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PERSPECTIVES AND PARADIGMS

Rethinking management success: a transformative roadmap for biological invasions management

Sonia Vanderhoeven · Evangelina Schwindt · K. V. Sankaran · Rafael D. Zenni · Llewellyn Foxcroft · Chika Egawa · Lora Peacock · Jana Müllerová · Maria L. Castillo · John K. Bukombe · Helen E. Roy · Anibal Pauchard · Peter Stoett · Chaeho Byun · Jan Pergl · Ana Luisa Nunes · Tanara Renard Truong · Andy Sheppard

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Abstract Countries that are parties to international agreements such as the Convention on Biological Diversity (CBD) Kunming-Montreal Global Biodiversity Framework are required to manage biological invasions. Achieving these objectives, whether on a global or local scale, depends on a shared understanding among scientists, stakeholders, and authorities of the effectiveness of management practices. Despite extensive management interventions worldwide, there remains no consensus on what constitutes 'success' in biological invasions management. Building on our experience in the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) thematic assessment report on invasive alien species and their control, hereafter IPBES IAS assessment, this article reexamines what constitutes "successful management," arguing that traditional ecology-centered approaches are insufficient. Rather, success must be defined through clear and measurable objectives that integrate ecological, social and economic dimensions. We emphasize the essential role of sustained long-term commitment, adequate

Associate Editor - Evangelina Schwindt

S. Vanderhoeven (✉)
Belgian Biodiversity Platform, Socio-Environmental Dynamics Research Group (SONYA), Institut Interfacultaire Des Transformations Socio-Écologiques (iiTSE), Université libre de Bruxelles, Brussels, Belgium
e-mail: s.vanderhoeven@biodiversity.be

E. Schwindt
Instituto de Biología de Organismos Marinos (IBIOMAR-CONICET), Puerto Madryn, Argentina

K. V. Sankaran
Kerala Forest Research Institute, Peechi 680 653, India

R. D. Zenni
Rafael D. Zenni—Department of Ecology and Conservation, Federal University of Lavras, Lavras, Brazil

L. Foxcroft
Scientific Services, South African National Parks, Skukuza, South Africa

L. Foxcroft
Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Stellenbosch, South Africa

C. Egawa
Institute for Agro-Environmental Sciences, National Agriculture and Food Research Organization, Tsukuba, Japan

L. Peacock
Biosecurity New Zealand, Ministry for Primary Industries, Christchurch, New Zealand

J. Müllerová
Jan Evangelista Purkyně University in Ústí Nad Labem, Ústí nad Labem, Czech Republic

M. L. Castillo · J. Pergl
Institute of Botany, Czech Academy of Sciences, Průhonice, Czech Republic

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funding, inclusive governance, and robust data systems in supporting effective and adaptive management. Particular attention is given to the need for monitoring, standardized data and indicators to link management actions to outcomes, while recognizing the importance of broad stakeholder engagement and knowledge exchange. By proposing an inclusive and adaptive approach, and encouraging transparency in communicating successes and failures, we provide a roadmap for strengthening management strategies. This perspective presents a transformative roadmap that redefines management success as an adaptive, evidence-based, and socially inclusive process aligned with global biodiversity and 'Nature Positive' goals.

Keywords Invasive alien species · Success evaluation · Objectives · Adaptive management · Management strategies · Evidence-based decision-making

Introduction

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) thematic assessment report on invasive alien species and their control (Roy et al. 2024b), hereafter the IPBES IAS assessment, marked a significant milestone in understanding and confronting a major driver of biodiversity decline. Through a comprehensive synthesis and evaluation of worldwide data on biological invasions spanning all ecosystems and taxonomic groups, the assessment highlights the pressing nature of this issue, considering impacts on nature, nature's contributions to peoples and good quality of life, and laying the groundwork for focused efforts in prevention and control (Roy et al. 2024a, c).

The threat of biological invasions is significant and growing, and action is more urgent than ever. Options for action exist and work all the more effectively when they fully consider prevention and prioritization of invasive alien species (Roy et al. 2024c). Aligning with the definitions of the IPBES IAS assessment, management of biological invasions includes any action taken to address the threats, risks, distribution, abundance and impacts of invasive alien species within a defined geographic area, specifically, prevention, preparedness, eradication, containment, control and ecosystem restoration, targeting species, pathways of introduction or invaded sites (Sankaran et al. 2024).

Mitigating the threats of biological invasions and other drivers of environmental change is critical to addressing the global biodiversity crisis and achieving sustainable development. It is acknowledged that developing a shared understanding of the justification and goals for management of biological invasions among authorities, stakeholders involved in management actions, and researchers is important, including documenting what does and does not work and noting effective approaches to minimise negative impacts

J. K. Bukombe
Tanzania Wildlife Research Institute, Arusha, Tanzania

H. E. Roy
UK Centre for Ecology & Hydrology, Benson Lane, Crowmarsh Gifford, Oxfordshire OX10 8EF, UK

H. E. Roy
Center for Ecology and Conservation, University of Exeter, Penryn Campus, Cornwall TR10 9FE, UK

A. Pauchard
Laboratorio de Invasiones Biológicas (LIB), Facultad de Ciencias Forestales, Universidad de Concepción, Concepción, Chile

A. Pauchard
Institute of Ecology and Biodiversity (IEB), Santiago, Chile

P. Stoett
Faculty of Social Science and Humanities, Ontario Tech University, Oshawa, Canada

C. Byun
Department of Biological Sciences, Gyeongkuk National University, Andong 36729, Republic of Korea

A. L. Nunes
IUCN, Biodiversity Assessment and Knowledge Team, Cambridge, UK

T. Renard Truong
Senckenberg Biodiversity and Climate Research Centre, Frankfurt, Germany

T. Renard Truong
Department of Animal Ecology & Systematics, Justus-Liebig University Giessen, Giessen, Germany

A. Sheppard
CSIRO, GPO Box 1700, Canberra, ACT 2602, Australia

(Sutherland et al. 2021). Many countries are parties to international agreements that require them to manage biological invasions, including treaties and goals such as the UN Sustainable Development Goals (e.g. Goal 15), the Convention on Biological Diversity (CBD) Kunming-Montreal Global Biodiversity Framework (Target 6), the International Plant Protection Convention (IPPC) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) and the World Organisation for Animal Health (WOAH). However, despite the proliferation of international frameworks and considerable management efforts linked to those, the evaluation of 'success' in biological invasions management remains inconsistent, often limited to ecological outcomes (such as successful population eradication, recovery of native species, etc.) rather than encompassing broader socio-ecological dimensions, giving attention to social, cultural, governance, and economic outcomes. Indeed, 'success' is itself an ambiguous and value-laden descriptor whose meaning shifts with the goals, scales, and stakeholders involved (Zedler 2007). Part of the unclear and inconsistent use of the term stems from the absence of a shared, operational definition.

Calls to improve systematic monitoring and evaluation of management actions have long been central to conservation and natural resource management, where they underpin adaptive management and evidence-based decision-making (e.g. Margoluis and Salafsky 1998; Pullin and Knight 2003; Stem et al. 2005; Mascia et al. 2014). In this respect, biological invasions present particular challenges, notably because they are often difficult to detect during the early stages of invasion (Morisette et al. 2020) and are driven by diverse and rapidly changing human activities, resulting in highly complex invasion dynamics. This makes their trajectories difficult to monitor and management outcomes difficult to evaluate (Hulme 2003).

Monitoring and evaluation of management actions provide evidence of progress towards key management objectives (e.g. prevention and preparedness, early detection and eradication, containment, control, and restoration) and help identify the most effective and cost-efficient management approaches. At the international level, they underpin reporting through indicators of societal responses to biological invasions, expressed as inputs, processes, outputs, and outcomes within frameworks such as the Theory of Change (an explicit, results-based logic model that traces how management inputs and activities are expected to lead to measurable outputs and longer-term outcomes) (McGeoch et al. 2010, 2024b; Vicente et al. 2022). At national and local scales, reflecting on management success is equally important: monitoring data help refine management strategies (García-Díaz et al. 2021), inform policy, and support more efficient use of resources (Pergl et al. 2016; Kumar Rai and Singh 2020). This is especially critical for developing economies. Although, to some extent, lower labour costs may facilitate the use of low-technology control methods (including physical, chemical, and biological approaches) (Nuñez and Pauchard 2010), this cannot detract from certain limitations, such as a lack of institutional continuity, underfunding of programmes and competing development priorities.

The 'Nature Positive' approach is increasingly being promoted for uptake in multinational biodiversity policies such as the Kunming-Montreal Global Biodiversity Framework (Thomas et al. 2024). As part of a broad policy objective for biodiversity recovery,

Governments and businesses are invited to focus on both supporting economic development and ensuring environmental protection through efforts to restore, conserve, and enhance biodiversity. This public–private 'Nature Positive' initiative is leading to the re-evaluation of existing policies and legislation across different levels of government, while promoting environmental credentials for industry projects and developments (Luxton et al. 2024). Management of biological invasions, by directly targeting biological threats to the environment, is inherently nature-positive in approach. Therefore, the development of credible evaluation and monitoring of management actions and associated indicators of positive environmental change will be critical to underpin the 'Nature Positive' philosophy (Birkeland 2022; McGeoch et al. 2024a). The need for metrics and indicators that demonstrate the impact of measures implemented by businesses to reduce the threat associated with biological invasions is increasingly recognised. For example, the Taskforce on Nature-related Financial Disclosures (TNFD) has developed a structured framework for identifying and assessing nature-related dependencies, impacts, risks, and opportunities, including those associated with biological invasions (McKenzie 2023). By encouraging organisations to incorporate mitigation of biological invasions into business risk assessments, management planning, and corporate disclosures, the framework highlights the importance of prevention and long-term monitoring in business decision-making.

There is also increasing attention to 'Nature Positive' and 'People Positive' approaches, acknowledging the integration of people and nature, ensuring consideration of benefits not only to economies, but also more holistic approaches including the need to incorporate society in achieving targets and goals (Obura et al. 2023). In this framing, 'People Positive' denotes an explicit commitment that biodiversity actions, including the management of biological invasions, deliver demonstrable benefits for human well-being, equity and livelihoods alongside ecological gains, rather than treating social outcomes as incidental.

The IPBES IAS assessment provided an opportunity to collaboratively review the global literature on management actions, techniques, and their effectiveness (Sankaran et al. 2024), for example, assessing the effectiveness of past and current programs, and the tools being used for local, national, and global prevention and control of biological invasions and their impacts. A core objective of the assessment was to determine the degree to which management actions are effectively and efficiently addressing the environmental, social and economic targets relevant to biological invasions. The assessment covers the development of decision support tools and frameworks, the existence of a wide range of techniques (established and novel), the program-level descriptions of management successes and failures mainly at a local scale, but also at different geographical scales, in different environments, and for different types of organisms. The assessment also refers to extensive interdisciplinary literature describing how management is carried out from a procedural perspective, and the approaches for engaging and collaborating with stakeholders and Indigenous Peoples and Local Communities, with a particular focus on inclusive engagement (McGeoch et al. 2024c).

Beyond the considerable work that has been carried out through the IPBES IAS assessment, it is important to acknowledge that obtaining an integrated perspective on the success of biological invasions management is challenging. Indeed, management programs cover various aspects that relate to diverse, complex, and sometimes antagonistic environmental, economic and social considerations. But it is critical to examine and document what is successful and what is not (and all the situations in between) and quantify beneficial impacts for such a context-specific issue while considering the diversity of stakeholders' views and values.

Building on the experience gained through the IPBES IAS assessment, we call for a rethinking of the concept of successful management, challenging the traditional ecologically centered perspectives and advocating for a transdisciplinary approach that includes comprehensive, adaptive, and multidimensional monitoring and evaluation.

This article is a perspective grounded in the authors' collective experience as contributors to the IPBES IAS assessment. Rather than a systematic review, it is a structured, expert-led synthesis (sensu Grant and Booth (2009)) that distils the assessment's findings and the wider literature into an applied roadmap; material from the assessment was incorporated through its chapters and underlying evidence base (Roy et al. 2024a, b, c; McGeoch et al. 2024c; Sankaran et al. 2024), complemented by literature published since. A variety of frameworks have conceptualised the ecological stages of biological invasions and the corresponding management options (Hobbs and Humphries 1995; Blackburn et al. 2011; Geburzi and McCarthy 2018; Robertson et al. 2020; Egawa et al. 2026). The roadmap we are proposing complements this, shifting the focus from which action to take at a given invasion stage toward how success itself should be defined, measured, learned from, and communicated across ecological, social and economic dimensions. Whereas Fig. 1 provides a sequential representation of the identified steps, the paper develops the conceptual foundations and reasoning from which these steps emerged, rather than describing them in sequence. As such, the seven roadmap steps in Fig. 1 (and the illustrative cases in Table 1) map directly onto the sections that follow: steps 1 and 3 - engaging stakeholders and defining clear objectives ('Defining success'; 'Integrating social and economic dimensions'), step 2 - fostering long-term commitment ('Long-term commitment'), steps 4, 5 and 6 - collecting standardised data, making it accessible, and developing indicators ('Measuring

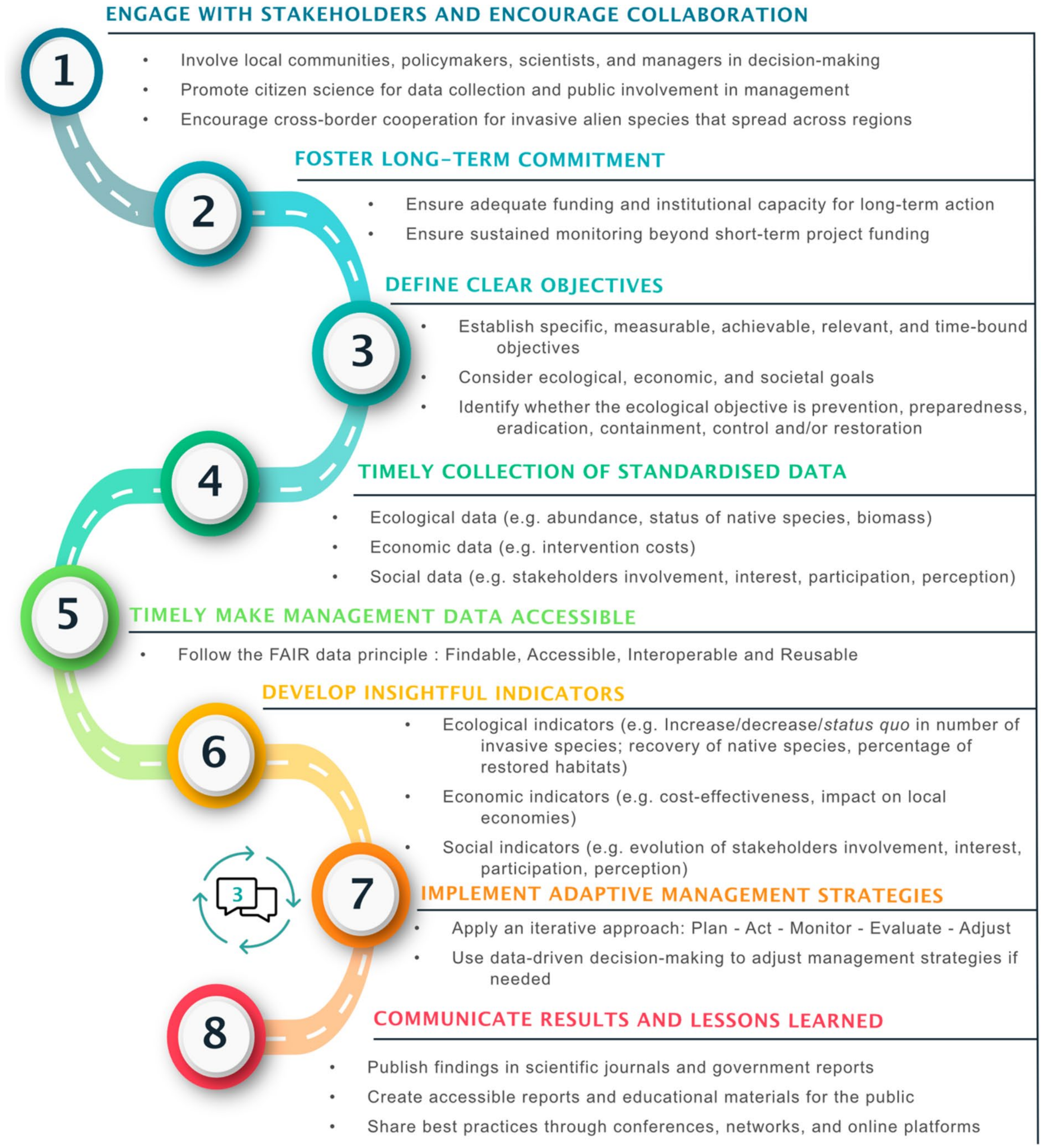

Fig. 1 Roadmap for improved biological invasions management strategies.The feedback loop relating to (7) "Implement adaptive management strategies" may lead back to step 3, namely the definition of new objectives

success'; 'Understanding success and failure'), step 7 - implementing adaptive management ('Adjust strategies'), and step 8 - communicating outcomes ('Communicate on management results').

The roadmap outlines a structured approach that is not intended to be an exhaustive list of actions to be taken, but rather a guide that fosters actionable progress, enhancing efforts to meet international biodiversity goals and targets, together with

Table 1 Illustrative example proposed for each step of the roadmap

		Examples	References
1.	Engage with stakeholders and encourage collaboration	A stakeholder mapping exercise was carried out in 2021 for six invasive species case studies across Argentina, Brazil, and Chile. For each stakeholder, levels of interest in the focal species and their management were assessed, the positive and negative ecological, economic, and social impacts experienced were documented, and consensus-based engagement strategies were developed	Erazo et al. (2025)
2.	Foster long-term commitment	In the Czech Republic, the European project '*Preservation of alluvial forest habitats in the Morávka basin*' (LIFE-Moravka) launched long-term herbicide management of knotweed populations of the genus *Reynoutria* (*Fallopia*) in the Morávka floodplain between 2007 and 2010. After the end of the LIFE project, which significantly reduced the area covered by the stands, different invaded sites were treated locally in different years, depending on financial resources and conservation needs. The authorities responsible for the nature reserves continued the chemical treatment effort. This long-term perseverance has allowed 17 years of management monitoring, providing a robust and unique overview of the invasion, reinvasion, and management success dynamics for an important invasive alien species	Švec et al. (2024)
3.	Define clear objectives	The *Great Lakes Phragmites Collaborative* helps support the definition of clear management objectives for controlling invasive *Phragmites australis* by fostering collaboration, shared goals, structured decision-making, and data-driven adaptive management across the Great Lakes region (North America). This enables individuals and organizations to evaluate progress toward their own objectives, align site-level strategies with shared landscape-scale goals outlined in the Common Agenda, and contribute valuable field-based empirical data to inform improvements in management practices	Braun et al. (2016)
4.	Timely collect standardised data	The Ballast Water Management Program for the Great Lakes has been sampling and measuring discharges for decades allowing evaluation of effectiveness in the management efforts	Bailey et al. (2011)

Table 1 (continued)

		Examples	References
5.	Timely make management data accessible	LIFE PanPuffinus! aims to reduce bycatch and predation by invasive species in breeding colonies of the Yelkouan and Balearic shearwater species. To this end, eradication and control actions are being carried out and an interactive map of the actions taken is available to anyone interested on the project website. For each record, the following information is provided: localisation of management action, contact details of managers and institutions in charge of management, area covered, starting and ending management dates, achievement, IAS of concern and beneficiary species	Life Panpuffinus! (2026)
6.	Develop insightful indicators	A recent assessment using 24 indicators evaluated the status of biological invasions and their management on the Prince Edward Islands, South Africa's sub-Antarctic territories, measuring progress toward Target 6 of the GBF and informing management recommendations	Fernández Winzer et al. (2025)
7.	Implement adaptive management strategies	For more than 20 years, South African National Parks have developed and implemented adaptive management strategies, including those focused on invasive species management. This made it possible to co-create desired states or visions, set objectives, formulate thresholds of potential concern, and monitor and evaluate the consequences of management decisions	Roux and Foxcroft (2011)
8.	Communicate results and lessons learned	The *Woody Weeds* projects developed, evaluated, and disseminated management strategies to mitigate the socio-economic and environmental impacts of *Prosopis spp, Lantana camara* and *Chromolaena odorata* in Eastern Africa. Outcomes and lessons learned were communicated through policy and practice briefs, field guides, Swahili-language resources, videos, and workshops, contributing to Kenya's National Prosopis Strategy and enhancing community capacity, including that of women's groups implementing management practices	Schaffner et al. (2025)

illustrative examples (Table 1). We push for a meaningful assessment that goes beyond the commonly perceived goal of management being eradication or control, but considers integrated, long-term ecological, social, and economic outcomes.

Many of the principles underpinning the proposed roadmap are shared with broader conservation and restoration practice. The particular relevance of these principles to biological invasions stems from the dynamics and characteristics of the invasion process, in addition to the governance approaches they promote. Unlike many conservation challenges, biological invasions management places considerable emphasis on prevention and early action, with management objectives changing through the biological invasion process.

Defining success in management: primarily a matter of setting objectives

Throughout, we use ‘success’ as shorthand for measurable progress toward explicitly stated objectives, rather than as an absolute or purely ecological endpoint (cf. Zedler (2007)). Framed this way, success is necessarily plural, scale-dependent, and judged against the goals a given programme has set. Success in biodiversity conservation is not merely about achieving immediate goals; it also involves long-term sustainability and adaptability to changing conditions while recognising the needs of people and nature. It encompasses both tangible environmental outcomes, such as native species and ecosystem recovery, and aspects often perceived as more intangible, like community empowerment, nature’s contributions to people, good quality of life, and good governance (Jones 2012; Bodin 2017; Fariss et al. 2023; Roy et al. 2024b).

As with all conservation efforts, evaluating the success or failure of management actions targeting biological invasions must be grounded in clearly defined goals and objectives (McGeoch et al. 2024c). We define objectives as measurable benchmarks by which progress is made toward a measurable management goal. Objectives that encompass environmental, social, and economic values and outcomes provide a more comprehensive basis for evaluating management success (Abeysinghe et al. 2023). When objectives are clearly defined, relevant, and readily understood by stakeholders, they also facilitate communication, support transparent decision-making, and improve the evaluation of management outcomes. Well-formulated objectives are often described as SMART—Specific, Measurable, Achievable, Relevant, and Time-bound—(Doran 1981) and this principle underpins the roadmap presented in Fig. 1. One key advantage of well-articulated objectives is that they allow for progress to be tracked over the course of the management plan, rather than relying solely on a single all-or-nothing outcome (Larson et al. 2011).

The formulation of objectives is inherently scale-dependent, as the effectiveness and appropriateness of management interventions can vary markedly across spatial and temporal scales. At a small scale, available management techniques can be effective in achieving local outcomes such as the eradication of an invasive alien species at the population level and associated measurable benefits to native species and local communities. However, scaling up to a larger geographical area or a more complex landscape opens up various challenges and requires other biological, social, and economic considerations that are likely to make eradication more difficult or even unattainable (Kettenring and Adams 2011). A well-documented example is common carp (*Cyprinus carpio)* control in Utah Lake, where intensive local removals significantly reduced adult biomass but failed to achieve landscape-level suppression because of gear selectivity, compensatory recruitment, dynamic habitat, and vastly underestimated effort and budget requirements (Walsworth et al. 2020) Accounting for this scale dependency is therefore essential both for scoping appropriate objectives and evaluating success (Prior et al. 2018; McMillan et al. 2023; McGeoch et al. 2024c).

In many contexts, particularly in the Global South, management objectives may be deliberately and legitimately modest or defensive (for example, to slow the spread, protect ecosystem services or safeguard livelihoods), rather than aiming for large-scale eradication. It is also worth noting that ambitious targets have been achieved in developing countries, such as the malaria-carrying *Anopheles gambiae* being eradicated from large areas of north-eastern Brazil (Simberloff 2003).

For many management initiatives, the formulation of objectives is not explicitly articulated, lacking time horizons or spatial scales (Buckley 2008; Liu et al. 2012). Biological invasions management is often treated as an end rather than a means to achieve broader socio-ecological outcomes, undertaken to satisfy regulatory obligations rather than strategic goals: doing ‘something’ simply because it is requested, whatever that ‘something’ may be. Such management is often undertaken without clearly defining the ecological or societal benefits it is intended to deliver, leaving little basis for prioritising interventions, evaluating success, or adapting management strategies over time.

To assist in the formulation of management objectives, various frameworks that conceptualise the ecological process of biological invasions and associated management options have been developed (Hobbs and Humphries 1995; Blackburn et al. 2011; Geburzi and McCarthy 2018). In particular, as a comprehensive synthesis of previous frameworks, an invasion-management framework has been developed as part of the IPBES IAS assessment (Egawa et al. 2026) based on the widely adopted conceptualization of invasion processes by Hobbs and Humphries (1995). The IPBES invasion-management framework is intended for use by decision-makers and management planners to help identify objectives, but also targets (species/pathways of introduction/sites) and actions based on the different stages of invasion, i.e., whether a species is absent, established, spread or widespread, and the type of ecosystem invaded. The framework is also designed to support rapid decision-making on the appropriate management approach to be used (e.g., preparedness and prevention; early detection and eradication; containment and control; or restoration) and to provide a range of fit-for-purpose decision-making tools.

Biological invasions are a consequence of human-driven actions, activities, situations, or events that are closely connected with human experiences, concerns, and values. Consequently, beyond ecological considerations, addressing management of threats and impacts requires meaningful, multi-directional stakeholder and community engagement involving communication, knowledge exchange, and co-development of decisions across the management process, as well as measurement of success and failure (Estévez et al. 2015; Rohal et al. 2018; Shackleton et al. 2019). Approaching biological invasions management through the lens of sustainability, Larson et al. (2011) identified a set of social objectives to be included in management plans: the involvement of multiple stakeholders in the management planning process, the communication of measurable progress, the involvement of community members in project implementation, the development of education and outreach programmes and the increased coordination of agencies and knowledge networks at all levels (Fig. 2).

Aspects of management that relate to process-oriented objectives are relatively rarely evaluated in practice, as demonstrated by Abeysinghe et al. (2023). However, evaluating their different components should help understand the factors that influenced success or failure in achieving the desired outputs or outcomes.

Integrating social and economic dimensions

Recognizing the diversity of worldviews, values, and objectives that underpin the management of biological invasions is crucial when designing inclusive and effective management plans (Roy et al. 2024a). While the ultimate goal is often shared (e.g., mitigating the negative impacts of biological invasions on biodiversity and nature's contribution to people), the rationale for intervention can vary across contexts and stakeholders' perceptions (Shackleton et al. 2019; Ballard et al. 2024). For example, in Indigenous communities with holistic worldviews, biological invasions management may be grounded in relational and cultural values and beliefs around the mother nature paradigm, rather than solely on ecological or economic arguments (Ballard et al. 2024). In some cases, management plans can indeed also be used as tools for strengthening knowledge sharing, integrating conventional scientific knowledge and Indigenous local knowledge for better outcomes (Ballard et al. 2024). These communities may use similar measures and tools, but do so to maintain the integrity of relationships with their lands and socio-ecological systems. Accounting for these different values, worldviews, and knowledge systems when defining objectives will increase the legitimacy, relevance and success of management plans (Pascual et al. 2023).

Whilst participatory approaches to biological invasion management emphasise co-design and stakeholder engagement through the integration of diverse knowledge systems, their implementation may be challenging in contexts characterised by governance instability (Lien et al. 2021), unequal power relations (Pagès et al. 2019), or limited institutional capacity (Ford-Thompson et al. 2012). These conditions can restrict the participation and influence of less visible or powerful stakeholders, and make it difficult to translate jointly developed ideas into management actions. The implementation of participatory approaches is inherently context-dependent, and should therefore be adapted to the local governance context rather than applied as a universal model. Where possible, they should be supported by efforts to strengthen institutional capacity, foster equitable participation, and build long-term partnerships.

Alongside cultural and social considerations, economic planning plays an equally important role in defining management success. Economic objectives

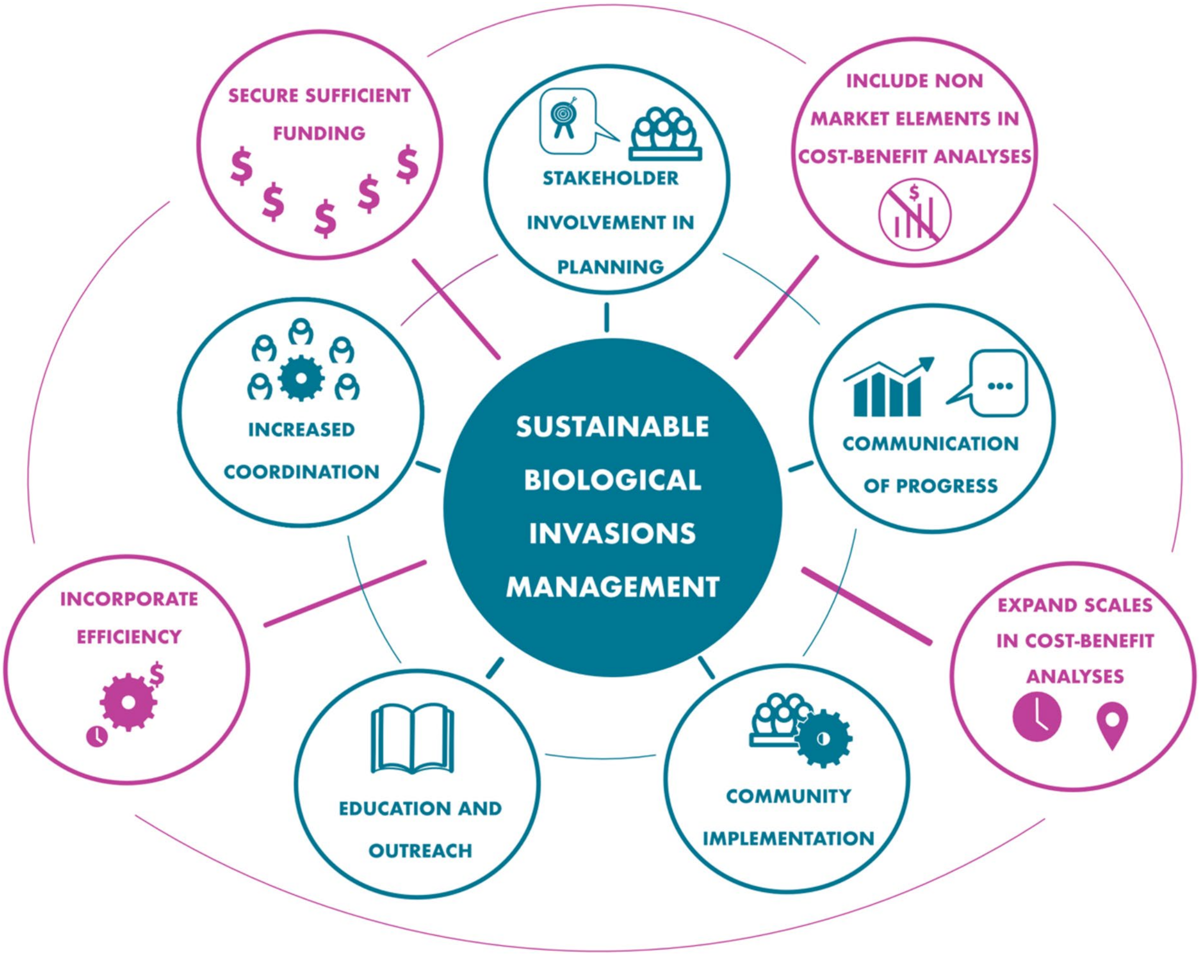

Fig. 2 Social (green) and economic (pink) objectives for biological invasions management, adapted from Larson et al. (2011)

for biological invasions management can be framed in terms of optimising resource allocation across prevention, surveillance, control, and restoration activities to minimize overall costs and damages while accounting for trade-offs among economic activities, species impacts, and management interventions (Epanchin-Niell 2017). From an economic perspective, Larson et al. (2011) recommend that management planning should incorporate non-market values into cost–benefit analyses (Hanley and Roberts 2019); adopt broader temporal and spatial scales for planning and cost–benefit analyses; integrate principles of cost-effectiveness into project selection and the choice of management practices (Epanchin-Niell 2017); and secure sufficient funding to ensure project completion (Fig. 2).

Since the publication of Larson et al. (2011), both the conceptual framing and practical application of best practice in the management of biological invasions have advanced substantially. Larson et al. (2011) broadened the definition of management success by highlighting the need to explicitly consider social and economic objectives alongside ecological ones. Figure 2 summarizes these objectives, which provide an important foundation for the more integrated approach proposed here. Building on these principles and the key messages emerging from the IPBES IAS assessment, we argue that contemporary best practice is now best understood as being grounded in partnerships among all relevant stakeholders, underpinned by co-design, co-implementation, and iterative social learning

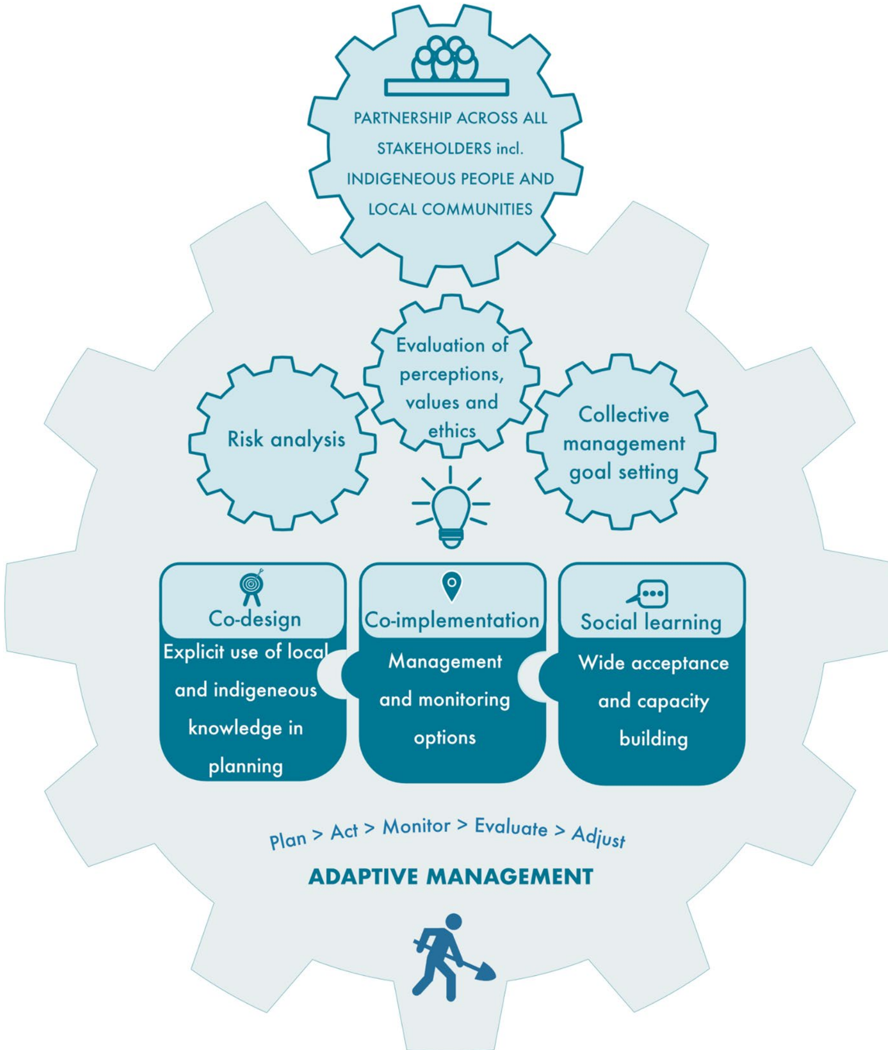

Fig. 3 Partnership-based approach for biological invasions management

(Fig. 3). Best practice is also based on collective understanding of impacts through impact analysis and a clear understanding of the environmental goals beyond species control by integrating it with ecosystem restoration. This approach promotes broad acceptance by addressing conflicting perceptions and values and any ethical issues associated with management options. It also supports capacity building, while explicitly integrating stakeholder and local and Indigenous knowledge into planning, management actions, and monitoring processes. Importantly, these collaborative processes can be further supported by cost-effectiveness analyses that explicitly account for both market and non-market values, helping stakeholders make transparent decisions about how limited resources can be allocated across competing management priorities. Combined with risk-based approaches to collective decision-making, these analyses provide a stronger basis for adaptive management. Effective monitoring and evaluation of management outcomes further ensures that interventions remain both contextually appropriate and operationally robust.

Long-term commitment as a cornerstone of biological invasions management

Adequate and sustained funding is critical for several reasons. Invasive alien species and their impacts are generally long-lasting, and complete eradication is rarely achievable and only under particular circumstances or in particular ecosystems (Sankaran et al. 2024), meaning that ongoing management coupled with monitoring and evaluation is necessary to suppress populations and prevent further spread or re-invasion (Švec et al. 2024). In aquatic ecosystems, eradication, control or containment of alien species is rarely achieved once they are established (Gallardo et al. 2016). Sustained investment in prevention and surveillance is therefore often the most reliable way to reduce new introductions and limit establishment (Matos et al. 2018; Reaser 2020; Hulme 2020a; Katsanevakis et al. 2023). Interruptions in funding are pervasive and can upend eradication programs, allowing more widespread species to rebound, making future control efforts more difficult and significantly more expensive (Hiatt et al. 2019; Mill et al. 2020; Pergl et al. 2020). Measurable environmental, societal, and economic benefits, including ecosystem services, are required to justify budget investments. This is a common concern in developing economies, but also where governance is weak, such that control and monitoring efforts are limited and have a fixed end date (Boy and Witt 2013). Additionally, the restoration of native ecosystems following the removal of invasive alien species is sometimes context-dependent (Rohal et al. 2019) and is often a gradual process requiring long-term monitoring, adaptive management, and continued investment to achieve lasting ecological recovery (Byun et al. 2023; Adams et al. 2025). For example, the restoration of a 3-ha drained palustrine wetland in central Minnesota was monitored over 23 years following invasive plant removal (Galatowitsch and Bohnen 2021). Repeated vegetation and hydrological assessments informed successive management interventions and revegetation efforts, demonstrating that successful recovery depended on sustained ecological monitoring and management rather than on the initial removal of invasive species alone. This case highlights that invasive species removal is often only the first step, with long-term support for monitoring and adaptive management being essential to secure durable restoration outcomes. Long-term funding also empowers managers and communities enabling more strategic planning, fosters collaboration among stakeholders, and increases the overall effectiveness and efficiency of management programs (Mill et al. 2020; García-Díaz et al. 2021). In contrast, short-term or sporadic funding regularly compromises progress, leading to setbacks, inefficient use of resources, or even complete loss of progress (e.g. feral animal control programs on fixed budgets) (Hone 2007).

In addition to robust financial mechanisms and institutional frameworks, long-term management requires clear cost-effectiveness above other environmental management options and socio-economic co-benefits (e.g., Indigenous livelihoods van Wilgen et al. 2016; Davis et al. 2024) or landscape-level co-reductions in carbon emissions (Davies et al. 2023) to sustain ongoing investment and implementation strategies (Lodge et al. 2006; McGeoch et al. 2024c). Government agencies fund surveillance and monitoring efforts, but these activities are too often short-term, focus on only a few species, and lack coordination, factors that collectively reduce the long-term effectiveness of management programs (Liebhold et al. 2021), unless co-benefits exist (Davis et al. 2024). There is a range of economic options available for long-term financing. Some are more appropriate for particular targets and certain socio-economic contexts, which makes financing largely context-dependent. These options include government funding; multilateral, bilateral and international organisations; philanthropic organisations; non-governmental organisations; the private sector (e.g., through carbon credits); and academic institutions (McGeoch et al. 2024c). In many developing economies, the central difficulty is precisely the limited availability, continuity and accessibility of these funding sources, which constrains sustained management of biological invasions.

Ensuring long-term commitment is an integral part of good governance of biological invasions at all scales, whether national, regional, or global. This is essential to enhance, for example, multilateral coordination and collaboration, build capacity to enable strategic actions, maintain up-to-date information systems and workflows that enable indicators, monitor policy and management effectiveness (Blossey 1999; Haubrock et al. 2023) and develop new solutions through research and innovation (Roy et al.

2024a). Such integrative governance increasingly draws on cross-sectoral framings such as One Health and One Biosecurity frameworks, which seek to align action across animal, plant, human and environmental health rather than addressing biological invasions in isolation (Hulme 2020b, 2021).

Measuring success: advancing data quantity, quality and accessibility

The current landscape of biological invasion data is characterised by significant challenges in terms of data quantity, quality, and accessibility. In recent years, considerable efforts have been made at global, regional and local levels to collect and aggregate species occurrence data that are openly available and can be used for decision-making and prioritising management actions (Groom et al. 2015; Deriu et al. 2017; McGeoch et al. 2024c). Obviously, it is important to know where species are present (and absent) before being able to manage them. However, evaluating the success of management relies not solely on species occurrence data. It also requires gathering and managing data for evaluating the response of the system of interest to the management, the financial costs associated with management actions or the involvement of communities in implementing management approaches and the benefits from the action (Georgiades et al. 2020). The data and information gathered needs to cover a wide range of aspects, from ecological, economic, and social perspectives, and adhere to data standards and a common vocabulary while ensuring relevance to the context of management evaluation. This is, however, far from being the case at present. These standards represent a strong aspiration rather than a precondition for action: where capacity and data are limited, a proportional or 'minimum viable' monitoring approach—tracking a small set of decision-relevant variables with the means available and strengthening them incrementally—allows progress to be demonstrated without surrendering to the unattainable ideal of complete, fully standardised data. The value of the activities and knowledge systems of certain Indigenous Peoples and local communities, which provide strong support for monitoring, must not be overlooked. This is the case, for example, with the Bukusu community in Kenya, who notify an elder when a new plant species is first found in their environment. A council of elders then confirms the discovery and a quarantine is imposed if deemed necessary (Wanzala et al. 2012).

Management success is typically assessed at local levels and documented in technical reports, often in languages other than English, making data collection, aggregation and diffusion notoriously difficult (Garcia-Lozano et al. 2025). Data sources remain highly fragmented and resource-dependent, inadequately addressing reporting needs while being subject to biases and political borders (Kurtul and Haubrock 2024). To this must be added the well-known underreporting of project failure or discontinuation, even though documenting such outcomes provides valuable learning opportunities (Catalano et al. 2019; Dickson et al. 2023). Addressing this bias may require a broader shift in operational culture towards more systematic reporting of unsuccessful or discontinued projects, thereby improving opportunities for evaluation and learning. This can be made explicit by knowledge-broker groups, intermediary individuals or organisations that translate, synthesise, and connect scientific evidence to the needs of decision-makers and managers (Bortolus et al. 2025).

The effectiveness of management actions is traditionally monitored in the field using a variety of metrics specific to the target species (being either an invasive species to be eradicated or a native species to be restored) and the invaded ecosystem. Change in species abundance, cover, or density are frequently used as population metrics, whether alien or native, by comparing pre- and post-management situations (Davis et al. 2022; Byun et al. 2024; Rodriguez et al. 2024). In aquatic ecosystems, where invasive species can degrade water quality, recovery of variables such as water quality, oxygen levels, and light penetration in water bodies, together with enhanced fish and other faunal diversity, can be used to reflect successful control of invasive alien plants and animals (Gallardo et al. 2016; Singh and Byun 2023). Appropriate success metrics are nonetheless context- and taxon-specific: not all aquatic invaders degrade water quality, and some, such as dreissenid mussels, can increase water clarity (Karatayev and Burlakova 2025), so no single variable should be treated as a universal indicator of management success.

Effective monitoring and evaluation programmes now generate quantities of data that are beyond the capacity of manual analysis. Automated data collection tools, AI search engines and technologies increasingly play a role in data collection, analysis and interpretation from prevention to control (Grossel et al. 2017; Sankaran et al. 2024). Purpose-built databases are needed for storing long-term monitoring data, which are increasingly stored on cloud-computing platforms (Shen et al. 2020). These enable the creation of federated data platforms that allow data with descriptors to be accessed and analysed from multiple data sources through an API (Application Programming Interface) without the need for data sharing agreements or a central data repository. Geographic information systems (GIS) interfaces can visualise data to support decision-making in managing responses to incursions in real time across a range of spatial scales and management contexts. At broader scales, GIS-based surveillance systems integrate spatial and temporal information to support the real-time detection and monitoring of animal disease outbreaks (Norstrøm 2001; Theng et al. 2024). At a finer operational scale, the New Zealand National Invasive Ant Programme uses GIS to support surveillance, prioritise management actions, and monitor eradication efforts for a specific invasive taxon (Peacock et al. 2025).

eDNA and DNA metabarcoding are becoming cheaper, enabling large-scale monitoring across diverse ecosystems for changes in invasive species range (Sepulveda et al. 2020; Morisette et al. 2021). These technologies have advantages over traditional visual and trapping surveillance in that they can be used to detect cryptic, early-stage species and low-density species (Brys et al. 2023) and are more affordable than conventional trapping tools. However, eDNA tools are most effective as a complement to traditional approaches, rather than as a replacement or proxy for them. As the technology matures, detection sensitivity will improve in conjunction with the optimisation of sampling regimes to get better results.

The volume of data generated by these approaches is enormous, and processing these data increasingly relies on artificial intelligence (AI) and machine learning for efficient processing and interpretation. For example, AI is used to analyse images from infrared camera traps by distinguishing target species from non-target species with predefined confidence levels, and it also underpins many other emerging technologies, including citizen science platforms (Burns et al. 2024; González-Moreno et al. 2025). The potential of data available, thanks to these new technologies, is enormous. Realising this potential nonetheless requires managing several well-documented constraints (Sepulveda et al. 2020). Molecular detections must contend with false positives and false negatives arising from contamination, transport, and degradation of genetic material. Uncertainty also remains in linking a detection to a viable, locally established population. Finally, the social acceptability and decision-readiness of eDNA evidence (whether managers and stakeholders trust and are willing to act on a positive detection) remain practical barriers to operational uptake.

Given this enormous potential for biological data, initiatives exist to develop and agree on standardized protocols for data collection and sharing, standardized data formats and controlled (Groom et al. 2015; ENETWILD consortium et al. 2020; Reyserhove et al. 2022). The Taxonomic Databases Working Group (TDWG), now known as Biodiversity Information Standards, has had a working group in place since 2024 to improve the Darwin Core standard to meet the needs of scientists, field managers and policymakers (Reyserhove et al. 2022). It aims to improve the findability, accessibility, interoperability, and reusability (FAIR) of reporting and management data. Further, Indigenous data sovereignty can be supported by the adoption of CARE (Collective benefit, Authority to control, Responsibility and Ethics) principles, which ensure inclusive and ethical data management (The Global Indigenous Data Alliance GIDA-global.org, Septembre 2019). Several initiatives have explored the operationalisation of FAIR and CARE principles, making Indigenous Peoples and local communities central to data management and use on their lands (Carroll et al. 2021, 2022; Gudde et al. 2026). Indeed, data that are well-documented through compliance with FAIR criteria have been found to be easier to manage when implementing the CARE principles (Carroll et al. 2021), suggesting that the two frameworks can be mutually reinforcing. Practical tools such as Traditional Knowledge Labels can further support this integration by allowing Indigenous communities to maintain cultural protocols over their data while enabling broader sharing where appropriate (Carroll et al. 2021). These steps are essential to enable the integration of data from sometimes very disparate sources through federated, interoperable databases and workflows (Groom et al. 2023, 2025).

While there is growing consideration of the importance of standardized biological data, socio-economic and technical data relating to management processes are harder to collect and share, despite this being just as necessary for evaluating management success. At the species level, the Global Register of Introduced and Invasive Species (GRIIS) is a comprehensive, global database that provides country-wise checklists of introduced (naturalized) and invasive species, supporting efforts to monitor, manage, and report on biological invasions and their impacts on biodiversity and ecosystems (Pagad et al. 2018). Aquatic invasions are still underrepresented in global databases and reliable records are dispersed and patchy. At the national level, different initiatives centralise data and knowledge, such as the French Centre de Ressources Espèces Exotiques Envahissantes, which has been compiling feedback since 2013 based on a consistent methodology, presenting the management approaches taken, the technical practicalities, the financial and human resources required, and the results obtained for more than 120 management interventions (Joly 2024). Also, the Cambridge Conservation Initiative is currently co-designing a platform allowing dynamic evidence collation on IAS management actions to guide practitioners and policymakers (Cambridge Conservation Initiative 2025). Although yet to be fully developed, these platforms offer the potential to be widely used for recording management actions based on technical, economic, and social features.

Collaborative management programmes necessitate the development of metrics able to assess social networks, processes, and outcomes (Graham et al. 2022; Abeysinghe et al. 2023). Social network analysis offers a means of assessing the extent to which a project consolidates pre-existing relationships while also generating new linkages with stakeholders who are typically excluded from conventional management initiatives (Rickowski et al. 2025). Participant feedback can also provide critical insights into social processes, including perceptions of transparency and the degree to which individuals feel they are treated with respect (Graham et al. 2022). However, without commonly agreed metrics, success evaluation may lead to subjective and inaccurate opinions on the effectiveness of management, potentially affecting credibility or funding allocation (Abeysinghe et al. 2023).

With regard to management costs, the global InvaCost database (Diagne et al. 2020) includes a range of data sets allocated to different geographical areas based on a standardised methodology for searching references throughout peer-reviewed and grey literature (Diagne et al. 2020). Although this centralisation of cost data is commendable, questions remain regarding how representative it is of current management costs, given the lack of systematic recording of intervention costs in practice, both by public authorities and managers in the field. Cost reporting spans many distinct cost components: the purchase costs of field equipment, the hourly costs of intervention teams, the labour hours required for each intervention, the cost of communication campaigns, the costs of developing and maintaining information systems and data-sharing platforms, the costs of border controls, and the costs of applied research for management. All of these form an integral part of management in the broad sense. Because such records are frequently incomplete, however, reported cost estimates remain very conservative. Systematic recording of costs across all components of biological invasion management is essential for a robust evaluation of intervention effectiveness. When these financial data are integrated with the ecological data described earlier, such as reductions in target species' abundance or distribution, recovery of native communities, or improvements in ecosystem functions, it becomes possible to establish a link between the resources invested and the ecological benefits achieved. This integration not only facilitates cost-effectiveness analyses and comparisons among management strategies but also provides a strong basis for optimising resource allocation and supporting evidence-based decision-making by managers and authorities (Reyns et al. 2018).

Understanding success and failure

Transforming management data into actionable insights relies on indicators that link interventions to outcomes, enabling progress to be assessed in a standardized and timely manner. This is illustrated by the Prince Edward Islands (South Africa), where a suite of 24 indicators was used to assess invasive species status, guide eradication and control priorities, identify gaps in biosecurity and monitoring, and track management progress over time (Fernández Winzer et al. 2025). Such indicators, defined on the basis of explicit and measurable objectives, make it possible to link management efforts to observed outcomes and to assess progress in a standardized and timely manner. They play a key role in translating dispersed observations into synthetic, comparable, and interpretable information. However, establishing standardized indicators remains a global challenge, as definitions, data availability, and national reporting frameworks vary widely across taxa and regions. Without such an indicator framework for management, the long-term evaluation of success would remain fragmented and would limit the capacity to improve management strategies or to justify their effectiveness to decision-makers (Pergl et al. 2020).

Recent years have also seen a number of initiatives aimed at developing relevant indicators and workflows for reporting on biological invasions in different national, regional and, international contexts (Vanderhoeven et al. 2017; McGeoch and Jetz 2019; McGeoch et al. 2021, 2023). Despite being central to assessing the success of interventions aimed at preventing and mitigating the impacts of biological invasions, the development, adoption, and application of indicators remained largely insufficient. Vicente et al. (2022) showed that few response indicators exist for measuring successes of policy and management actions, and those found were local to regional in scale and mostly focused on individual species. For example, the Target 6 of the Kunming-Montreal Global Biodiversity Framework has a single headline indicator, “rate of invasive alien species establishment”, without providing a real framework for monitoring (Hughes and Grumbine 2023). No indicator is proposed to address management effectiveness, although, paradoxically, the same framework proposes a set of guiding questions for national target-setting that focus on effectiveness of prevention, management, control, eradication and their potential for improvement (CBD 2024), as well as the potential ecological, economic, and social opportunities and constraints in taking actions towards the target. Beyond good intentions, it is legitimate to question the operationalization of these approaches. The IPBES IAS assessment identified a set of options for strengthening the information value of biological invasion indicators and their relevance for policy (McGeoch et al. 2024c). In particular, this includes prioritising research need to support robust scientific formulations of indicators, the metrics on which they are based, how they are modelled, and the interpretation of associated uncertainty.

Adjust strategies: towards adaptive management

The very purpose of evaluating management lies in the possibility of actively improving actions based on the results obtained. Although this may seem self-evident, to what extent is the process of dynamically adjusting management actions an integral part of biological invasion management in practice?

Adaptive management is often proposed as an approach to the conservation of biodiversity and ecosystem services that bases decision-making on the ability to account for the complexity and uncertainties of socio-environmental systems. As a stepwise process of learning and adaptation, it uses structured decision-making to learn, incorporate new information, set management goals, and improve future decision-making (Buckley 2008; Månsson et al. 2023; Roux et al. 2025). Practical frameworks and case studies operationalize this approach at different scales, including for the management of biological invasions (Foxcroft 2004; Leffler and Sheley 2012); Richardson et al. 2020; Thompson et al. 2025). For example, the South African National Parks have experienced a substantial change in the thinking and practice of management stakeholders, allowing the establishment and implementation of an adaptive management framework (Foxcroft and McGeoch 2011; Roux et al. 2025). Beyond the iterative process based on the sequence ‘plan-act-monitor-evaluate-adjust’, their approach focuses explicitly on developing mutual understanding and appreciation by stakeholders regarding the socio-environmental dynamics surrounding management and the assessment of the response of ecosystems to management actions (Roux and Foxcroft 2011). Monitoring data coupled with threshold-linked indicators and forecast modelling are used adaptively to support decision-making processes, modify management strategies if needed and potentially revise objectives (Foxcroft 2009; Uden et al. 2015; Lambin et al. 2020).

Importantly, shifts towards such adaptive management workflows require governance systems that allow for flexibility (Månsson et al. 2023). Inadequate institutional structures and poor coordination among governance actors can prevent synergies that enable knowledge sharing and create uncertainty about who is responsible and who has the legitimacy to act.

In many practical situations, management is essentially adaptive even when formal adaptive management frameworks are difficult to implement (Foxcroft and McGeoch 2011). Managers, practitioners, and local communities often adjust surveillance, control measures, and stakeholder engagement in response to field experience and the outcomes of previous interventions. These changes are typically made incrementally as new challenges emerge. Such informal learning helps maintain management under changing or resource-constrained conditions, although lessons learned are not always documented or shared beyond the individuals and organisations directly involved.

Governance arrangements must evolve to facilitate adaptive management by providing the institutional conditions for coordination, flexibility, learning, and the integration of new evidence and diverse social values into collective decision-making through multi-actor networks that link science, policy, and local practice (Norton and Steinemann 2001; Maris and Béchet 2010; Miyanaga and Nakai 2021; Månsson et al. 2023). It must be acknowledged, however, that alternative or complementary approaches to adaptive management may be more appropriate depending on constraints related to monitoring, available resources, or policy contexts. These include structured decision-making (Liu et al. 2012), precaution and risk-based prioritisation (Robertson et al. 2020), scenario planning (Buchadas et al. 2017), and resilience-based or Indigenous-based frameworks (Wehi et al. 2023).

Communicate on management results, success, failure, and lessons learned

Communication fulfils several operational and social functions that directly impact management success, shaping, among other things, trust and perceived legitimacy (Hart and Larson 2014; Estévez et al. 2015; Reaser et al. 2020; Verbrugge et al. 2021; Golebie et al. 2022). To achieve this, transparency must be ensured regarding the decision-making processes that define management objectives, the human and financial resources deployed, the results of management actions, whether successful or unsuccessful, and on lessons learned from both technical and socio-economic perspectives. In this regard, communication also plays a fundamental role because, as mentioned earlier, disclosure of information on project failure provides an important learning opportunity (Catalano et al. 2019; Dickson et al. 2023), essential in any adaptive management initiative.

Expanding best practices can be achieved through a wide range of media, including conferences, stakeholder meetings, workshops, networks, newsletters, magazines, newspaper articles and books on biological invasions management. The Trialogue approach—a facilitated dialogue model that deliberately convenes three constituencies (commonly science, policy, and practice or society) to build shared understanding and co-develop solutions—developed by the Biodiversity and Ecosystem Services Network (BES-Net), was implemented following the IPBES IAS assessment in Central and West Africa to engage practitioners from Benin, Côte d'Ivoire, the Democratic Republic of Congo, Gabon, Senegal and Togo in establishing an inclusive multi-stakeholder framework for communication and joint development of strategies and action plans (BES-Net 2024a, 2024b). Such an approach therefore supports the co-development of management options by integrating multiple knowledge systems, and the social learning needed for adaptive management.

Reference projects, such as multi-scale cross-sectoral projects, projects focusing on a shared pathway (e.g., river or basin) or programmes involving multiple countries with shared languages or ethnic groups, can act as platforms for the exchange of knowledge and experience. Such projects can also be used for disseminating the results of on-going management actions in test areas (López-Cañizares et al. 2025). This is important because geographic location influences stakeholder's perception of IAS (Shackleton et al. 2019) and there may be practical inter-ethnic differences when communicating Indigenous knowledge of IAS management (Reo and Ogden 2018). Civic engagement contributes to establishing co-responsibility when dealing with invasions if facilitated by appropriate communication (Zeng et al. 2021). Aligning messages conveyed with the values of the stakeholders involved in management and decision-makers for whom they are intended is particularly relevant when there are conflicting perceptions or ethical tensions surrounding management decisions

(Crowley et al. 2017; Jones et al. 2024; Haubrock et al. 2025; Latombe et al. 2025). This is also key in countries implementing pioneering management strategies or with early attempts at management measures (Schulz et al. 2021). In these situations, appropriate communication that fully embraces the diversity of social values of the target audience can reduce potential conflicts and misunderstandings or help to establish trust. This holds even at the earliest stages of an invasion, when species and their impacts are still largely invisible. When communication is well handled, it can also mobilise citizens to participate in monitoring or management activities (Novoa et al. 2018).

Conclusion

Biological invasions are a major threat to biodiversity and ecosystem services and, their prevention and control remain one of the most achievable and cost-effective means of protecting and restoring threatened species and ecosystems. Evaluating success in managing biological invasions, however, requires more than ecological benchmarks. It requires inter- and transdisciplinary approaches that integrate environmental, social, and economic objectives as long-term value and investment will only be achieved through the delivery of co-benefits. Success evaluation cannot be viewed on a short time scale but must be understood as a continuous, long-term process of positive change and benefit based on adaptive learning and shared responsibility among stakeholders. Managing biological invasions is a core priority for most land management-focused community groups as perceived cost-effectiveness and feasibility bring them naturally together under environmental stewardship (Donaldson and Mudd 2010). There is also a need to embrace interdisciplinary frameworks that inclusively span animal, plant, human, and environmental sectors including through One Health and One Biosecurity (Hulme 2020b, 2021).

By investing in inclusive governance, adaptive and standardized approaches, data systems, and the identification and recognition of co-benefits, adaptive management provides the best pathway to long-term funding. Communication that encompasses both successes and failures will also facilitate the transition towards management frameworks that contribute to 'Nature' and 'People Positive' outcomes. Building directly on the IPBES IAS assessment, the roadmap presented here (Fig. 1; Table 1) is offered in this spirit. While it may appear to be an unattainable ideal, is it in fact a flexible scaffold where each of the steps offers opportunities for progress both independently and collectively. Each step can be implemented, scaled, and sequenced according to local capacity. Progress will often be incremental (Adams et al. 2021), and incremental progress, transparently reported, is itself a form of success so that we should not let the perfect become the enemy of the good. Ultimately, mitigating the threat of biological invasions offers one of the most cost-effective means of managing threats to biodiversity and ecosystem services. Success will depend on our ability to implement these principles at all scales driven by technological solutions that enable local actions and contribute to meaningful global progress toward biodiversity and One health.

The analysis of gaps in knowledge and implementation carried out as part of the IPBES assessment on invasive alien species (Roy et al. 2024b) has identified several research questions relevant to the discussion we have conducted in this article. These include, for example developing design principles for integrated governance systems to manage biological invasions, identifying mechanisms for effective collaboration between the various components of socio-ecological systems, and improving control options for marine invasive alien species and invasive microbial and fungal pathogens affecting plants and animals (Renard Truong et al. Submitted). Addressing these issues will be essential to translating our roadmap into more meaningful management of biological invasions.

The roadmap proposed here is consistent with the priorities identified in the IPBES IAS Assessment and with the broader ambition of 'Nature Positive' approaches to halt and reverse biodiversity loss. We hope that it will contribute to these efforts by promoting a more integrated approach to biological invasions management that can be applied across policy, research, and practice in a wide range of ecological and governance contexts.

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Data availability No new data was generated as part of this work.

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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