strategies for advancing NIS research, using a structured, interactive and expert-driven methodology. The process began with a comprehensive evaluation of ongoing activities, research methodologies and specific needs. This assessment provided information for the development of an initial set of suggestions to ameliorate NIS research, which were collectively discussed and refined, leading to the identification of six good practices identified by the acronym TRACKS and described as: *i*) Tracking NIS in biodiversity data collection; *ii*) Reference protocols for NIS data collection; *iii*) Active participation; *iv*) Collaboration and FAIR principles; *v*) Knowledge hub for NIS data; *vi*) Strategic communication.

A SWOT framework was then applied to analyse the internal and external factors influencing the Strengths, Weaknesses, Opportunities and Threats associated with each good practice. Consensus-building techniques were used throughout the evaluation process to ensure the robustness of outcomes. Finally, a quantitative assessment of the SWOT analysis revealed a strong consensus amongst experts regarding the various strengths, weaknesses, opportunities and threats of the different good practices, along with a general optimism about the opportunities and strengths associated with their implementation. Developed within the Italian research community, this approach offered valuable insights to researchers worldwide working on NIS and enabled the expert assessment of six best practices that may serve as a benchmark for advancing the science of biological invasions.

Key words: Expert elicitation, good practices, invasive species, structured evaluation

Introduction

Every day, researchers collect biodiversity data worldwide, which reveal the increasing occurrence of Non-Indigenous Species (NIS) across a wide range of terrestrial and aquatic ecosystems (Seebens et al. 2017). NIS have long been recognised as a key indicator of global environmental change (Vitousek et al. 1996) and a pervasive feature of our globalised world (Lockwood and McKinney 2001). A subset of them, more than 3,500 globally (IPBES 2023), are recognised as Invasive Alien Species (IAS) capable of altering biodiversity patterns and ecosystem functioning at multiple scales (Simberloff 2013; Bellard et al. 2016). IAS may also degrade ecosystem services (Vilà and Hulme 2017), pose serious health risks to plants and animals (Hulme 2021) and, ultimately, jeopardise human well-being (Shackleton et al. 2018). The global economic impact of IAS is estimated at approximately 400 billion euros annually, a figure comparable to the costs of major natural disasters such as earthquakes (Turbelin et al. 2023) and wildfires (Thomas et al. 2017) and is expected to continue rising in the future (IPBES 2023).

In recent decades, the growing urgency to mitigate these impacts has driven national and international authorities to establish strategies aimed at monitoring, preventing or limiting their introduction. This response has been shaped by several global and regional frameworks, including the Convention on Biological Diversity (CBD) and its Aichi Targets and Kunming-Montreal Global Biodiversity Framework, which explicitly call for the control of IAS. At the regional level, instruments such as the European Biodiversity Strategy for 2030, adopted in 2020 (European Commission 2020) and the EU Regulation No. 1143/2014 (European Commission 2014) on IAS have provided legal and policy tools to guide management actions, while national strategies and biosecurity frameworks have been developed by individual countries to coordinate surveillance, risk assessments and rapid response mechanisms. In parallel, an expanding body of scientific literature has emerged, offering key recommendations on how to direct NIS research on prevention and early-detection strategies (e.g. Byers et al. (2002); Wittenberg and Cock (2005); Ojaveer et al. (2014)). This need for robust information is further emphasised in the recent IPBES assessment (IPBES 2023), which underscores the fundamental role of research in enabling evidence-based management of biological invasions. The report highlights that scientific research is essential for improving our understanding of the risks and impacts associated with NIS, as it provides critical knowledge on species distributions, introduction pathways and their ecological, economic and health-related consequences. However, a major challenge identified by IPBES is the persistent gap between the accelerating pace of biotic homogenisation and the current capacity of research to monitor and respond to this phenomenon at national, regional and local scales. This discrepancy has hindered management actions, particularly in under-studied regions or for poorly-known taxonomic groups (Byers et al. 2002). Another significant obstacle is the fragmented management of NIS, as terrestrial, freshwater and marine ecosystems are often governed through sectoral policies and disconnected institutional responsibilities. This lack of integration hampers coordinated surveillance, data sharing and response efforts, further complicating timely and effective action against biological invasions.

To address these challenges, a variety of good practices could be proposed, such as enhancing surveillance, strengthening active participation with relevant stakeholders or fostering an adaptive management framework. This need for best practices has been strongly emphasised in the context of managing biological invasions in both terrestrial and aquatic systems (Whitlock 2011; Groom et al. 2015, 2017; Deriu et al. 2017; Seebens et al. 2020; Azzurro et al. 2024a; Vilizzi et al. 2025). Closely related is the necessity for effectively communicating information about NIS and their societal impacts, as public awareness and the involvement of a wide array of stakeholders play a crucial role in the sustainable management of biodiversity (Young et al. 2014; Sosa et al. 2021; Golebie et al. 2022; Rodríguez-Rey et al. 2022; Doley and Barman 2023).

Despite this, surprisingly few initiatives have been undertaken to advance research on NIS. While some efforts have aimed at identifying overarching research priorities within invasion science (Ricciardi et al. 2021), there is an emerging need for a systematic evaluation of the different ways through which NIS research practices can be improved.

Identifying good practices is a common goal in ecological research (Burbidge et al. 2011) and numerous studies have attempted to define such practices across various ecological domains, particularly within biodiversity research frameworks (Gioia 2010; Gullison et al. 2015; Pocock et al. 2015). In some cases, these initiatives have focused on specific taxonomic or functional groups, including pests (Poulin 2019; Montgomery et al. 2021; Grünwald et al. 2024).

Building on these premises, this study aims to identify and to evaluate a set of good practices that can be effectively adopted by the scientific research community working on NIS. To this end, Italy is used as a case study. Italy, recognised as one of the most biodiverse countries in Europe (Convention on Biological Diversity 2019), also represents a critical hotspot for biological invasions in both terrestrial and aquatic systems (e.g. Servello et al. (2019); Domina (2021)), making it an ideal setting for assessing current practices and identifying pathways for improvement. According to data from the Italian Institute for Environmental Protection and Research (ISPRA; https://specieinvasive.isprambiente.it), nearly 3,800 NIS have been recorded in Italy, of which 3,659 are currently established, with significant ecological consequences and negative impacts on productive sectors such as agriculture, forestry, fisheries and aquaculture. Effective management of this complex issue depends on the availability of accurate and up-to-date data. However, such data are often only partially available, fragmented across different research groups and infrastructures, difficult to access or reuse and seldom communicated to the wider public.

In this study, we followed a participatory strategy involving a broad community of Italian researchers working on NIS to develop a set of good practices aimed at enhancing NIS research. These expert-based proposals were then subjected to a quantitative SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis, a structured decision-making tool widely applied in various sectors (Gregory et al. 2012), including conservation (Mukherjee et al. 2015). Although rarely used in good practice evaluation (Benzaghta et al. 2021), SWOT analysis offers a flexible framework for evaluating management strategies, particularly in contexts where data are incomplete, an issue commonly encountered in biodiversity monitoring (Patrício et al. 2016). Here, by involving scientists from terrestrial, marine and freshwater domains, we aimed at integrating diverse research perspectives into a set of shared proposals, with the goal of enhancing the quality, coherence and overall impact of NIS research across disciplines.

Materials and methods

A structured four-step approach (Fig. 1) was employed to identify and assess good practices for enhancing NIS research. The workflow comprised: a survey amongst experts on NIS and biological invasions to initially identify potential good practices (Step 1); a workshop utilising the Delphi method to evaluate the feasibility of each practice, complemented by focus-group discussions on their advantages and disadvantages (Step 2); a second workshop where the selected good practices were refined and SWOT indicators were developed (Step 3); and a final survey performing a quantitative SWOT analysis to assess these practices, considering their strengths, weaknesses, opportunities and threats (Step 4).

Step 1 - Identification of experts and collection of recommendations for good practices

Between July and November 2022, we engaged 90 experts specialising in the NIS taxonomy, biology, ecology, monitoring and management in Italy to gather insights into national research activities. Experts were identified through three main strategies: (i) reviewing existing studies on NIS carried out in Italy; (ii) identifying individuals involved in major conservation projects related to NIS and (iii) employing a snowball approach, where experts were asked to recommend additional colleagues. All participants completed an online questionnaire (Suppl. material 1: appendix S1), primarily composed of open-ended questions. This survey aimed to map key research efforts, identify the most frequently studied NIS in Italy and compile ongoing research projects and monitoring activities across diverse ecosystems. Additionally, it explored major gaps in current research activities and assessed experts' willingness to participate in a harmonised approach for NIS monitoring and data sharing. Based on the survey results, we identified an initial set of nine potential good practices aimed at standardising data collection, sharing and communication about biological invasions (Suppl. material 1: appendix S2).

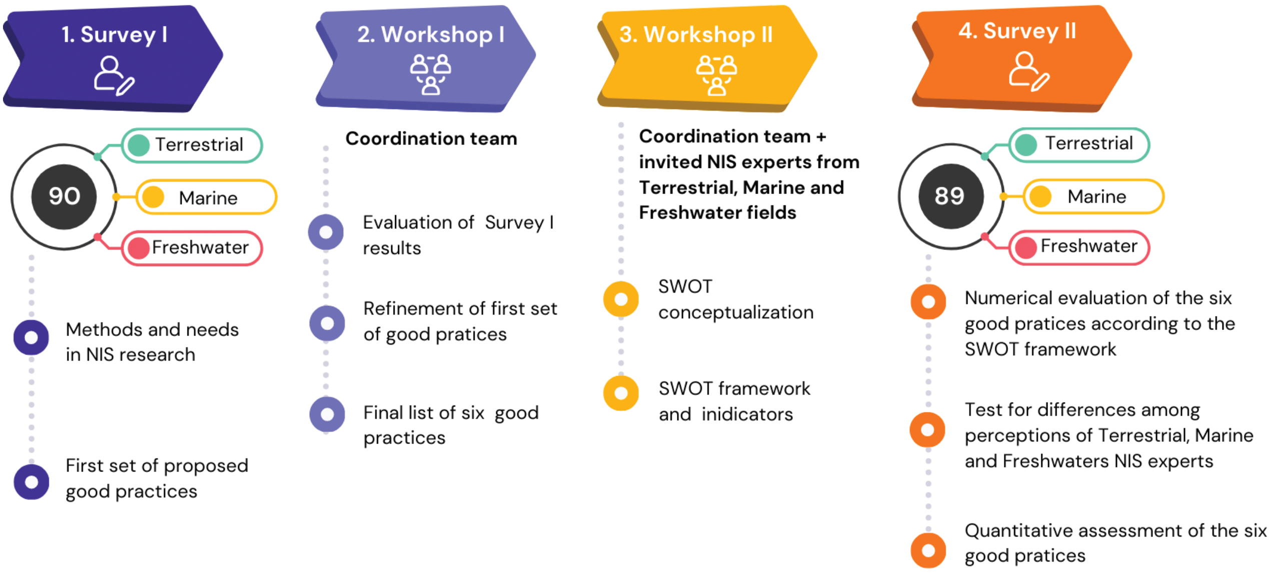

Figure 1. Approach overview. Workflow illustrating the four-step methodology used to identify and qualitatively assess good practices for NIS research. A total of 90 experts specialising in terrestrial, marine and freshwater NIS were actively involved throughout the process.

Step 2 - Six good practices to be submitted to quantitative evaluation

The nine potential good practices defined during Step 1 were discussed and refined, ultimately consolidating them into a final list of six good practices through a consensus-based analysis (Suppl. material 1: appendix S2). These good practices, detailed in Table 1, include: i) Tracking NIS in biodiversity data collections; ii) Reference protocols for NIS data collection; iii) Active participation; iv) Collaboration and FAIR principles; v) Knowledge hub for NIS data; vi) Strategic communication.

Step 3 - Conceptualisation of SWOT indicators through a consensus-based approach

The conceptualisation of the SWOT analytical method followed Chang and Huang (2006) and involved developing a comprehensive set of indicators categorised within each good practice across the four SWOT components. This process was supported by collaborative focus-group discussions (Nyumba et al. 2018), which facilitated the integration of diverse expert perspectives and provided information for the subsequent quantitative evaluation.

Step 4 - Quantitative evaluation of the six good practices

Expert researchers were subsequently re-engaged to quantitatively evaluate the six selected good practices. Their corresponding SWOT indicators were used solely to ensure consistency and clarity in the assessment process, but they were not themselves quantified (Table 1). A total of 89 researchers participated in this evaluation, categorised according to their area of expertise: terrestrial (n = 33), marine (n = 28) and freshwater (n = 28) bioinvasions. Participants assessed the strengths, weaknesses, opportunities and threats of each practice using a seven-point scale (1 to 7) in an online survey administered via Google Forms. Detailed information about the survey structure is provided in Suppl. material 1: appendix S3.

Table 1. A detailed description of the six good practices included in the TRACKS framework, along with the corresponding indicators used for the quantitative evaluation within each SWOT category.

TRACKS	S - Strengths	W - Weaknesses	O - Opportunities	T - Threats
GP1. Tracking NIS in biodiversity data collections: All research groups involved in collecting data on species abundance and/or distribution are encouraged to verify the presence of NIS (Non-Indigenous Species) among the species in their study, ensuring correct identification at the lowest taxonomic level for all species in a fully sampled community.	S1: Growing scientific interest in NIS	W1: Shortage of taxonomists in Italy	O1: Increasing importance of NIS data for management and monitoring	T1: Risk of misidentification of NIS due to lack of expertise
	S2: Existing data on species abundance and distribution	W2: Inaccessible datasets.	O2: Opportunities for research collaborations	
	S3: Existing taxonomic expertise in Italy	W3: Variability across data sources		
GP2. Reference protocols for NIS data collection: For NIS data collection, it is recommended to adhere to established protocols when available. To facilitate this, it would be valuable to create a national list of reference protocols for NIS data collection.	S1: Available protocols for specific habitats and taxa	W1: Missing protocols for several NIS	O1: Positive sinergies with data collection	T1: Risk of errors in protocol implementation
		W2: Reluctance to adapt practices	O2: Enhanced use of NIS data for monitoring and research	
GP3. Active participation: When appropriate, the potential contribution of local communities to NIS data collection through participatory actions and citizen science (CS) should be evaluated. The Local Ecological Knowledge (LEK) method, which utilizes the knowledge and observations of local communities, is currently applied only in marine environments. It is suggested to expand and experiment with this approach in terrestrial and freshwater environments as well.	S1: Existing protocols and networks for CS and LEK	W1: Clear taxonomic limitations.	O1: CS and LEK expand spatial/temporal coverage of monitoring and improve early detection	T1: Risk of misinformation due to conflicts of interest
	S2: Active community groups (e.g., fishermen, nature associations)	W2: Limited ability to generate quantitative data	O2: Strengthening partnerships for monitoring	T2: Risk of inaccurate taxonomic identification if NIS data are not properly validated
	S3: Active social media platforms and networks	W3: Need for data validation		
		W4: Reluctance from some stakeholders		
GP4. Collaboration and FAIR principles: The national scientific community should be encouraged to share and promote NIS data through best practices in Open and FAIR (Findable, Accessible, Interoperable, Reusable) Science. This can be achieved by highlighting the advantages of these practices and the associated tools in various research contexts through communication activities such as seminars, workshops, institutional training, and university courses.	S1: Scientific community increasingly recognize the value of NIS data	W1: Lack of knowledge on how to produce shareable data	O1: Shared databases enhance collaboration and the potential to access to international funds and projects	T1: Limited external threats
	S2: Alignment with international Open Science standards	W2: Reluctance due to competition and data ownership concerns		
		W3: Lack of expertise in FAIR data management		
GP5. Knowledge hub for NIS data: Given the large volume of NIS data generated nationally, the development of an open-access reference repository to consolidate this information would be highly beneficial.	S1: Low initial cost using existing tools	W1: Need to align with international systems	O1: Fosters collaboration and improves NIS data management	T1: Risk of erroneous data being entered into the repository
	S2: National data could be consolidated in one location	W2: Long-term funding and maintenance issues	O2: Contributes to international databases	T2: Risk of increased competition could lead to conflicts among research groups
		W3: Rapid obsolescence of the system		
GP6. Strategic communication: Data collected, along with accompanying video/photo documentation, can be leveraged in communication efforts on biological invasions at all levels. This would help raise awareness and increase the involvement of local communities in participatory research and monitoring activities.	S1: A general media's receptiveness to NIS issues	W1: Many researchers lack communication skills and/or are not interested in communication	O1: Increased public awareness should facilitate management actions on NIS	T1: Overly alarmist communication could backfire
	S2: Visual content enhances public engagement via social media	W2: Limited potential of engagement with small, not conspicuous NIS species	O2: Synergies with CS and LEK for long-term engagement of local communities	T2: Misuse or politicization of scientific content, with manipulations of messages related to NIS

Data analysis

We aggregated the scores for the Strengths and Weaknesses and for the Opportunities and Threats, of each good practice, into two quantitative scores (hereinafter named "SW" for strengths and weaknesses and "OT" for opportunities and threats), following the approach of Scolozzi et al. (2014). Namely, for each good practice, we calculated SW final scores by subtracting the score assigned to weaknesses from the score assigned to strengths. Similarly, we calculated OT final scores by subtracting the score assigned to threats from those assigned to opportunities.

This resulted in six SW and six OT final scores, two for each good practice. Each score reflected the comprehensive assessment of strengths, weaknesses, opportunities and threats, using a bipolar scale that ranged from -7 ("Not important at all") to +7 ("Extremely important"). We divided our data analysis into three different steps. First, we employed cross-plots, to visually assess the level of agreement amongst experts on each of the six good practices, showing the mean as well as the first and third quartiles of SW and OT scores. Moreover, we used Partitioning Around Methods (PAM, Kassambara (2017)) cluster analysis to identify homogeneous groups of experts, based on the SW and OT scores assigned to the six good practices. This method was chosen due to its robustness against non-normality in the data, compared to conventional k-means clustering. The optimal number of clusters was assigned by graphically exploring the average silhouette width, the gap statistics and the within-cluster sum of squares (Kassambara 2017). Once the groups of respondents were identified, we tried to understand their nature, by comparing SW and OT scores and by checking their professional background.

Finally, we used the Kruskal-Wallis test to check for significant differences in the SW and OT scores assigned to each good practice, amongst experts working mostly on terrestrial, freshwater or marine ecosystems. Statistical analysis was carried out through the software R version 4.4.2 (R Core Team 2025) and the cluster analysis with the "cluster" package (Maechler 2019).

Results

TRACKS: Six good practices to improve NIS research under a SWOT framework

The consensus-driven process illustrated in Fig. 1 led to the identification of six good practices and 49 associated key indicators (Table 1). These indicators were categorised within each practice and mapped across the four SWOT components, capturing both internal and external factors that influence the effectiveness of each measure.

Numerical evaluation of SWOT

The analysis of crossplots indicated a good agreement about the six good practices amongst experts working on terrestrial, freshwater and marine NIS (Fig. 2). All three groups of experts evaluated the six good practices positively, in terms of their strengths and opportunities. However, evaluations of the SW component were more uncertain than those of the OT component (Fig. 2). Experts working on freshwater NIS were slightly more uncertain in their evaluation of SW and OT scores. This uncertainty is mainly related to GP3. Active participation, which involves the use of Citizen Science (CS) and Local Ecological Knowledge (LEK) for monitoring NIS and to the GP5. Knowledge hub for NIS data, which imply the development of an open-access reference repository to consolidate NIS-related information.

The cluster analysis identified two groups of experts (Suppl. material 1: figs S1, S2). These two groups were rather homogeneous in their composition, in terms of experts working with terrestrial NIS (43.4% vs. 44.1%), with most of their differences being limited to SW and OT scores (Fig. 3) and in the proportion of experts working on freshwater (32.6% vs. 16.2%) and marine (23.9% vs.

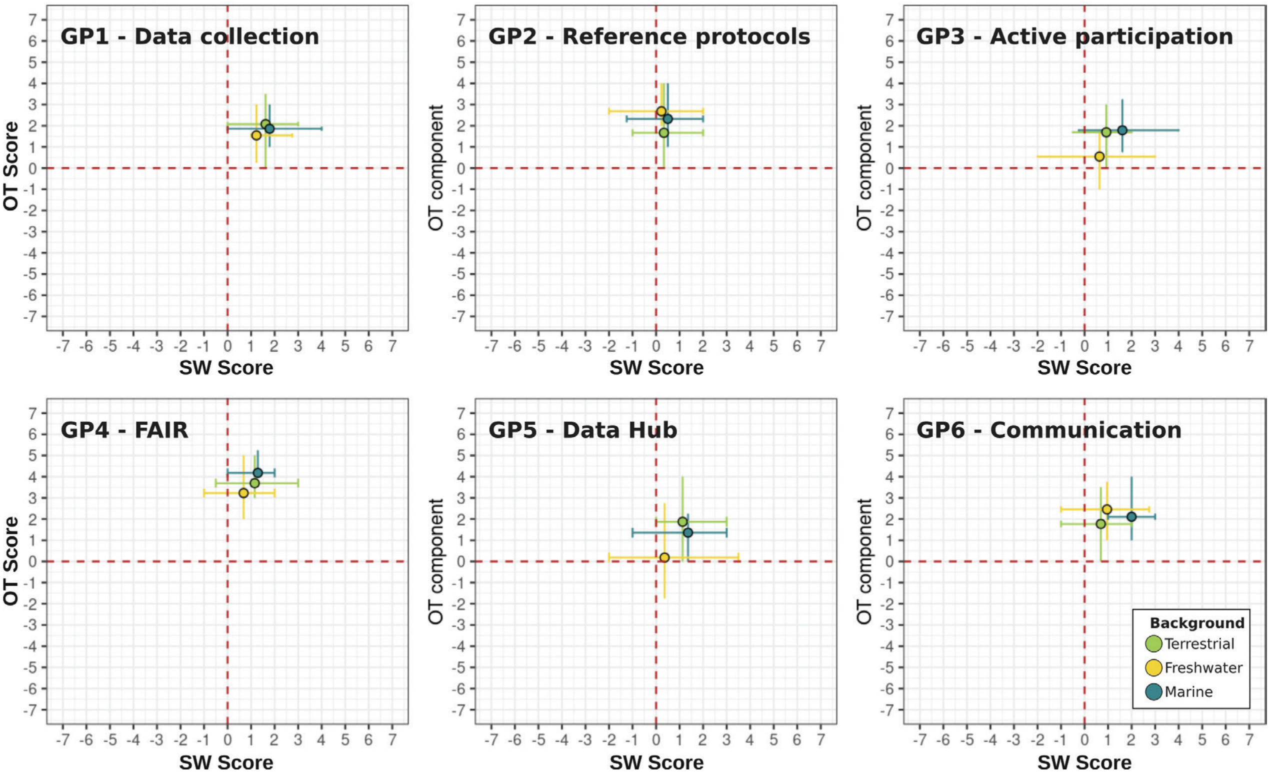

Figure 2. Distribution of Strengths and Weaknesses (SW) and Opportunities and Threats (OT) scores. Scores were calculated for NIS experts with three different backgrounds (Terrestrial, Freshwater, Marine) across the six good practices. Horizontal bars represent the SW component, ranging from negative values (weaknesses) to positive values (strengths), whereas vertical bars represent the OT score, ranging from negative values (threats) to positive values (opportunities). Points represent each group in terms of its arithmetic mean for the SW and OT scores, while bars represent the first and third quartile of SW and OT scores.

39.5%) NIS. Namely, one group of experts assigned higher SW and OT scores to the development of a centralised repository for NIS data (GP5, Fig. 3) and to the communication about NIS risk to people (GP2, Fig. 3).

The Kruskall-Wallis test did not highlight any significant difference in SW and OT scores for the six good practices between expert groups (Suppl. material 1: figs S3, S4).

Discussion

As in other fields of ecological science, NIS research depends heavily on key aspects that form a common foundation and efforts to identify and establish a shared set of good practices are increasingly promoted by the scientific community (e.g. Groom et al. (2017)). Current challenges often stem from existing heterogeneous data collection methods and workflows, as well as from different scientific practices of bioinvasion researchers (Tedersoo et al. 2021). Defining a focused set of good practices can guide strategies, streamline workflows and enhance communication and knowledge sharing. This effort is further strengthened by a structured and transparent assessment of these practices, which provides a detailed framework for their evaluation in the context of NIS research.

While we acknowledge that the proposed practices are not exhaustive, the SWOT analysis and its quantitative assessment indicate that the TRACKS approach is applicable across terrestrial, marine and freshwater ecosystems, with strong consensus amongst bioinvasion experts.

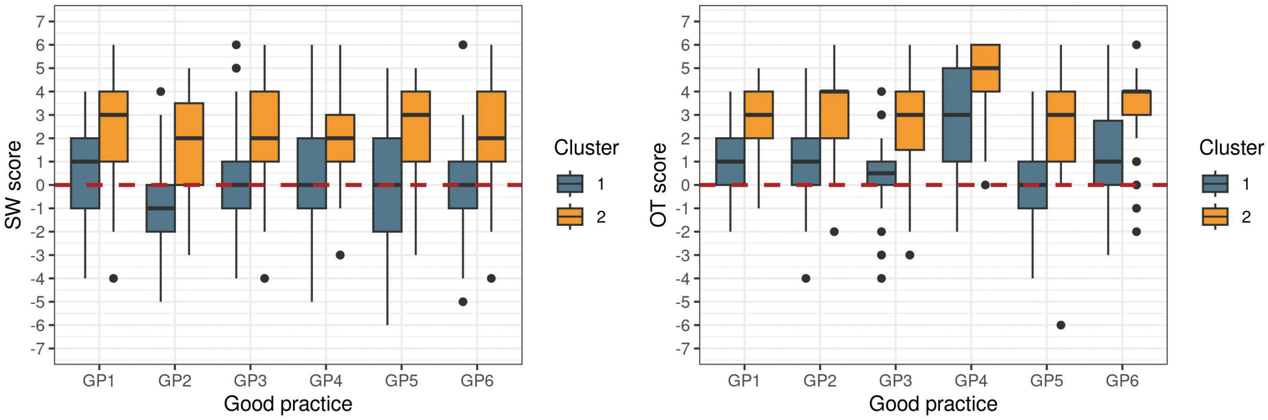

Figure 3. Distribution of Strengths and Weaknesses (SW) and Opportunities and Threats (OT) scores. Differences between the two groups of experts (blue and orange) identified through cluster analysis, for the six good practices.

The analysis of Strengths captured existing assets and capabilities, while Weaknesses highlighted critical limitations potentially hindering implementation or requiring improvement. Opportunities identified external trends and potential synergies favouring adoption, whereas Threats recognised possible challenges necessitating mitigation actions.

In the following sections, we provide a comprehensive discussion of each of the six identified good practices and we discuss how future research could be employed to evaluate their effectiveness.

GP1 - Tracking NIS in data collections

Good Practice 1 encourages research groups already collecting biodiversity data to verify and report NIS occurrences. This approach would imply the need for an accurate identification of NIS at the lowest taxonomic level, contributing to a more comprehensive understanding of sampled communities.

According to our experts, GP1 is characterised by significant strengths and opportunities that could facilitate its adoption by the scientific community, with only minor differences across terrestrial, marine and freshwater ecosystems. This likely reflects the growing interest in NIS ecology and evolution (Campbell and Simberloff 2022; Gozlan et al. 2024), as well as the increasing recognition of NIS monitoring in national and international policy frameworks (Genovesi et al. 2015; Essl et al. 2020; but see also Lenzner et al. (2024)). However, some emerging drawbacks, such as the progressive loss of fieldwork experience amongst ecologists (Soga and Gaston 2025) and more specifically the shortage of trained taxonomists, remains a critical barrier to the accurate identification of NIS. This shortfall increases the risk of misidentification, particularly for certain taxonomic groups (Golo et al. 2023) and it is shared across countries in all fields of conservation science (Agnarsson and Kuntner 2007; Engel et al. 2021; Löbl et al. 2023). In Italy, this shortage may be further exacerbated by long-standing cuts in public research funding and its disproportionate impact on the scientific sector compared to other European countries (Viesti 2018).

Addressing the challenge of a correct NIS identification requires stronger collaboration amongst research institutions to train a new generation of taxonomists. This could be achieved through dedicated courses, workshops and summer schools, co-organised with environmental agencies and supported by diverse funding sources. Additionally, systematic searches for species already present in neighbouring countries should be promoted. These efforts should also extend to the emerging field of DNA barcoding, which holds great promise for improving NIS identification (Antil et al. 2023).

A strategic implementation of GP1 would help overcome the limited knowledge of NIS distribution and significantly contribute to the development and dissemination of large-scale distribution maps for NIS in Italy and surrounding regions (Magliozzi et al. 2022, 2024; Petrosyan et al. 2023). Implementing GP1 will require a strong collaboration amongst specialised research groups, bioinvasion experts and taxonomists, ideally coordinated through a structured, long-term national programme. Such a programme should promote standardised data collection protocols, ensure long-term monitoring and facilitate the integration of regional datasets into interoperable, FAIR-compliant repositories, as highlighted in GP4. In this way, Italy or other countries could move towards a more comprehensive, transparent and responsive system for tracking NIS across natural ecosystems.

GP2 - Reference protocols for NIS data collection

For NIS data collection, Good Practice 2 recommends following established protocols whenever available. To support this effort, building a national repository of reference protocols for NIS monitoring would be highly valuable. Data collection is a fundamental component of any management strategy for NIS and IAS (Blossey 1999; Mehta et al. 2007) and its standardisation is a prerequisite for large-scale data collection initiatives in ecology and in environmental sciences (Kissling et al. 2018). The use of standardised protocols for data collection paves the way for the creation of synergies between biodiversity researchers and experts in data warehousing and data science (Farley et al. 2018) and will increase the use of NIS data in research, for example, in studies about global change or biogeography, due to their inclusion in large and freely accessible global biodiversity data infrastructures, such as GBIF (https://www.gbif.org/).

For many animal and plant species covered by the Habitats Directive (92/43/EEC), the Water Framework Directive (2000/60/EC) and the Marine Strategy Framework Directive (2008/56/EC), monitoring protocols already exist. In Italy, significant efforts have been made in this direction: collaboration amongst leading scientific societies and national experts has led to the development of protocols for more than 300 taxa, including 117 plant and 215 animal species (Ercole et al. 2016; Stoch and Genovesi 2016). Although primarily developed for native species, many of these protocols can be adapted to NIS that are taxonomically or ecologically similar to native taxa. However, they do not cover the full spectrum of NIS and the development of comprehensive monitoring programmes, especially for the early detection of NIS, remains an open issue. Based on these premises, our expert discussion identified three main challenges to the fulfilment of GP2. The first concerns the need to update existing protocols (Ercole et al. 2016; Stoch and Genovesi 2016). In Italy, for instance, it will be important to include NIS that have been recently reported, as well as species with a high likelihood of future introduction (e.g. Mammals: Bertolino et al. (2020); marine NIS; Tsiamis et al. (2020)). Secondly, it will be important to standardise reference protocols across taxa, to ensure that NIS records are collected according to consistent quality standards. This is crucial because different taxonomic groups are often monitored by experts with diverse approaches to species identification and to the collection of data and metadata. Finally, efforts should be made to refine and promote reference protocols to ensure that they are accessible, clear and usable by a wide range of stakeholders with different levels of expertise and digital literacy. If protocols are ambiguous, user-unfriendly or unintuitive, their adoption is likely to remain limited.

Particular attention should also be given to monitoring NIS introduction gateways, such as ports, airports, nurseries, garden centres, aquaculture facilities and bivalve shellfish purification and expedition centres, to promptly detect new introductions (Pace et al. 2022). In Europe, the Marine Strategy Framework Directive 2008/56/EC has already adopted this approach by carrying out monitoring for Descriptor 2 (NIS) in areas with a higher risk of introduction, such as ports of international economic importance and mussel farms (ISPRA 2020). Moreover, according to Regulation 708/2007/EC, following an introduction of NIS or non-routine translocation for aquaculture purposes, a monitoring plan is defined by the competent authority, in order to assess whether the impacts were accurately predicted or if there are additional or different impacts on susceptible habitats. The plan lasts two years or a full generation cycle, whichever is longer. It is carried out by the applicant and can involve other stakeholders, such as environmental agencies, fishermen and angling associations. This need calls for training initiatives aimed at diffusing protocols for data collection outside the research community, by involving technicians working in aquaculture facilities, plant nurseries or garden centres.

GP3 - Active participation

Our expert panel emphasised that data from Citizen Science (CS) and Local Ecological Knowledge (LEK) initiatives offer significant strengths and opportunities, which would support their broader adoption in bioinvasion research. Recent guidelines on the use of these approaches for NIS have also been published (e.g. Alien 2023). Both CS and LEK have proven to be valuable sources of information due to their ability to increase spatial coverage and improve early detection of NIS (Pocock et al. 2024). Several studies have shown that integrating official records with CS data can help create more accurate representations of the invaded range of NIS (e.g. for plants, Crall et al. (2015); Gervazoni et al. (2023); e.g. for insects, Maistrello et al. (2018)), predict the environmental suitability of invaded habitats (Di Febbraro et al. 2023) and support management and eradication efforts (Leza et al. 2020).

At the European level, González-Moreno et al. (2025) compared official databases with CS platforms in their ability to report first records of NIS and found that CS platforms reported new NIS earlier than official sources in 20% of cases and within the same year in another 30%. Furthermore, CS initiatives and the involvement of local communities can help strengthen relationships between the scientific community and stakeholders (Encarnação et al. 2020; Pocock et al. 2024; Roy et al. 2024). Nowadays, the use of data from CS is facilitated and promoted by the existence of established practices, active communities and dedicated platforms (e.g. iNaturalist.org). Finally, the use of smartphones and specific apps has significantly enhanced citizen engagement and increased both volume and spatiotemporal coverage of data on NIS occurrences (Howard et al. 2022). This phenomenon is amplified by the widespread use of social media platforms, such as Facebook, Instagram and TikTok, which have proven to be valuable tools for collecting records of animals and plants, including NIS (Chowdhury et al. 2024). A step towards the standardisation of such procedures in Italy is represented by the National Guidelines for the Collection, Validation and

Transmission of Data on IAS of EU Relevance under EU Regulation 1143/14, which has been enacted in Italy through Legislative Decree No. 12/2022. Similar actions can be also undertaken at the local regional level (Bonacito et al. 2024).

Regarding the weaknesses of CS and LEK data, both approaches are more easily applied to taxa that are easier to observe and identify (Callaghan et al. 2021; Knape et al. 2022). As a result, they tend to under-represent important, but less conspicuous NIS, such as small or unattractive species. For instance, Price-Jones et al. (2022) noted a significant rise in CS projects related to NIS in Europe and found that most of these focused on plants and insects, likely due to their accessibility and prevalence in urban areas, while birds and other groups remained under-represented. Similar imbalances can be observed in the marine environment, where most actions primarily target NIS megafauna, particularly fishes (Azzurro et al. 2019). Another weakness is the relatively low potential of CS and LEK data to provide quantitative information, such as species abundance, although they can effectively capture site occupancy, which has long been recognised as a proxy for abundance (Gaston et al. 2000; Steenweg et al. 2018; Price-Jones et al. 2022). Our expert evaluation suggested that future research should explore these elicitation methods across all natural ecosystems where human interaction occurs. Moreover, protocols such as IDEA (Hemming et al. 2018) could be adapted to involve citizen scientists and local communities in probabilistic assessments of NIS occurrence. The main risks associated with CS and LEK relate to the lack of rigorous validation, particularly when not supported by collaboration with taxonomists, as recommended by GP1 and GP2. Misidentified records may compromise the reliability of scientific conclusions, as well as the performance of algorithms used for image classification and the automated integration of new data (Koch et al. 2023). For this reason, robust validation systems in CS and LEK projects are increasingly adopted (Price-Jones et al. 2022).

GP4 - Collaboration and FAIR principles

Experts emphasised the importance of sharing NIS data within the scientific community, through the adoption of Open Science practices and FAIR (Findable, Accessible, Interoperable, Reusable) principles, recognising their benefits in various research contexts. Aligning with FAIR principles (Wilkinson et al. 2016) and Open Science practices (Groom et al. 2017) goes well beyond academic interest, being essential for providing information for evidence-based decisions by environmental managers and policy-makers (Groom et al. 2015; Reyserhove et al. 2020). GP 4 received the highest Opportunities and Threats (OT) score amongst the evaluated good practices (Fig. 2 and Suppl. material 1: fig. S4), demonstrating the considerable opportunities deriving from data sharing and the growing awareness amongst conservationists and researchers working on bioinvasions about this topic. Data sharing enhances the visibility of results within the scientific community, increases citation rates (Leimu and Koricheva 2005; Tahamtan et al. 2016) and promotes the reuse of data beyond the scope of the original collection and publication (Wallace et al. 2020; Wallace et al. 2021; Bertram et al. 2023). On the contrary, NIS data that are not shared tend to have a short life cycle, which ends soon after publication.

A key strength of this good practice lies in the availability of well-established quality standards about the creation and publication of biodiversity datasets (Sequeira et al. 2021), which increasingly serve as a foundation for harmonised data management in conservation science. Scholars and data managers working on NIS are actively engaged in the development, enhancement and adoption of community-agreed standards (Wallace et al. 2020). These include shared terminologies (Groom et al. 2019a; Soto et al. 2024; Vilizzi et al. 2025), data and metadata schemas (Groom et al. 2017), workflows (Reyserhove et al. 2020; Seebens et al. 2020; Seebens and Kaplan 2022) and canonical repositories for long-term storage (Pagad et al. 2022). Amongst these, Darwin Core stands out as a widely adopted standard for publishing and integrating biodiversity information, including controlled vocabularies for NIS/IAS research (Wieczorek et al. 2012; Groom et al. 2019b). The adoption of such standards in European Commission-funded projects (Open Research Europe 2022) underscores their pivotal role in promoting collaborative research, data interoperability and long-term stewardship.

The most significant potential weakness of data sharing includes researchers' reluctance to share data, due to competition between research teams. In the case of NIS, it is crucial to emphasise that any newly-recorded species should be reported immediately upon detection, without waiting for the formal publication process, particularly for species of Union concern.

Delayed reporting not only reduces the likelihood of successful eradication, but also significantly increases costs (Genovesi et al. 2024) and may even result in infringement proceedings at the EU level. Researchers must, therefore, recognise the urgency of promptly sharing NIS data as part of their contribution to biodiversity conservation (Groom et al. 2015). The adoption of FAIR principles and Open Science practices further supports this process by ensuring proper citation and, thus, recognition for the researchers who share their data, as well as facilitating reuse through the assignment of persistent identifiers (e.g. DOIs) and licences that clearly define permitted uses.

GP5 - Knowledge Hub for NIS Data

As revealed by the results of Survey 1, a substantial volume of NIS data is generated at the national level, but remains fragmented across various databases and repositories. This issue is common across multiple disciplines, including ecology, forestry, microbiology, humanities and social sciences (Hampton et al. 2013; Tedersoo et al. 2021). In light of these findings, the expert panel proposed the development of an open-access reference repository to consolidate this information, a measure considered highly beneficial to NIS research. The practice received high scores in both the Strengths and Weaknesses (SW) and Opportunities and Threats (OT) assessments, particularly amongst one of the two identified clusters of bioinvasion experts (Fig. 3). This outcome underscores the widespread need for a centralised system to store, preserve, access and disseminate up-to-date NIS information, a need already expressed or attempted by other authors (e.g. Haubrock et al. (2023); Onley et al. (2025)).

Despite existing challenges, the development of a centralised, open-access repository presents numerous strengths and opportunities, making it both feasible and attractive to the bioinvasion research community. Its implementation could be anchored to international platforms, such as the Global Invasive Species Database (https://www.iucngisd.org/gisd/) or built upon existing national databases. In the case of Italy, a national IAS database is currently available (https://www.specieinvasive.isprambiente.it/ricerca-db-italia), along with the Register of Alien Species in Aquaculture (https://www.registro-asa.it/), developed in accordance with EC Regulation No. 708/2007 under the Ministry of Agriculture, Food Sovereignty and Forests. Generally speaking, the implementation of a national database to be used as a reference repository requires close collaboration amongst all research institutions working on NIS, with the support of national digital research infrastructures (Colangelo et al. 2017; Di Muri et al. 2023).

An alternative, bottom-up approach, is to aggregate georeferenced records of NIS occurrences into open-access platforms, which help tracking NIS across national borders (e.g. ORMEF - Occurrence Records of Mediterranean Exotic Fishes (www.ormef.eu, see Azzurro et al. (2024b)). The aggregation of georeferenced records from different research groups would be particularly advantageous to centralise NIS data in countries of the Global South, where the digitalisation of biodiversity data is still limited (García-Roselló et al. 2023). Nevertheless, reference repositories should be designed to ensure their interoperability with major international databases, such as GBIF Global Biodiversity Information Facility (https://www.gbif.org/), an aspect that would minimise conflicts of interest amongst research groups by providing a neutral, third-party-managed platform.

The weaknesses and threats associated with GP5 require to be carefully addressed. Meeting international data quality standards (Wieczorek et al. 2012; Chapman et al. 2020) and ensuring the long-term sustainability of a central database in terms of funding and maintenance remain major challenges. Establishing a pipeline for data centralisation and validation will require the formation and continuous support of a network of expert taxonomists, who must also be trained to use the system effectively. Maintaining this network is essential to prevent the inclusion of erroneous records and will depend on stable, long-term funding.

Furthermore, it is crucial that the national repository is designed to support the rapid communication of new NIS records, encouraging researchers to report data promptly rather than waiting for their formal publication (Genovesi et al. 2024). Timely reporting to the Ministries of Environment and Agriculture, ISPRA and Regional Administrations is particularly critical for IAS of Union Concern under EU Regulation 1143/2014, which requires the implementation of eradication or management measures upon detection.

GP6 - Strategic communication

Communication activities and awareness campaigns are commonly linked to NIS research (Haley et al. 2023), serving as vital tools to prevent new introductions (García-Llorente et al. 2008), mitigate the negative effects of invasions (Roy et al. 2024) and address potential conflicts that may arise (Novoa et al. 2017; Biasetti et al. 2021). The media are highly receptive towards biological invasions, particularly for certain taxonomic groups (e.g. terrestrial vertebrates, Lioy et al. (2019)), although sometimes with some distortions (Woodworth et al. 2023; Wong 2024). Therefore, our panel of experts highly ranked the idea of promoting communication on NIS.

To maximise effectiveness, communication messages should be positive yet realistic, aiming at informing rather than at persuading citizens (Blastland et al. 2020), emphasising the active role they can play.

Amongst the strengths of this good practice, experts highlighted that existing voluntary codes of conduct, targeted at different stakeholders and activities potentially linked to NIS introductions (e.g. angling, boating, horticulture, pets, aquaria), are particularly valuable tools to facilitate proactive citizen engagement. Today, several EU-funded projects (e.g. CSMON-Life, https://www.csmon-life.eu/; Life ASAP, https://lifeasap.eu/index.php/it/; Alien CSI, https://www.ceh.ac.uk/our-science/projects/alien-csi-about-action) successfully employ the 'bioblitz' method of participatory activities involving both citizens and researchers in identifying species within a defined area and timeframe, typically 24 hours (Schofield 2020). Such initiatives effectively raise public awareness about biological invasions and have successfully led to the detection of new NIS occurrences (Meeus et al. 2023). The main weaknesses of this proposal are related to the fact that invasion biologists may lack communication skills or interest in public outreach. Therefore, collaboration with communication professionals, many of whom already work within scientific institutions across Italy, is essential. Communication experts can strategically enhance outreach campaigns in two critical ways: first, by raising awareness about the importance of reporting and monitoring smaller, less charismatic NIS, which typically receive limited public attention and are under-reported; second, by employing communication skills to prevent overly alarmist messaging that can discourage public engagement and potentially result in unintended negative consequences.

Risks associated with this activity were also discussed. If messages are not effectively communicated or reach the wrong audience, especially since different stakeholder groups may hold contrasting views on NIS, they can become counterproductive, wasting resources or even triggering behavioural changes that exacerbate the problem or provoke backlash (revised by Haley et al. (2023)). Expert-guided communication strategies can also help prevent the politicisation of NIS and related monitoring efforts, which are sometimes misleading or instrumentally framed (Ernwein and Fall 2015; Chinn et al. 2024; Reeb and Heberling 2024) and the decision to perform a public awareness campaign should be made after a process of thoughtful consideration.

Conclusions

In this study, we identified six good practices that can enhance both the processes and outcomes of NIS research. These practices aim to improve how researchers collect, manage and share data, as well as how they engage and inform the public. They were derived from and quantitatively evaluated through the contributions of a large and diverse group of NIS experts working across terrestrial, freshwater and marine realms.

As these experts operate in highly diverse contexts, addressing a wide range of taxa, habitats and methodological approaches, the resulting practices can be intended as general guidelines. They are broadly applicable across different settings, while recognising their respective strengths, weaknesses, opportunities and threats. Importantly, they are not meant to overlap with or replace existing guidelines, which are often tailored to specific taxa or ecosystems. Instead, they are designed to support all research groups collecting NIS data, including those without a primary focus on NIS, but whose work could nonetheless provide valuable information on NIS occurrence, abundance and distribution.

We expect that this synthesis will stimulate broader debate within the scientific community on how to improve NIS research and future monitoring programmes. Furthermore, it may foster methodological harmonisation and stronger integration amongst research groups with diverse expertise, ranging from taxonomists, fisheries and aquaculture biologists and veterinarians to specialists in agricultural entomology and public health, all of whom play critical roles in advancing NIS research.

Such integration would help bridge the cultural and operational divide between terrestrial and aquatic systems, reduce fragmentation amongst researchers and strengthen collective capacity to effectively investigate NIS and respond to rapidly changing ecosystems.

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

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Author contributions

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Data availability

The data, altogether with a README file, have been already uploaded on Open Science Framework at the link: https://osf.io/sf3ag/overview. Data have been archived under the CC BY 4.0 NC ND license and are fully available.

References

Agnarsson I, Kuntner M (2007) Taxonomy in a changing world: Seeking solutions for a science in crisis. Systematic Biology 56: 531–539. https://doi.org/10.1080/10635150701424546

Alien CSI (2023) Using citizen science with alien species: a practical guide for project initiators. Available under Creative Commons Zero Universal licence. https://doi.org/10.5281/zenodo.7521429

Antil S, Abraham JS, Sripoorna S, Maurya S, Dagar J, Makhija S, Bhagat P, Gupta R, Sood U, Lal R, Toteja R (2023) DNA barcoding, an effective tool for species identification: A review. Molecular Biology Reports 50: 761–775. https://doi.org/10.1007/s11033-022-08015-7

Azzurro E, Sbragaglia V, Cerri J, Bariche M, Bolognini L, Ben Souissi J, Busoni G, Coco S, Chryssanthi A, Fanelli E, Ghanem R, Garrabou J, Gianni F, Grati F, Kolitari J, Letterio G, Lipej L, Mazzoldi C, Milone N, Pannacciulli F, Pešić A, Samuel-Rhoads Y, Saponari L, Tomanic J, Topçu NE, Vargiu G, Moschella P (2019) Climate change, biological invasions, and the shifting distribution of Mediterranean fishes: A large-scale survey based on local ecological knowledge. Global Change Biology 25: 2779–2792. https://doi.org/10.1111/gcb.14670

Azzurro E, Bahri T, Valbo-Jørgensen J, Ma X, Strafella P, Vasconcellos M [Eds] (2024a) Fisheries responses to invasive species in a changing climate – Lessons learned from case studies. FAO. Fisheries Technical Paper, No. 704. Rome, FAO. https://doi.org/10.4060/cd1400en

Azzurro E, D'Amen M, Chiappi M, Ferri F, Grifoni P, Napoli E, Luna GM, Strafella P, Smeraldo S, Biancone N (2024b) ORMEF: A geospatial web platform for mapping and visualizing exotic fish records in the Mediterranean and surrounding seas. Management of Biological Invasions: International Journal of Applied Research on Biological Invasions 15(4): 601–616. https://doi.org/10.3391/mbi.2024.15.4.09

Bellard C, Genovesi P, Jeschke JM (2016) Global patterns in threats to vertebrates by biological invasions. Proceedings. Biological Sciences 283: 20152454. https://doi.org/10.1098/rspb.2015.2454
Benzaghta MA, Elwalda A, Mousa MM, Erkan I, Rahman M (2021) SWOT analysis applications: An integrative literature review. Journal of Global Business Insights 6(1): 54–72. https://doi.org/10.5038/2640-6489.6.1.1148
Bertolino S, Ancillotto L, Bartolommei P, Benassi G, Capizzi D, Gasperini S, Lucchesi M, Mori E, Scillitani L, Sozio G, Falaschi M, Ficetola GF, Cerri J, Genovesi P, Carnevali L, Loy A, Monaco A (2020) A framework for prioritising present and potentially invasive mammal species for a national list. NeoBiota 62: 31–54. https://doi.org/10.3897/neobiota.62.52934
Bertram MG, Sundin J, Roche DG, Sánchez-Tójar A, Thoré ES, Brodin T (2023) Open science. Current Biology 33: R792–R797. https://doi.org/10.1016/j.cub.2023.05.036
Biasetti P, Ferrante L, Bonelli M, Manenti R, Scaccini D, de Mori B (2021) Value-conflicts in the conservation of a native species: A case study based on the endangered white-clawed crayfish in Europe. Rendiconti Lincei. Scienze Fisiche e Naturali 32: 389–406. https://doi.org/10.1007/s12210-021-00987-1
Blastland M, Freeman AL, van der Linden S, Marteau TM, Spiegelhalter D (2020) Five rules for evidence communication. Nature 587: 362–364. https://doi.org/10.1038/d41586-020-03189-1
Blossey B (1999) Before, during and after: The need for long-term monitoring in invasive plant species management. Biological Invasions 1: 301–311. https://doi.org/10.1023/A:1010084724526
Bonacito C, Massara M, Rizzioli B (2024) Strategia regionale di contrasto alle specie esotiche invasive. Settore "Sviluppo sostenibile, biodiversità e aree naturali" della Regione Piemonte. https://www.regione.piemonte.it/web/sites/default/files/media/documenti/2024-09/STRATEGIA_IAS_PIEMONTE.pdf
Burbidge AH, Maron M, Clarke MF, Baker J, Oliver DL, Ford G (2011) Linking science and practice in ecological research and management: How can we do it better? Ecological Management & Restoration 12(1): 54–60. https://doi.org/10.1111/j.1442-8903.2011.00577.x
Byers JE, Reichard S, Randall JM, Parker IM, Smith CS, Lonsdale WM, Atkinson IAE, Seastedt TR, Williamson M, Chornesky E, Hayes D (2002) Directing research to reduce the impacts of nonindigenous species. Conservation Biology: The Journal of the Society for Conservation Biology 16(3): 630–640. https://doi.org/10.1046/j.1523-1739.2002.01057.x
Callaghan CT, Poore AGB, Mesaglio T, Moles AT, Nakagawa S, Roberts C, Rowley JJL, Vergés A, Wilshire JH, Cornwell WK (2021) Three frontiers for the future of biodiversity research using citizen science data. Bioscience 71: 55–63. https://doi.org/10.1093/biosci/biaa131
Campbell SE, Simberloff D (2022) Forty years of invasion research: More papers, more collaboration... bigger impact? NeoBiota 75: 57–77. https://doi.org/10.3897/neobiota.75.86949
Chang HH, Huang WC (2006) Application of a quantification SWOT analytical method. Mathematical and computer modelling 43(1-2): 158–169. https://doi.org/10.1016/j.mcm.2005.08.016
Chapman AD, Belbin L, Zermoglio PF, Wieczorek J, Morris PJ, Nicholls M, Rees ER, Veiga AK, Thompson A, Saraiva AM, James SA, Gendreau C, Benson A, Schigel D (2020) Developing Standards for Improved Data Quality and for Selecting Fit for Use Biodiversity Data. Biodiversity Information Science and Standards 4: e50889. https://doi.org/10.3897/biss.4.50889
Chinn S, Hiaeshutter-Rice D, Hart PS, Larson BM (2024) Testing how militaristic and xenophobic language affects engagement with Facebook posts about invasive species. Environmental Communication 18: 351–357. https://doi.org/10.1080/17524032.2023.2267787
Chowdhury S, Ahmed S, Alam S, Callaghan CT, Das P, Di Marco M, Di Minin E, Jarić I, Labi MM, Rokonuzzaman M, Roll U, Sbragaglia V, Siddika A, Bonn A (2024) A protocol for harvesting biodiversity data from Facebook. Conservation Biology : The Journal of the Society for Conservation Biology 38: e14257. https://doi.org/10.1111/cobi.14257
Colangelo P, Fontaneto D, Marchetto A, Ludovisi A, Basset A, Bartolozzi L, Bertani I, Campanaro A, Cattaneo A, Cianferoni F, Corriero G, Ficetola GF, Nonnis-Marzano F, Pierri C, Rossetti G, Rosati I, Boggero A (2017) Alien species in Italian freshwater ecosystems: A macroecolog-

ical assessment of invasion drivers. Aquatic Invasions 12: 299–309. https://doi.org/10.3391/ai.2017.12.3.04

Convention on Biological Diversity (2019) Sixth national report for the Convention on Biological Diversity. https://chm.cbd.int/database/record?documentID=245699

Crall AW, Jarnevich CS, Young NE, Panke BJ, Renz M, Stohlgren TJ (2015) Citizen science contributes to our knowledge of invasive plant species distributions. Biological Invasions 17: 2415–2427. https://doi.org/10.1007/s10530-015-0885-4

Deriu I, D'Amico F, Tsiamis K, Gervasini E, Cardoso AC (2017) Handling Big Data of Alien Species in Europe: The European Alien Species Information Network Geodatabase. Frontiers in ICT (Lausanne, Switzerland) 4: 20. https://doi.org/10.3389/fict.2017.00020

Di Febbraro M, Bosso L, Fasola M, Santicchia F, Aloise G, Lioy S, Tricarico E, Ruggieri L, Bovero S, Mori E, Bertolino S (2023) Different facets of the same niche: Integrating citizen science and scientific survey data to predict biological invasion risk under multiple global change drivers. Global Change Biology 29: 5509–5523. https://doi.org/10.1111/gcb.16901

Di Muri C, Lazic T, Rosati I, Pierri C, Boggero A, Corriero G, Basset A (2023) Alien and native species in Italian marine and transitional waters. Biodiversity Data Journal 11: e101464. https://doi.org/10.3897/BDJ.11.e101464

Doley DM, Barman P (2023) Importance of communicating biodiversity for sustainable wildlife management: A review. Journal of Environmental Studies and Sciences 13: 321–329. https://doi.org/10.1007/s13412-023-00819-8

Domina G (2021) Invasive aliens in Italy: enumeration, history, biology and their impact. Invasive Alien Species: observations and issues from around the world 3: 190–214. https://doi.org/10.1007/s13412-023-00819-8

Encarnação J, Teodósio MA, Morais P (2020) Citizen science and biological invasions: A review. Frontiers in Environmental Science 8: 602980. https://doi.org/10.3389/fenvs.2020.602980

Engel MS, Ceríaco LMP, Daniel GM, Dellapé PM, Löbl I, Marinov M, Reis RE, Young MT, Dubois A, Agarwal I, Lehmann PA, Alvarado M, Alvarez N, Andreone F, Araujo-Vieira K, Ascher JS, Baêta D, Baldo D, Bandeira SA, Barden P, Barrasso DA, Bendifallah L, Bockmann FA, Böhme W, Borkent A, Brandão CRF, Busack SD, Bybee SM, Channing A, Chatzimanolis S, Christenhusz MJM, Crisci JV, D'Elía G, Da Costa LM, Davis SR, De Lucena CAS, Deuve T, Fernandes Elizalde S, Faivovich J, Farooq H, Ferguson AW, Gippoliti S, Gonçalves FMP, Gonzalez VH, Greenbaum E, Hinojosa-Díaz IA, Ineich I, Jiang J, Kahono S, Kury AB, Lucinda PHF, Lynch JD, Malécot V, Marques MP, Marris JWM, McKellar RC, Mendes LF, Nihei SS, Nishikawa K, Ohler A, Orrico VGD, Ota H, Paiva J, Parrinha D, Pauwels OSG, Pereyra MO, Pestana LB, Pinheiro PDP, Prendini L, Prokop J, Rasmussen C, Rödel MO, Rodrigues MT, Rodríguez SM, Salatnaya H, Sampaio Í, Sánchez-García A, Shebl MA, Santos BS, Solórzano-Kraemer MM, Sousa ACA, Stoev P, Teta P, Trape JF, Van-Dúnem Dos Santos C, Vasudevan K, Vink CJ, Vogel G, Wagner P, Wappler T, Ware JL, Wedmann S, Zacharie CK (2021) The taxonomic impediment: A shortage of taxonomists, not the lack of technical approaches. Zoological Journal of the Linnean Society 193: 381–387. https://doi.org/10.1093/zoolinnean/zlab072

Ercole S, Giacanelli V, Bacchetta G, Fenu G, Genovesi P [Eds] (2016) Handbooks for monitoring species and habitats of Community interest (Council Directive 92/43/EEC) in Italy: plant species. ISPRA, Series Handbooks and Guidelines, 140 pp.

Ernwein M, Fall JJ (2015) Communicating invasion: Understanding social anxieties around mobile species. Geografiska Annaler. Series B, Human Geography 97: 155–167. https://doi.org/10.1111/geob.12071

Essl F, Latombe G, Lenzner B, Pagad S, Seebens H, Smith K, Wilson JRU, Genovesi P (2020) The Convention on Biological Diversity (CBD)'s Post-2020 target on invasive alien species–

what should it include and how should it be monitored? NeoBiota 62: 99–121. https://doi.org/10.3897/neobiota.62.53972

European Commission (2014) Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species. Official Journal of the European Union, 2014; L317/35. (Nov 4, 2014). http://eur-lex.europa.eu/eli/reg/2014/1143/oj

European Commission (2020) EU Biodiversity Strategy for 2030. Bringing nature back into our lives. European Parliament resolution of 20 April 2012 on our life insurance, our natural capital: an EU biodiversity strategy to 2020 (COM/2020/ 380 final). https://eur-lex.europa.eu/resource.html?uri=cellar:a3c806a6-9ab3-11ea-9d2d-01aa75ed71a1.0001.02/DOC_1&format=PDF

Farley SS, Dawson A, Goring SJ, Williams JW (2018) Situating ecology as a big-data science: Current advances, challenges, and solutions. Bioscience 68: 563–576. https://doi.org/10.1093/biosci/biy068

García-Llorente M, Martín-López B, González JA, Alcorlo P, Montes C (2008) Social perceptions of the impacts and benefits of invasive alien species: Implications for management. Biological Conservation 141: 2969–2983. https://doi.org/10.1016/j.biocon.2008.09.003

García-Roselló E, González-Dacosta J, Lobo JM (2023) The biased distribution of existing information on biodiversity hinders its use in conservation, and we need an integrative approach to act urgently. Biological Conservation 283: 110118. https://doi.org/10.1016/j.biocon.2023.110118

Gaston KJ, Blackburn TM, Greenwood JJ, Gregory RD, Quinn RM, Lawton JH (2000) Abundance–occupancy relationships. Journal of Applied Ecology 37: 39–59. https://doi.org/10.1046/j.1365-2664.2000.00485.x

Genovesi P, Carboneras C, Vila M, Walton P (2015) EU adopts innovative legislation on invasive species: A step towards a global response to biological invasions? Biological Invasions 17: 1307–1311. https://doi.org/10.1007/s10530-014-0817-8

Genovesi P, Carnevali L, Hoffmann BD, Monaco A, Roy HE, Simberloff D (2024) Conservation action should come before publication. Current Biology 34: R49–R50. https://doi.org/10.1016/j.cub.2023.11.054

Gervazoni P, Minuti G, Fuentes-Rodriguez D, Coetzee J, Sosa A, Sabater L, Franceschini C (2023) Citizen science improves the known and potential distribution of a strong wetland invader: Implications for niche modeling and invasion management. Environmental Management 71: 1176–1187. https://doi.org/10.1007/s00267-023-01802-3

Gioia P (2010) Managing biodiversity data within the context of climate change: Towards best practice. Austral Ecology 35(4): 392–405. https://doi.org/10.1111/j.1442-9993.2010.02047.x

Golebie EJ, van Riper CJ, Arlinghaus R, Gaddy M, Jang S, Kochalski S, Lu Y, Olden JD, Stedman R, Suski C (2022) Words matter: A systematic review of communication in non-native aquatic species literature. NeoBiota 74: 1–28. https://doi.org/10.3897/neobiota.74.79942

Golo R, Vergés A, Díaz-Tapia P, Cebrian E (2023) Implications of taxonomic misidentification for future invasion predictions: Evidence from one of the most harmful invasive marine algae. Marine Pollution Bulletin 191: 114970. https://doi.org/10.1016/j.marpolbul.2023.114970

González-Moreno P, Anđelković AA, Adriaens T, Botella C, Demetriou J, Bastos R, Bertolino S, López-Cañizares C, Essl F, Fišer Ž, Glavendekić M, Herremans M, Hulme PE, Jani V, Katsada D, Kleitou P, La Porta N, Lapin K, López-Darias M, Lozano V, Martinou AF, Oldoni D, Per E, Rorke S, Roy HE, Schweinzer K-M, Swinnen K, Tricarico E, Vicente JR, de Groot M, Pocock MJO (2025) Citizen science platforms can effectively support early detection of invasive alien species according to species traits. People and Nature 7: 278–294. https://doi.org/10.1002/pan3.10767

Gozlan RE, Bommarito C, Caballero-Huertas M, Givens J, Mortillaro JM, Pepey E, Ralaiarison RP, Senff P, Combe M (2024) A One-Health approach to non-native species, aquaculture, and food security. Water Biology and Security 3: 100250. https://doi.org/10.1016/j.watbs.2024.100250

Gregory R, Failing L, Harstone M, Long G, McDaniels T, Ohlson D (2012) Structured Decision Making: A Practical Guide to Environmental Management Choices. Wiley-Blackwell, Oxford, UK. https://doi.org/10.1002/9781444398557

Groom QJ, Desmet P, Vanderhoeven S, Adriaens T (2015) The importance of open data for invasive alien species research, policy and management. Management of Biological Invasions: International Journal of Applied Research on Biological Invasions 6: 119. https://doi.org/10.3391/mbi.2015.6.2.02

Groom QJ, Adriaens T, Desmet P, Simpson A, De Wever A, Bazos I, Cardoso AC, Charles L, Christopoulou A, Gazda A, Helmisaari H, Hobern D, Josefsson M, Lucy F, Marisavljevic D, Oszako T, Pergl J, Petrovic-Obradovic O, Prévot C, Ravn HP, Richards G, Roques A, Roy HE, Rozenberg M-AA, Scalera R, Tricarico E, Trichkova T, Vercayie D, Zenetos A, Vanderhoeven S (2017) Seven recommendations to make your invasive alien species data more useful. Frontiers in Applied Mathematics and Statistics 3: 13. https://doi.org/10.3389/fams.2017.00013

Groom Q, Desmet P, Reyserhove L, Adriaens T, Oldoni D, Vanderhoeven S, Baskauf SJ, Chapman A, McGeoch M, Walls R, Wieczorek J, Wilson JRU, Zermoglio PFF, Simpson A (2019a) Improving Darwin Core for research and management of alien species. Science and Standards 3: e38084. https://doi.org/10.3897/biss.3.38084

Groom Q, Strubbe D, Adriaens T, Davis AJS, Desmet P, Oldoni D, Reyserhove L, Roy HE, Vanderhoeven S (2019b) Empowering citizens to inform decision-making as a way forward to support invasive alien species policy. Citizen Science: Theory and Practice 4(1): 1–11. https://doi.org/10.5334/cstp.238

Grünwald NJ, Bock CH, Chang JH, Alves De Souza A, Del Ponte EM, du Toit LJ, Dorrance AE, Dung J, Gent D, Goss EM, Lowe-Power TM, Madden LV, Martin FN, McDowell J, Naegele RP, Potnis N, Quesada-Ocampo LM, Sundin GW, Thiessen L, Vinatzer BA, Zeng Q (2024) Open access and reproducibility in plant pathology research: Guidelines and best practices. Phytopathology 114: 910–916. https://doi.org/10.1094/PHYTO-12-23-0483-IA

Gullison T, Hardner JJ, Anstee S, Meyer M (2015) Good practices for the collection of biodiversity baseline data. Business and Biodiversity Offsets Programme (BBOP), Washington, D.C., 52 pp. https://doi.org/10.18235/0006516

Haley AL, Lemieux TA, Piczak ML, Karau S, D'Addario A, Irvine RL, Beaudoin C, Bennett JR, Cooke SJ (2023) On the effectiveness of public awareness campaigns for the management of invasive species. Environmental Conservation 50: 202–211. https://doi.org/10.1017/S037689292300019X

Hampton SE, Strasser CA, Tewksbury JJ, Gram WK, Budden AE, Batcheller AL, Duke CS, Porter JH (2013) Big data and the future of ecology. Frontiers in Ecology and the Environment 11: 156–162. https://doi.org/10.1890/120103

Haubrock PJ, Balzani P, Macêdo R, Tarkan AS (2023) Is the number of non-native species in the European Union saturating? Environmental Sciences Europe 35: 48. https://doi.org/10.1186/s12302-023-00752-1

Hemming V, Burgman MA, Hanea AM, McBride MF, Wintle BC (2018) A practical guide to structured expert elicitation using the IDEA protocol. Methods in Ecology and Evolution 9: 169–180. https://doi.org/10.1111/2041-210X.12857

Howard L, van Rees CB, Dahlquist Z, Luikart G, Hand BK (2022) A review of invasive species reporting apps for citizen science and opportunities for innovation. NeoBiota 71: 165–188. https://doi.org/10.3897/neobiota.71.79597

Hulme PE (2021) Advancing One Biosecurity to address the pandemic risks of biological invasions. Bioscience 71: 708–721. https://doi.org/10.1093/biosci/biab019

IPBES (2023) Thematic assessment report on invasive alien species and their control of the Intergovernmental science-policy platform on biodiversity and ecosystem services. In: Roy HE, Pauchard A, Stoett P, Renard Truong T (Eds) IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.7430682

ISPRA (2020) Report Nazionale sui Programmi di Monitoraggio per la Direttiva sulla Strategia Marina Art. 11, Dir. 2008/56/CE. https://www.mase.gov.it/sites/default/files/archivio/allegati/strategia_marina/d2_programmi_monitoraggio_2021-2026_giugno_2020.pdf

Kassambara A (2017) Practical guide to cluster analysis in R: Unsupervised machine learning (Vol. 1). Sthda.

Kissling WD, Ahumada JA, Bowser A, Fernández M, Fernández N, García EA, Guralnick RP, Isaac NJB, Kelling S, Los W, McRae L, Mihoub JB, Obst M, Santamaria M, Skidmore AK, Williams KJ, Agosti D, Amariles D, Arvanitidis C, Bastin L, De Leo F, Egloff W, Elith J, Hobern D, Martin D, Pereira HM, Pesole G, Peterseil J, Saarenmaa H, Schigel D, Schmeller DS, Segata N, Turak E, Uhlir PF, Wee B, Hardisty AR (2018) Building essential biodiversity variables (EBV s) of species distribution and abundance at a global scale. Biological Reviews of the Cambridge Philosophical Society 93: 600–625. https://doi.org/10.1111/brv.12359

Knape J, Coulson SJ, van der Wal R, Arlt D (2022) Temporal trends in opportunistic citizen science reports across multiple taxa. Ambio 51: 183-198. https://doi.org/10.1007/s13280-021-01550-w

Koch W, Hogeweg L, Nilsen EB, O'Hara RB, Finstad AG (2023) Recognizability bias in citizen science photographs. Royal Society Open Science 10: 221063. https://doi.org/10.1098/rsos.221063

Leimu R, Koricheva J (2005) Does scientific collaboration increase the impact of ecological articles? Bioscience 55: 438–443. https://doi.org/10.1641/0006-3568(2005)055[0438:DSCITI]2.0.CO;2

Lenzner B, García-Rodríguez A, Colling G, Dullinger S, Fugger J, Glaser M, Hennenfeind JH, Kaplan E, Liu D, Omer A, Pauchard A, Roy HE, Schernhammer T, Schertler A, Stoett P, Tedeschi L, Vorstenbosch T, Wessely J, Essl F (2024) The neglected importance of managing biological invasions for sustainable development. People and Nature 6: 1804–1811. https://doi.org/10.1002/pan3.10712

Leza M, Herrera C, Picó G, Morro T, Colomar V (2021) Six years of controlling the invasive species *Vespa velutina* in a Mediterranean island: The promising results of an eradication plan. Pest Management Science 77: 2375–2384. https://doi.org/10.1002/ps.6264

Lioy S, Marsan A, Balduzzi A, Wauters LA, Martinoli A, Bertolino S (2019) The management of the introduced grey squirrel seen through the eyes of the media. Biological Invasions 21: 3723–3733. https://doi.org/10.1007/s10530-019-02084-9

Löbl I, Klausnitzer B, Hartmann M, Krell FT (2023) The silent extinction of species and taxonomists—An appeal to science policymakers and legislators. Diversity 15: 1053. https://doi.org/10.3390/d15101053

Lockwood JL, McKinney ML [Eds] (2001) Biotic homogenization. Kluwer Academic/Plenum Publishers, New York, NY, 81–102. https://doi.org/10.1007/978-1-4615-1261-5

Maechler M (2019) Finding groups in data: Cluster analysis extended Rousseeuw et al. R package version 2(0): 242–248.

Magliozzi C, Deriu I, Gervasini E, Melone B, D'Amico F, Akuma G, Cardoso AC (2023) Baseline distribution of invasive alien species added to the Union list by Comm. Impl. Reg. (EU) 2022/1203, Publications Office of the European Union, Luxembourg, 2023. https://doi.org/10.2760/166450

Magliozzi C, Gervasini E, Cardoso AC (2024) Informing spatiotemporal trends of Invasive Alien Species of Union concern with biological knowledge, Publications Office of the European Union, Luxembourg, 2024. https://data.europa.eu/doi/10.2760/298316

Maistrello L, Dioli P, Dutto M, Volani S, Pasquali S, Gilioli G (2018) Tracking the Spread of Sneaking Aliens by Integrating Crowdsourcing and Spatial Modeling: The Italian Invasion of *Halyomorpha halys*. Bioscience 68: 979–989. https://doi.org/10.1093/biosci/biy112

Malek R, Zapponi L, Eriksson A, Ciolli M, Mazzoni V, Anfora G, Tattoni C (2019) Monitoring 2.0: Update on the *Halyomorpha halys* invasion of Trentino. ISPRS International Journal of Geo-Information 8: 564. https://doi.org/10.3390/ijgi8120564

McClenachan L, Cooper AB, McKenzie MG, Drew JA (2015) The importance of surprising results and best practices in historical ecology. Bioscience 65(9): 932–939. https://doi.org/10.1093/biosci/biv100

Meeus S, Silva-Rocha I, Adriaens T, Brown PMJ, Chartosia N, Claramunt-López B, Martinou AF, Pocock MJO, Preda C, Roy HE, Tricarico E, Groom QJ (2023) More than a bit of fun: The multiple outcomes of a bioblitz. Bioscience 73: 168–181. https://doi.org/10.1093/biosci/biac100

Mehta SV, Haight RG, Homans FR, Polasky S, Venette RC (2007) Optimal detection and control strategies for invasive species management. Ecological Economics 61: 237–245. https://doi.org/10.1016/j.ecolecon.2006.10.024

Montgomery GA, Belitz MW, Guralnick RP, Tingley MW (2021) Standards and best practices for monitoring and benchmarking insects. Frontiers in Ecology and Evolution 8: 579193. https://doi.org/10.3389/fevo.2020.579193

Mukherjee N, Hugé J, Sutherland WJ, McNeill J, Van Opstal M, Dahdouh-Guebas F, Koedam N (2015) The Delphi technique in ecology and biological conservation: Applications and guidelines. Methods in Ecology and Evolution 6: 1097–1109. https://doi.org/10.1111/2041-210X.12387

Novoa A, Dehnen-Schmutz K, Fried J, Vimercati G (2017) Does public awareness increase support for invasive species management? Promising evidence across taxa and landscape types. Biological Invasions 19: 3691–3705. https://doi.org/10.1007/s10530-017-1592-0

Nyumba T, Wilson K, Derrick CJ, Mukherjee N (2018) The use of focus-group discussion methodology: Insights from two decades of application in conservation. Methods in Ecology and Evolution 9: 20–32. https://doi.org/10.1111/2041-210X.12940

Ojaveer H, Galil BS, Minchin D, Olenin S, Amorim A, Canning-Clode J, Chainho P, Copp GH, Gollasch S, Jelmert A, Lehtiniemi M, McKenzie C, Mikuš J, Miossec L, Occhipinti-Ambrogi A, Pećarević M, Pederson J, Quilez-Badia G, Wijsman JWM, Zenetos A (2014) Ten recommendations for advancing the assessment and management of non-indigenous species in marine ecosystems. Marine Policy 44: 160–165. https://doi.org/10.1016/j.marpol.2013.08.019

Onley IR, Cassey P, McGeoch MA (2025) Biodiversity data sharing platforms are vital for the management and prevention of biological invasions. Biodiversity and Conservation 34: 2247–2257. https://doi.org/10.1007/s10531-025-03058-1

Open Research Europe (2022) FAIR Data - A Quick Guide for Researchers. https://horizoneuropencpportal.eu/sites/default/files/2022-09/ore-fair-data-guide.pdf

Pace R, Ascolese R, Miele F, Russo E, Griffo RV, Bernardo U, Nugnes F (2022) The Bugs in the Bags: The Risk Associated with the Introduction of Small Quantities of Fruit and Plants by Airline Passengers. Insects 13: 617. https://doi.org/10.3390/insects13070617

Pagad S, Bisset S, Genovesi P, Groom Q, Hirsch T, Jetz W, Ranipeta A, Schigel D, Sica YV, McGeoch MA (2022) Country compendium of the global register of introduced and invasive species. Scientific Data 9: 391. https://doi.org/10.1038/s41597-022-01514-z

Patrício J, Little S, Mazik K, Papadopoulou KN, Smith CJ, Teixeira H, Hoffmann H, Uyarra MC, Solaun O, Zenetos A, Kaboglu G, Kryvenko O, Churilova T, Moncheva S, Bučas M, Borja A, Hoepffner N, Elliott M (2016) European marine biodiversity monitoring networks: Strengths, weaknesses, opportunities and threats. Frontiers in Marine Science 3: 161. https://doi.org/10.3389/fmars.2016.00161

Petrosyan V, Osipov F, Feniova I, Dergunova N, Warshavsky A, Khlyap L, Dzialowski A (2023) The TOP-100 most dangerous invasive alien species in Northern Eurasia: Invasion trends and species distribution modelling. NeoBiota 82: 23–56. https://doi.org/10.3897/neobiota.82.96282

Pocock MJO, Newson SE, Henderson IG, Peyton J, Sutherland WJ, Noble DG, Ball SG, Beckmann BC, Biggs J, Brereton T, Bullock DJ, Buckland ST, Edwards M, Eaton MA, Harvey MC, Hill MO, Horlock M, Hubble DS, Julian AM, Mackey EC, Mann DJ, Marshall MJ, Medlock JM, O'Mahony EM, Pacheco M, Porter K, Prentice S, Procter DA, Roy HE, Southway SE, Shortall CR, Stewart AJA, Wembridge DE, Wright MA, Roy DB (2015) Developing and enhancing biodiversity monitoring programmes: A collaborative assessment of priorities. Journal of Applied Ecology 52(3): 686–695. https://doi.org/10.1111/1365-2664.12423

Pocock MJO, Adriaens T, Bertolino S, Eschen R, Essl F, Hulme PE, Jeschke JM, Roy HE, Teixeira H, de Groot M (2024) Citizen science is a vital partnership for invasive alien species management and research. iScience 27(1): 108623. https://doi.org/10.1016/j.isci.2023.108623

Poulin R (2019) Best practice guidelines for studies of parasite community ecology. Journal of Helminthology 93(1): 8–11. https://doi.org/10.1017/S0022149X18000598

Price-Jones V, Brown PMJ, Adriaens T, Tricarico E, Farrow RA, Cardoso AC, Gervasini E, Groom Q, Reyserhove L, Schade S, Tsinaraki C, Marchante E (2022) Eyes on the aliens: Citizen science contributes to research, policy and management of biological invasions in Europe. NeoBiota 78: 1–24. https://doi.org/10.3897/neobiota.78.81476

R Core Team (2025) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Reeb RA, Heberling JM (2024) Lost in translation: The need for updated messaging strategies in invasion biology communication. Plants, People, Planet 7(3): 536–545. https://doi.org/10.1002/ppp3.10603

Reyserhove L, Desmet P, Oldoni D, Adriaens T, Strubbe D, Davis AJS, Vanderhoeven S, Verloove F, Groom Q (2020) A checklist recipe: Making species data open and FAIR. Database : The Journal of Biological Databases and Curation 2020: baaa084. https://doi.org/10.1093/database/baaa084

Ricciardi A, Iacarella JC, Aldridge DC, Blackburn TM, Carlton JT, Catford JA, Dick JTA, Hulme PE, Jeschke JM, Liebhold AM, Lockwood JL, MacIsaac HJ, Meyerson LA, Pyšek P, Richardson DM, Ruiz GM, Simberloff D, Vilà M, Wardle DA (2021) Four priority areas to advance invasion science in the face of rapid environmental change. Environmental Reviews 29(2): 119–141. https://doi.org/10.1139/er-2020-0088

Rodríguez-Rey M, Borrell YJ, Dopico E, Muha TP, Rolla M (2022) Understanding public perceptions toward invasive species in different parts of Europe. Journal of Environmental Planning and Management 65: 2257–2275. https://doi.org/10.1080/09640568.2021.1969899

Roy HE, Pauchard A, Stoett PJ, Truong TR, Meyerson LA, Bacher S, Galil BS, Hulme PE, Ikeda T, Sankaran K, McGeoch MA, Nuñez MA, Ordonez A, Rahlao SJ, Schwindt E, Seebens H, Sheppard AW, Vandvik V (2024) Curbing the major and growing threats from invasive alien species is urgent and achievable. Nature Ecology & Evolution 8: 1216–1223. https://doi.org/10.1038/s41559-024-02412-w

Schofield PJ (2020) Expert bioblitzes facilitate non-native fish tracking and interagency partnerships. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 11: 139. https://doi.org/10.3391/mbi.2020.11.1.10

Scolozzi R, Schirpke U, Morri E, D'Amato D, Santolini R (2014) Ecosystem services-based SWOT analysis of protected areas for conservation strategies. Journal of Environmental Managemen 146: 543–551. https://doi.org/10.1016/j.jenvman.2014.05.040

Seebens H, Kaplan E (2022) DASCO: A workflow to downscale alien species checklists using occurrence records and to re-allocate species distributions across realms. NeoBiota 74: 75–91. https://doi.org/10.3897/neobiota.74.81082

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8: 1–9. https://doi.org/10.1038/ncomms14435

Seebens H, Clarke DA, Groom Q, Wilson JRU, García-Berthou E, Kühn I, Roigé M, Pagad S, Essl F, Vicente J, Winter M, McGeoch M (2020) A workflow for standardising and integrating alien species distribution data. NeoBiota 59: 39–59. https://doi.org/10.3897/neobiota.59.53578

Sequeira AMM, O'Toole M, Keates TR, McDonnell LH, Braun CD, Hoenner X, Jaine FRA, Jonsen ID, Newman P, Pye J, Bograd SJ, Hays GC, Hazen EL, Holland M, Tsontos VM, Blight C, Cagnacci F, Davidson SC, Dettki H, Duarte CM, Dunn DC, Eguíluz VM, Fedak M, Gleiss AC, Hammerschlag N, Hindell MA, Holland K, Janekovic I, McKinzie MK, Muelbert MMC, Pattiaratchi C, Rutz C, Sims DW, Simmons SE, Townsend B, Whoriskey F, Woodward B, Costa DP, Heupel MR, McMahon CR, Harcourt R, Weise M (2021) A standardisation framework for bio-logging data to advance ecological research and conservation. Methods in Ecology and Evolution 12: 996–1007. https://doi.org/10.1111/2041-210X.13593

Servello G, Andaloro F, Azzurro E, Castriota L, Catra M, Chiarore A, Crocetta F, D'Alessandro M, Denitto F, Froglia C, Gravili C, Langer M, Lo Brutto S, Mastrototaro F, Petrocelli A, Pipitone C, Piraino S, Relini G, Serio D, Xentidis NJ, Zenetos A (2019) Marine alien species in Italy: A contribution to the implementation of Descriptor D2 of the Marine Strategy Framework Directive. Mediterranean Marine Science 20: 1–48. https://doi.org/10.12681/mms.18711

Shackleton RT, Biggs R, Richardson DM, Larson BM (2018) Social-ecological drivers and impacts of invasion-related regime shifts: Consequences for ecosystem services and human wellbeing. Environmental Science & Policy 89: 300–314. https://doi.org/10.1016/j.envsci.2018.08.005

Simberloff D (2013) Invasive species: what everyone needs to know. Oxford University Press. https://doi.org/10.1093/wentk/9780199922017.001.0001

Soga M, Gaston KJ (2025) Extinction of experience among ecologists. Trends in Ecology & Evolution. https://doi.org/10.1016/j.tree.2024.12.010

Sosa AJ, Jiménez NL, Faltlhauser AC, Righetti T, McKay F, Bruzzone OA, Stiers I, Fernández Souto A (2021) The educational community and its knowledge and perceptions of native and invasive alien species. Scientific Reports 11: 21474. https://doi.org/10.1038/s41598-021-00683-y

Soto I, Balzani P, Carneiro L, Cuthbert RN, Macêdo R, Tarkan AS, Ahmed DA, Bang A, Bacela-Spychalska K, Bailey SA, Baudry T, Ballesteros-Mejia L, Bortolus A, Briski E, Britton JR, Buřič M, Camacho-Cervantes M, Cano-Barbacil C, Copilaș-Ciocianu D, Coughlan NE, Courtois P, Csabai Z, Dalu T, De Santis V, Dickey JW, Dimarco RD, Falk-Andersson J, Fernandez RD, Florencio M, Franco ACS, García-Berthou E, Giannetto D, Glavendekic MM, Grabowski M, Heringer G, Herrera I, Huang W, Kamelamela KL, Kirichenko NI, Kouba A, Kourantidou M, Kurtul I, Laufer G, Lipták B, Liu C, López-López E, Lozano V, Mammola S, Marchini A, Meshkova V, Milardi M, Musolin DL, Nuñez MA, Oficialdegui FJ, Patoka J, Pattison Z, Pincheira-Donoso D, Piria M, Probert AF, Rasmussen JJ, Renault D, Ribeiro F, Rilov G, Robinson TB, Sanchez AE, Schwindt E, South J, Stoett P, Verreycken H, Vilizzi L, Wang YJ, Watari Y, Wehi PM, Weiperth A, Wiberg-Larsen P, Yapıcı S, Yoğurtçuoğlu B, Zenni RD, Galil BS, Dick JTA, Russell JC, Ricciardi A, Simberloff D, Bradshaw CJA, Haubrock PJ (2024) Taming the terminological tempest in invasion science. Biological Reviews of the Cambridge Philosophical Society 99: 1357–1390. https://doi.org/10.1111/brv.13071

Steenweg R, Hebblewhite M, Whittington J, Lukacs P, McKelvey K (2018) Sampling scales define occupancy and underlying occupancy–abundance relationships in animals. Ecology 99: 172–183. https://doi.org/10.1002/ecy.2054

Stoch F, Genovesi P [Eds] (2016) Handbooks for monitoring species and habitats of Community interest (Council Directive 92/43/EEC) in Italy: animal species. ISPRA, Series Handbooks and Guidelines, 141 pp.

Tahamtan I, Safipour Afshar A, Ahamdzadeh K (2016) Factors affecting number of citations: A comprehensive review of the literature. Scientometrics 107: 1195–1225. https://doi.org/10.1007/s11192-016-1889-2

Tedersoo L, Küngas R, Oras E, Köster K, Eenmaa H, Leijen Ä, Pedaste M, Raju M, Astapova A, Lukner H, Kogermann K, Sepp T (2021) Data sharing practices and data availability upon request differ across scientific disciplines. Scientific Data 8: 192. https://doi.org/10.1038/s41597-021-00981-0

Thomas D, Butry D, Gilbert S, Webb D, Fung J (2017) The costs and losses of wildfires. NIST special publication 1215(11): 1–72. https://doi.org/10.6028/NIST.SP.1215

Tsiamis K, Azzurro E, Bariche M, Çinar ME, Crocetta F, De Clerck O, Galil B, Gómez F, Hoffman R, Jensen KR, Kamburska L, Langeneck J, Langer MR, Levitt-Barmats Y, Lezzi M, Marchini A, Occhipinti-Ambrogi A, Ojaveer H, Piraino S, Shenkar N, Yankova M, Zenetos A, Žuljević A, Cardoso AC (2020) Prioritizing marine invasive alien species in the European Union through horizon scanning. Aquatic Conservation 30: 794–845. https://doi.org/10.1002/aqc.3267

Turbelin AJ, Cuthbert RN, Essl F, Haubrock PJ, Ricciardi A, Courchamp F (2023) Biological invasions are as costly as natural hazards. Perspectives in Ecology and Conservation 21: 143–150. https://doi.org/10.1016/j.pecon.2023.03.002

Viesti G (2018) La laurea negata: le politiche contro l'istruzione universitaria. Gius. Laterza & Figli Spa.

Vilà M, Hulme PE [Eds] (2017) Impact of biological invasions on ecosystem services (Vol. 12). Springer International Publishing, Cham, Switzerland, 354 pp. https://doi.org/10.1007/978-3-319-45121-3

Vilizzi L, Piria M, Pietraszewski D, Yoğurtçuoğlu B, Almeida D, Al-Wazzan Z, Atique U, Boggero A, Duniš L, Goulletquer P, Herczeg G, Jukonienė I, Kopecký O, Koutsikos N, Koyama A, Kvach Y, Li S, Lukas J, Malmstrøm M, Marszał L, Mendoza R, Monteiro JG, Perdikaris C, Petrulaitis L, Pickholtz R, Preda C, Simonović P, Slovák Švolíková K, Špelić I, Števove B, Raghavan Suresh V, Ualiyeva D, Vardakas L, Verreycken H, Vila-Gispert A, Wei H, Yazlık A, Zięba G, Giannetto D (2025) To be, or not to be, a non-native species in non-English languages: Gauging terminological consensus amongst invasion biologists. Management of Biological Invasions : International Journal of Applied Research on Biological Invasions 16(1): 15–31. https://doi.org/10.3391/mbi.2025.16.1.02

Vitousek PM, d'Antonio CM, Loope LL, Westbrooks R (1996) Biological invasions as global environmental change. American Scientist 84: 468–478.

Wallace RD, Bargeron CT, Reaser JK (2020) Enabling decisions that make a difference: Guidance for improving access to and analysis of invasive species information. Biological Invasions 22: 37–45. https://doi.org/10.1007/s10530-019-02142-2

Wallace RD, Bargeron CT, LaForest JH, Carroll RL (2021) The Life Cycle of Invasive Alien Species Occurrence Data. In: Pullaiah T, Ielmini MR (Eds) Invasive Alien Species. https://doi.org/10.1002/9781119607045.ch49

Whitlock MC (2011) Data archiving in ecology and evolution: Best practices. Trends in Ecology & Evolution 26(2): 61–65. https://doi.org/10.1016/j.tree.2010.11.006

Wieczorek J, Bloom D, Guralnick R, Blum S, Döring M, Giovanni R, Robertson T, Vieglais D (2012) Darwin Core: An evolving community-developed biodiversity data standard. PLoS ONE 7: e29715. https://doi.org/10.1371/journal.pone.0029715

Wilkinson MD, Dumontier M, Aalbersberg IJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten JW, da Silva Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJ, Groth P, Goble C, Grethe JS, Heringa J, 't Hoen PA, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone SA, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B (2016) The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data 3: 160018. https://doi.org/10.1038/sdata.2016.18

Wittenberg R, Cock MJ (2005) Best practices for the prevention and management of invasive alien species. In: Invasive Alien Species: A Toolkit of Best Prevention and Management Practices. CAB International, Wallingford, UK, 209–232.

Wong MK (2024) Misrepresentation of invasive species in the mass media with images of unrelated organisms. Conservation Biology: The Journal of the Society for Conservation Biology 38: e14382. https://doi.org/10.1111/cobi.14382

Woodworth E, Tian A, Blair K, Pullen J, Lefcheck JS, Parker JD (2023) Media myopia distorts public interest in US invasive plants. Biological Invasions 25: 3193–3205. https://doi.org/10.1007/s10530-023-03101-8

Young JC, Waylen KA, Sarkki S, Albon S, Bainbridge I, Balian E, Davidson J, Edwards D, Fairley R, Margerison C, McCracken D, Owen R, Quine CP, Stewart-Roper C, Thompson D, Tinch R, Van den Hove S, Watt A (2014) Improving the science-policy dialogue to meet the challenges of biodiversity conservation: Having conversations rather than talking at one-another. Biodiversity and Conservation 23: 387–404. https://doi.org/10.1007/s10531-013-0607-0

Supplementary material 1

Additional information and appendix

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Data type: zip

Explanation note: The supplementary materials, which include appendises (appendises S1–S3), supplementary figures (figs S1–S4), as well as reproducible data and software code, are available at: https://osf.io/sf3ag/.

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