Received: 3 November 2023 | Accepted: 20 May 2025

DOI: 10.1002/pan3.70073

BRITISH ECOLOGICAL SOCIETY People and Nature

REVIEW AND SYNTHESIS

Expanding the Resist–Accept–Direct framework for developing nature-based solutions and societal adaptations to biological invasions

Ninad Avinash Mungi[1] | Alejandro Ordonez Gloria[1] | Rajat Rastogi[2,3,4] | Jens-Christian Svenning[1]

[1]Department of Biology, ECONOVO (Center for Ecological Dynamics in a Novel Biosphere), Aarhus University, Aarhus, Denmark

[2]Helmholtz Centre for Environmental Research (UFZ), Leipzig, Germany

[3]German Center for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany

[4]Martin Luther University, Halle, Germany

Correspondence
Ninad Avinash Mungi
Email: shastri.ninad@gmail.com

Funding information
Villum Fonden, Grant/Award Number: 16549; Danmarks Grundforskningsfond, Grant/Award Number: DNRF173; Deutscher Akademischer Austauschdienst, Grant/Award Number: PKZ: 91865186; GLOBALI

Handling Editor: Shonil Bhagwat

Abstract

1. Biological invasions threaten biodiversity and human well-being, making invasive species management a global necessity. Despite substantial investments in engineering-based management approaches, preventing invasions is becoming harder with rising species introductions. Additionally, widespread use of a few control methods raises ethical concerns, demands long-term human control over natural ecosystems and risks unintended socio-ecological impacts. Hence, there is a growing interest in alternatives that strengthen ecological processes to control invasions, aiming to enhance ecological autonomy while reducing dependence on intensive human control.
2. Nature-based solutions (NbS) for biological invasions coupled with the Resist–Accept–Direct/Adapt (RAD+) framework offer a promising alternative. Here, we define NbS for biological invasions as 'measures developed to strengthen ecological processes that control biological invasions and their undesirable impacts, enhancing long-term ecological autonomy, resilience, and human well-being, with the potential to scale through ecological and social feedback'.
3. NbS for biological invasions are context-specific, bottom-up and require flexibility for objective application. To guide their contextual implementation, we reconceptualize the RAD+ framework, allowing stakeholders to either resist invasion by strengthening ecological processes that limit invasive species, accept invasions and direct mixed-species communities towards a state with native species dominance, or accept invaded ecosystems and assist societal adaptation to mitigate negative impacts.
4. By reviewing global case studies, we highlight the scalability of NbS across spatiotemporal contexts. These solutions strengthen ecological processes that control invasive species, support native biodiversity and contribute to climate change mitigation, while benefiting and empowering Indigenous Peoples and Local Communities. By limiting intensive human control of ecosystems, NbS for

biological invasions help address ethical dilemmas associated with lethal and pervasive management practices.

5. *Synthesis and applications*: Integrating NbS for biological invasions into policies and research using the RAD+ framework can reduce the negative outcomes of human interventions in ecosystems, strengthen ecological autonomy and pave the way for sustainable and socially just approaches to invasive species management.

KEYWORDS
biodiversity, ecological restoration, invasive species management, novel ecosystems, resilience

1 | INTRODUCTION

In the Anthropocene, the spread of human-introduced species has become nearly ubiquitous, with even the least modified ecosystems no longer immune to their presence (Hughes et al., 2020). These introduced alien species and the socio-ecological disruptions they cause have become emblematic of human-driven global change and are collectively referred to as biological invasions (Table 1) (Seebens et al., 2017). Invasions trigger cascading effects on ecosystem functioning, human livelihoods and economies, potentially undermining the overall quality of life (Pyšek et al., 2020). Their consequences have ranged from intensifying pandemics (Bertelsmeier & Ollier, 2020) to contributing to biodiversity declines (Bellard et al., 2016) and inflicting substantial economic losses (Diagne et al., 2021). A recent global assessment has underscored both the widespread impact of invasions and the urgent need for their effective control strategies (IPBES, 2023). In response, interventions have typically focused on intensive management across large spatial scales (Sankaran et al., 2024), including control or eradication of invasive species through engineering-based solutions that rely heavily on industrial, chemical or biotechnological tools. These approaches often imply continuous human oversight, such as weeding or culling, and rarely result in ecosystems free of invasions or resilient to invasions (Kopf et al., 2017). The cost of such methods has exceeded USD 120.5 billion over the last five decades (Diagne et al., 2021), yet despite this investment, invasive species remain increasingly difficult to manage in our highly interconnected world (Seebens et al., 2021). Moreover, the indiscriminate use of lethal methods has raised ethical questions, especially when outcomes fall short of intended goals (Estévez et al., 2015; Kopf et al., 2017). The IPBES assessment underscores the need for adaptive management approaches that are tailored to local socio-ecological contexts to develop cohesive and objective actions.

In many cases, the scale of invasions has far outpaced the capacity of conventional methods to yield meaningful outcomes. For example, over two-thirds of India's forest and open ecosystems (~750,905 km^2) are invaded by at least 11 alien plant species (Mungi, Qureshi, & Jhala, 2023), and their total removal would demand resources many-fold greater than the national environmental budget (Mungi et al., 2020). Engineering solutions, such as using bulldozers for removing invasive plants or routine chemical applications, may offer short-term, localized success (Bhagwat et al., 2012). Still, they are often cost-prohibitive when implemented at landscape scale, with potentially several undesirable social and ecological ramifications (Bergstrom et al., 2009; Fleischman et al., 2020; Zavaleta et al., 2001). Can such conventional, costly methods guarantee a return to pre-invasion ecological baselines? Merely removing invasive species cannot always ameliorate the declining biodiversity or ecosystem services, particularly when climate change and land degradation have co-driven these declines (Díaz et al., 2019). Even with successful eradication, global changes may prevent ecosystems from returning to their historical baselines (Lampert et al., 2014) and moreover, controlling invasive species populations in isolation from the broader pressures of global change, especially when invasive species are 'passengers' of exogenous pressures, risks overlooking the root causes of their persistence and spread (Essl et al., 2020). For example, increasing intensities of wildfires and fragmentation in the Amazon forest facilitate invasion of alien grasses, which may not be controlled effectively without addressing the underlying loss of native forest (Silvério et al., 2013). In this context, there is a pressing need for an alternative, ecosystem-based paradigm that offers sustainable solutions considering biological invasions and the concurrent pressure of climate change and biodiversity loss (Cohen-Shacham et al., 2019; IUCN, 2020).

What is required is a robust framework that consolidates the uncertainty inherent in invasion management and supports adaptive, forward-looking strategies for practitioners and policymakers (Heller & Hobbs, 2014). This includes developing more nuanced ways to differentiate between harmful and benign alien species (Blackburn et al., 2011; Lemoine & Svenning, 2022) and reassessing how invasions are prioritized and managed. Amidst growing recognition of the limits of conventional methods, a paradigm shift is emerging, one that seeks not just to remove invaders, but to harness ecological processes for more resilient outcomes.

Here, we explore a suite of nature-based solutions (NbS, as defined in Table 1) (Seddon et al., 2021) to transform the way we address biological invasions. We argue that NbS offer a pathway to mitigate the undesirable impacts of invasive species while simultaneously sustaining biodiversity, enhancing ecosystem services and reinforcing the long-term viability of management interventions. Building on this, we demonstrate how NbS can be strategically implemented through adaptive, scale-sensitive expansion of

TABLE 1 Concepts and their meanings as used in this manuscript.

Concept	Meaning
Alien species (synonymous to introduced species)	Species that are introduced to a new locality by human agency and have established self-sustaining populations there (IPBES, 2023)
Biological invasion	The process of intentional or unintentional transport or movement of a species outside its natural range by human activities and its introduction to new regions, where it may become established and spread (IPBES, 2023; Roy et al., 2024)
Control of invasive species	Strategies and actions taken to manage, mitigate or eradicate invasive species that threaten ecosystems, biodiversity and human activities (IPBES, 2023)
Ecological autonomy (synonymous to nature's autonomy or self-sustaining ecosystems)	Degree to which an ecosystem can maintain its structure, function and processes independently of human management or artificial inputs, relying on natural feedback mechanisms to sustain its resilience and adapt to environmental changes (Odum, 1969)
Ecological processes	The flow of energy and materials through the biotic and abiotic components of an ecosystem. It includes many processes, such as biomass production, trophic transfer through plants and animals, nutrient cycling and heat transfer (IPBES, 2018)
Ecological restoration	The process of assisting the recovery of ecosystems that have been degraded or destroyed, as well as conserving the ecosystems that are still intact (United Nations Environment Programme [UNEP] & Food and Agriculture Organization of the United Nations, 2022)
Ecosystem-based adaptations (synonymous to Nature-based adaptations)	Use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change at local, national, regional and global levels (United Nations Environment Programme [UNEP], 2019)
Invasive alien species	A subset of introduced species that have negative impacts on the environment, society or economy (Roy et al., 2024)
Mixed-species community	Used here to refer to a community of species consisting of a mix of populations of both native and introduced species, and where the number of introduced species present can range from one to several (McGeoch, Clarke, et al., 2024; McGeoch, Ordonez, et al., 2024)
Native species	Species within their natural range, including those shifting their range, without human involvement (IPBES, 2023)
Nature-based solutions	Actions to protect, sustainably manage and restore natural or modified ecosystems, which address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2020)
Novel ecosystems	Self-reinforcing systems which have biotic or abiotic structures different from historical baselines, as a result of direct or indirect human agency (Hobbs et al., 2006; Kerr et al., 2024).
Resilience	The ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions (Van Meerbeek et al., 2021)
Trophic rewilding	Ecological restoration strategy that uses species introductions to restore top-down trophic interactions and associated trophic cascades to promote self-regulating biodiverse ecosystems (Svenning et al., 2024)

frameworks, such as the Resist–Accept–Direct (RAD) model (Lynch et al., 2021). To strengthen our suggestions, we provide real-world examples of NbS-aligned strategies that address invasive species within the broader context of ecosystem change. Finally, by positioning biological invasions within an ecosystem-centric lens, we highlight how NbS can generate potentially cohesive solutions to multiple global challenges. Across these arguments, we underscore the value of NbS in supporting ecosystem managers to design context-sensitive, effective and socially acceptable interventions. This includes enhancing nature's contribution to the good quality of life of particularly nature-dependent people. We conclude by identifying key knowledge gaps, emphasizing the need for research to provide further evidence to support the RAD framework for NbS for biological invasions and avoiding the temptation of considering NbS as a one-size-fits-all solution.

2 | NbS FOR BIOLOGICAL INVASIONS

Nature-based solutions have emerged as a flagship concept to guide innovative actions for protecting and restoring ecosystems (Table 1), while delivering simultaneous benefits for biodiversity and human well-being (Cohen-Shacham et al., 2019; IUCN, 2020). These solutions encompass both long-standing ecological processes and novel interventions, such as natural climate solutions, which are inspired by nature and informed by ecosystem functioning (Seddon et al., 2021). In practice, NbS aim to initiate targeted interventions that ultimately enhance the self-regulating capacity of ecosystems, building ecosystems' autonomy and resilience (Table 1) to exogenous stressors over the long term (Seddon et al., 2020). At their core, NbS are bottom-up approaches that are inspired by unique characteristics of ecosystems and are scaled contextually, responding to ecological and social conditions across regions (Eggermont et al., 2015). When applied to managing biological invasions, NbS should aim to achieve both ecological and social outcomes: protecting biodiversity, enhancing human well-being—particularly for Indigenous Peoples and Local Communities (IPLCs)—and offering economically and ecologically feasible pathways for scalable implementation (Cohen-Shacham et al., 2019). To support this vision, we propose a working definition of NbS for biological invasions:

> Measures developed to strengthen ecological processes that control biological invasions and their undesirable impacts, enhancing long-term ecological autonomy, resilience, and human well-being, with potential to scale through ecological and social feedbacks.

The ecological rationale behind this framing of NbS stems from the evidence that many alien species fail to lead widespread invasions due to inherent biotic resistance and self-regulatory mechanisms within ecosystems (Williamson & Fitter, 1996). Even if contextually true, this pattern highlights the potential for leveraging ecological processes while managing invasions so as to reinforce ecological processes for invasion control.

The classification of an action as 'nature-based' requires objective evidence. What constitutes 'nature' in intervention strategies can be as contentious as defining nature itself (Simberloff, 2014). For this reason, we argue for clarity in defining nature in two aspects of the intervention: (1) the goal: interventions must lead to a desirable and resilient state of the natural system with ecological autonomy (Table 1), and (2) the intervention itself: actions must enhance the role of ecological processes (Table 1) and entities. For this review, we assume that the long-term goal of managing biological invasions is to reduce their negative impacts on both ecological and social systems. This includes halting biodiversity loss, preserving ecological interactions and maintaining ecosystem services that underpin human well-being. Furthermore, for an intervention to qualify as NbS, it must be inspired by fundamental ecological mechanisms that support the resilience of the ecosystem (Seddon et al., 2020). For example, in tropical grassy biomes, the abundance of invasive plants may be reduced either through wild herbivore grazing (Guyton et al., 2020) or through mechanical removal, such as bulldozing or clearcutting (Sample et al., 2019). While both are 'disturbance-based' interventions, only the former harnesses natural ecosystem processes. By conserving viable consumer populations, ecosystems can resist invasion, promote native plant regeneration and reduce the need for repeated human intervention, making this approach a more enduring, ecosystem-embedded NbS. In contrast, mechanical removal requires ongoing human input and carries greater uncertainty in post-removal outcomes, such as the re-invasion of alien plants due to the disruptive impacts of mechanical methods (Sample et al., 2019). The former aligns more closely with NbS principles, as it builds on natural processes, enhances biodiversity and supports a more autonomous ecosystem response (IUCN, 2020).

Reducing human interventions does not entail dissociating people from ecosystems. Many ecosystems are embedded within cultural landscapes shaped by a legacy of traditional use, where local interventions are related to biodiversity conservation and the regulation of ecological processes (Reyes-García et al., 2024). Given their intrinsic link to human well-being, NbS must also consider how people interact with and depend on the ecosystems (Cohen-Shacham et al., 2019). Cultural dependence, particularly the extractive dependence on resources like plant biomass, can potentially create temporary disturbances in the ecosystem that favour invasive plant spread (Mungi et al., 2020). NbS must buffer native ecosystems in the post-management phase from the impacts of such disturbances while promoting resilience to withstand future disturbances. Considering the interplay between human intervention, provision of ecosystem services and ecosystem resilience (Table 1) is thus crucial in developing NbS (Eggermont et al., 2015), making NbS a multi-faceted and complex approach.

The socio-ecological complexity implicit in NbS creates opportunities for inclusive, locally adapted management in the face of rapid environmental change and shifting human dependencies. For example, *Prosopis juliflora* is an ecologically damaging invasive plant valued for its fuelwood and fodder in arid regions of Africa and South Asia (Shackleton et al., 2014). Here, the NbS approach might not aim solely at eradication, but rather promote adaptive strategies, such as education campaigns to shift community perceptions and encourage sustainable alternatives. These efforts can halt anthropogenic propagation of alien plants while allowing for phased removal of established plants using ongoing local interventions (Sharma et al., 2024). Coupled with restoration of native vegetation and fire-herbivory regimes, this approach would promote long-term resistance to re-invasions, thus strengthening ecological processes to naturally control invasions. Such inclusive strategies can help secure ecosystem services like grazing resources for livestock, while reinforcing native biodiversity and ecosystem resilience. Ultimately, NbS for biological invasions must be guided by clear management goals; whether focused on invasive species removal, restoration of native biodiversity or both. Development of such objective solutions requires a heuristic and adaptive approach that can accommodate ecological complexity, social context and evolving priorities over time.

3 | ALIGNING NbS FOR BIOLOGICAL INVASIONS TO THE RESIST–ACCEPT–DIRECT/ADAPT (RAD+) FRAMEWORK

Frameworks based on dynamic, adaptive management have been increasingly advocated to address the complexities of rapidly transforming ecosystems globally (Lynch et al., 2021). The RAD framework proposed by Lynch et al. (2021) was developed to guide decision-making amidst ecosystem transformation. We retain the core RAD structure, which considers whether managers should resist change, accept it, or direct it towards a desirable trajectory (Aplet & Mckinley, 2017; Schuurman et al., 2022). For the management of biological invasions, we reconceptualize RAD framework as Resist–Accept–Direct/Adapt (RAD+) framework. In the case of invasive species management, interventions range from those that employ minimally intrusive actions to 'resist' the invasion of species, to responses that accept their presence. Subsequent strategies then either directly guide mixed-species communities towards desirable state with dominance of native biodiversity or support adaptive changes that help societies adjust to the novel ecosystem states induced by invasions (Blackburn et al., 2011; Pyšek et al., 2020).

Addition of 'Adapt' explicitly acknowledges the importance of societal responses to *invaded novel ecosystems*, which may emerge as an outcome of *Accept* strategies. In our reconceptualization, accepting invasions is not a solution in itself, as it entails severe undesirable impacts on biodiversity and human well-being. Acceptance of invasive species must be followed by a suite of interventions that either control the abundance of invasive species in ecosystems or mitigate the undesirable impacts of invasions. In this framing, *Accept and Direct* refers to interventions that guide ecological trajectories towards desirable states (e.g. native biodiversity recovery), which ensures harnessing ecological processes to ensure native species dominance, while securing conventional ecosystem services generated by these mixed-species communities. Alternatively, when invasive species steer a novel ecosystem state and controlling the abundance of the invasive species is not feasible, *accept and adapt* refers to strategies that mitigate the undesirable impacts of invasions. While *Direct* encapsulates ecological dynamics of mixed-species communities, *Adapt* captures the societal dimension—how communities respond and adjust to transformed ecosystems in ways that reduce harm, support well-being and may contribute positively to biodiversity and ecosystem function. The RAD+ framework better reflects the socio-ecological realities of managing biological invasions with NbS. It is designed to suit the spectrum of varying abundance and impacts of invasive species (Blackburn et al., 2011; Pyšek et al., 2020), integration of invasive species into ecological communities and interactions (Campbell et al., 2022), availability of resources and feasibility of societal adaptations (Vimercati et al., 2022) (Figure 1).

By considering factors, such as the invaded area, ecological interactions and resources available for interventions, managers can: (1) 'resist' the onset of invasions to retain pre-invasion conditions; (2) if resistance is not feasible or in case of existing widespread invasions, accepting invasions as a property of the ecosystem can help in choosing between the next two alternatives; (3a) 'direct' ecosystems along trajectories of community dynamics that favour native biodiversity despite the presence of aliens; and (3b) support societal

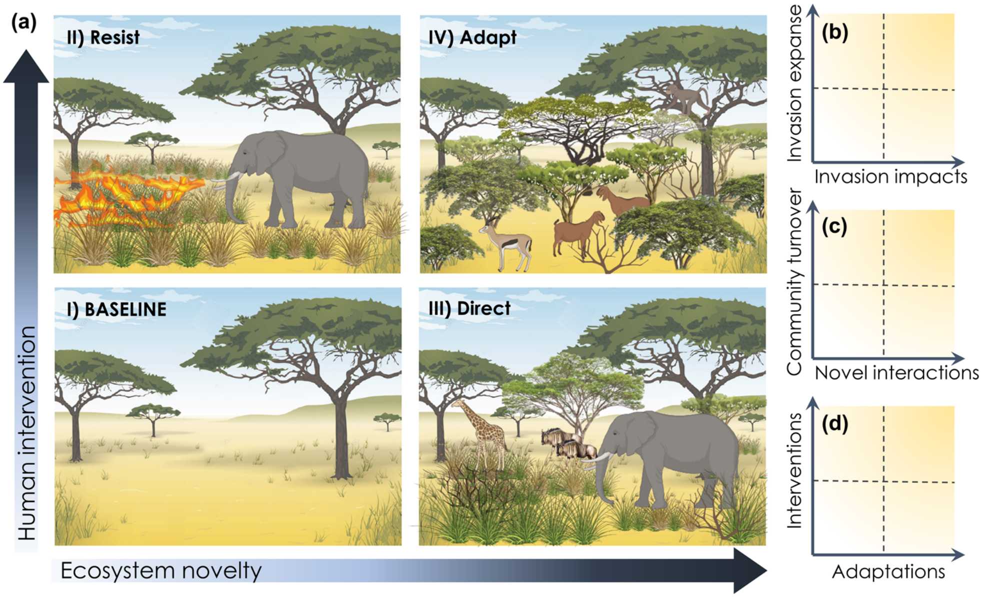

FIGURE 1 (a) Illustrating RAD+ (Resist–Accept–Direct/Adapt) framework for implementing nature-based solutions (NbS) for biological invasions in a hypothetical example of woody plant invasions in dry savannas. The type of NbS for biological invasions could be chosen based on the (b) prevalence and impacts of invasive species, (c) novel interactions between and within native and alien species and the resultant community dynamics, and (d) feasible human interventions and societal adaptations necessary for ecosystem management. In grassy savannas (i), natural or traditional fire regimes and grazing limit invasion of woody plants. Prolonged suppression of fire and herbivory, however, can weaken this natural control, facilitating plant invasions. If invasion is at an early stage, assisted burning and reintroducing large herbivores can resist invasion by removing invasive plants and promoting fire- and herbivory-adapted native species (II). In cases of large-scale, dense invasions by fire-adapted plants (III), reintroducing fire may cause intense burns and trigger further alien plant invasions. Eliminating fire altogether can also promote plant invasions and diminish native forage and herbivore diversity. Introducing herbivores with diverse feeding preferences in such contexts can reduce alien plant abundance, providing a reprieve for native species and steering the ecosystem towards a resilient, mixed-species community (III). When alien species pervasively dominate and the use of fire or herbivores is unfeasible/inconsequential (IV), local communities may adapt to the novel invaded state by harvesting alien plants or adapting grazing strategies, thus reducing negative impacts while assisting native biodiversity recovery. We view the measures aimed at resisting invasions and directing mixed communities as NbS for biological invasions, and adaptations to invaded states as nature-based adaptations.

'adaptations' to irreversible changes in ways that minimize negative societal impacts, which may promote native biodiversity (Figure 1). We use the RAD+ framework as a lens through which to envisage NbS for biological invasions—employing resist and direct strategies to guide interventions while advocating for adaptive measures when invasions exceed practical control, thereby emphasizing the necessity of nature-based adaptations (Table 1). This framework also allows flexible application across invasion scenarios. For example, when invasions are *passengers* of anthropogenic changes (e.g. forest fragmentation aiding invasive plants), eradicating invasive species population and strengthening invasions resistance by halting/mitigating the anthropogenic change (e.g. restoring native forest plants) can be the option. If invasions are pervasive, becoming *drivers* of complex changes, mitigating their undesirable impacts through nature-based adaptations (e.g. switching the dependence from native plant biomass to invasive plant biomass) may be a pragmatic option. We have listed examples of NbS for biological invasions aligned to RAD+ in Table 2 to outline the importance of contextuality.

3.1 | Resist

Nature-based solutions in the resist category target the inherent ecological processes that limit the establishment or spread of invasive species, thereby conserving the native species composition (Beaury et al., 2020; Mungi et al., 2021). This approach is particularly effective in the early stages of invasion, when the spatial expanse and impact of invasive species are still limited and have not become fully integrated into community interactions (Figure 1b,c). We identify five key ecological processes—consumption, competition, rewiring of ecological associations, ecosystem interactions and natural disturbance regimes—that can naturally prevent biological invasions (Table 2). For instance, on islands in Indonesia, the endemic toad *Ingerophrynus celebensis* preys on the alien ant *Anoplolepis gracilipes*, thus potentially serving as a natural control (Wanger et al., 2011). In Hawaiian Acacia koa forests, a dense canopy structure can competitively limit the spread of alien understorey grasses, such as *Pennisetum clandestinum* and *Ehrharta stipoides* (Funk & McDaniel, 2010). Such examples highlight how biotic resistance is bolstered by ecological functions provided by native predators, competitors and their communities. Nevertheless, pervasive global change and extensive human exploitation have depleted the diversity of consumers and competitors (Dirzo et al., 2014), diminishing the ecological processes that could resist invasions. Thus, protecting biodiverse ecosystems from disturbances, curbing poaching and restoring functional diversity can serve to support NbS that promote natural resistance (Table 2). Yet in today's largely defaunated and degraded landscapes (Dirzo et al., 2014), merely declaring an area as protected from human impacts would be insufficient to harness ecological processes that resist invasions. Active conservation and restoration measures that promote trophic control and ecological autonomy are needed (Svenning et al., 2024). While such proactive measures may require sustained, though intermittent, human involvement, they help strengthen ecological self-regulation in contrast to continual, resource-intensive engineering solutions.

Given the dynamic nature of ecosystems, resistance should be seen working alongside inherent ecological variability (Aplet & Mckinley, 2017). Therefore, we assume that ecosystem variability driven by inherent ecological functions and mechanisms can add to the diversity of ecological interactions that synergistically resist invasions (Turner, 2010; Van Meerbeek et al., 2021). For example, natural disturbances caused by fire and flooding in tropical savannas can periodically curb the abundance of invasive plants and promote the regeneration of native flora (DeSantis et al., 2011; Te Beest et al., 2012). NbS that help maintain or restore such natural disturbance regimes—through assisted burning, controlled flooding or periodic biodiversity restoration—can enhance resistance. However, these solutions require careful contextualization; disturbances that control invasive herbaceous species in one ecosystem may, under different conditions, promote the spread of invasive plants. For example, in the Sonoran Desert, prescribed burning controls alien grass but promotes alien forb recruitment (Schwab et al., 2023). Thus, the suitability of any intervention must be weighed against local ecological settings, species traits and potential unintended consequences.

3.2 | Accept and direct

With increasing invasions, the inherent resistance and resilience of native ecosystems (Table 1) are diminishing due to multiple factors, and ecosystem managers are witnessing rapid transitions from established to emerging novel ecosystems following biological invasions (Lynch et al., 2022). With a constant rise in the prevalence of invasive species across global ecosystems (Seebens et al., 2017), transitions towards mixed communities of native and alien species (Table 1) are becoming widespread. In scenarios where mixed-species communities predominate, objectives solely focused on resisting invasion can prove inadequate, necessitating interventions that reduce the abundance of invasive species and the negative impacts of unavoidable invasions on biodiversity and ecosystem services (Figure 2).

The 'direct' approach encompasses interventions designed to leverage ecological processes to control invasive species abundance and enhance ecosystem resilience. We elaborate on four key directing interventions that can serve as NbS for biological invasions, namely, biological control, trophic rewilding, ecosystem recovery and the creation of designer ecosystems (Table 2). For example, the reintroduction of large herbivores in Mozambique's Gorongosa National Park resulted in the control of the invasive *Mimosa pigra* (Guyton et al., 2020), and the introduction of the fungus *Puccinia spegazzinii* has been used to control the invasive climber *Mikania micrantha* in Papua New Guinea and Vanuatu (Ellison & Cock, 2017). In these cases, invaders are not eradicated but rather reduced in abundance, providing a respite for native species to reassert themselves and resulting in mixed-species communities dominated by natives. Management interventions, such as reintroducing locally extinct species, implementing biological control, conducting active trophic

TABLE 2 Examples of nature-based solutions (NbS) for biological invasions with respect to the ecological or social mechanisms underlying them and key examples demonstrating the utility of NbS for biological invasions.

Underlying socio-ecological mechanisms	Key nature-based solutions (NbS) for biological invasions	Key examples
Resist		
Controlling invasion by natural consumption	Protecting the diversity of consumer guild; reviving the population of key consumers; preventing poaching of consumers; protecting natural areas with a high abundance of consumers; maintaining connectivity in different populations of consumers to ensure their long-term demographic viability	Endemic toad *Ingerophrynus celebensis* on an island in Indonesia control on invasive ant *Anoplolepis gracilipes* by predation (Averett et al., 2016). White-tailed deer *Odocoileus virginianus* in the United States control invasive plants *Celastrus orbiculatus* and *Ligustrum vulgare* by herbivory (Wanger et al., 2011)
Controlling invasion by natural competition	Protecting areas with rich native biodiversity; preventing fragmentation of terrestrial ecosystems; reviving the population of key competitors through population and habitat management	Dense native tree canopy in Hawaiian forest competitively limit invasion of understorey *Pennisetum clandestinum* and *Ehrharta* stipoides (Funk & McDaniel, 2010). Allelopathic leaf litter of many native plants in Panama inhibit growth of invasive *Saccharum spontaneum* (Cummings et al., 2012)
Resistance by native ecological communities	Preserving species richness and abundance of hyperdiverse tropical forests; preserving ecosystem engineers; restoring trophic cascades; reviving ecological functional diversity	Native plant richness protected from human impacts naturally resist alien plant invasions in temperate forests in the United States (Beaury et al., 2020). Native species richness along with structural intactness of native plant cover resist invasions in tropical wet and humid biomes in India (Mungi et al., 2021)
Resistance by mutualistic interactions between native species	Preserving functional diversity of mutualistic interactions to assist mutualistic rewiring among native species within mixed-species communities can assert dominance of native species; preventing mutualistic interactions among native and invasive species (e.g. removing flowers of invasive plants to reduce visitation by pollinators)	In South China evergreen forest, mutualistic relationships between soil biota and native plants synergistically reduce the abundance of invasive *Mikania micrantha* and *Eupatorium catarium* (Chen et al., 2017). In Patagonian temperate forests the mutualistic relationship among native plants, pollinators and seed dispersers reinforces native species diversity, reducing impacts of invasive bumblebee (Vitali et al., 2022)
Removal via natural disturbances	Reviving natural fire regime in the fire-adapted ecosystems; reviving natural flood regime in flood-adapted ecosystems	Using controlled levels of fire reduced invasions of woody plants in North America's forest-prairie ecotone (DeSantis et al., 2011); and controlled invasive *Chromolaena odorata* in South African savanna (along with mechanical control) (Te Beest et al., 2012)
Accept and direct		
Reviving lost resistance by restoring trophic diversity	Reintroducing extinct native consumer species; reintroducing native competitor species; population augmentation of megafauna; introducing a functional analogue of an extinct ecosystem engineer	In Rhode Island, Mauritius, introduced tortoises—functional analogue of the extinct tortoises, control invasive plants by herbivory (Griffiths et al., 2010). In Mozambique, trophic rewilding with mammalian herbivores reduced invasive plant *Mimosa pigra* (Guyton et al., 2020)
Introducing novel biological consumer	Evidence-based introduction of novel biocontrol agents; introduction of a host-specific disease inducing organisms; sterile insect technique	Globally, more than 450 novel control agents have been experimented to control 175 invasive plants (Schwarzländer et al., 2018). Hatchery-raised sea urchins *Tripneustes gratilla* were introduced to control macroalgae invasions on coral reefs in Hawai'I (Neilson et al., 2018)
Recovery of nature in abandoned human landscapes or areas with reduced biodiversity	Assisting trophic rewilding in abandoned landscapes for recovering ecosystems resilient to impacts of invasive species; Restoring/rewilding ecosystems by reintroducing extinct megafauna or analogous trophic complexity	Recovery of novel plant assemblage in abandoned fields in Mediterranean region assists diverse native plants and soil nutrients reducing negative impacts of invasions (Sitzia et al., 2018). Recovery of *Bison bison* in North America has reduced invasive plants in restored areas (Ratajczak et al., 2022)
Designing ecologically resilient systems	Restoring coral reefs in socio-ecologically appropriate areas; planting mangroves in suitable conditions; integration of alien species with benign or positive impacts; integrating climatic range shifters to create resilient ecosystems under climate change	Restoring mangroves increased ecological complexity and resists invasive species (Suarez-Menendez et al., 2020); climate change induced range shifting species can add to ecological complexity and reduce the negative impacts of invasive species (Cranston et al., 2022)

(Continues)

TABLE 2 (Continued)

Underlying socio-ecological mechanisms	Key nature-based solutions (NbS) for biological invasions	Key examples
Accept and adapt		
Harnessing values of invasion induced alternate state	Valuing and conserving novel ecosystems; utilizing novel interactions in native and alien species to promote biodiversity and resultant resistance to future invasions	Accepting the dense forest developed by alien plants on Ascension Island can retain novel biodiversity (along with restored sites for native species) (Wilkinson, 2004). Globally, introduced dispersers can assist certain plants (e.g. those who rely on birds/mammals to disperse seeds) to follow changing climate (Fricke et al., 2022)
Autochthonous adaptations by human societies	Local behavioural changes by people for reducing the harvest of invasion impacted native species; utilizing alien species as a resource to shift explicit dependence on native species	Local communities in Central India harvest multiple alien plants for medicinal and ethnic use thereby reducing invasions and benefiting from it (Wagh & Jain, 2018). Communities in the Western Ghats have switched from using native plant biomass to invasive *Lantana camara* biomass for livelihood sustenance, which allows native plants to recover and potentially limit invasions (Howard, 2019; Kannan et al., 2014)
Planned adaptations by human societies	Replacing commercially important native species impacted by invasions, with alien species; industrial scale utilization of invasive species for livelihood opportunities to people who lost resources due to invasion; commercial production of pharmacological applications, bioactive compounds, etc. using invasive species	Industrial utilization of marine invasive species for use in pharmacological applications is suggested to reduce invasion while benefitting financially (Giakoumi et al., 2019). In Caribbean and western Atlantic, invasive marine fishes are commercially consumed for providing a reprieve to depleted native fishes and concomitantly reduce invasive fishes (Noll & Davis, 2020)

rewilding on abandoned landscapes and facilitating assisted biodiversity recovery, can serve as NbS for directing ecosystems towards a biodiverse trajectory (Derham et al., 2018). Such strategies are also effective when invasive species are removed on a large scale, and native species fail to recover due to the absence of a source population or the unsuitability under ongoing global change (Prior et al., 2018). Active ecosystem restoration using the *direct* principle may incorporate functional analogues of extinct species to counteract the impacts of dominant invasives, potentially resisting future invasions and maximizing biodiversity and its associated benefits for human well-being (Campbell et al., 2022). For example, *Aldabrachelys gigantea* and *Astrochelys radiata* tortoises were introduced in Mauritius to consume alien plants and restore the native species component in these mixed communities (Griffiths et al., 2010).

Although novel ecological trajectories remain contentious and evoke uncertainty, such uncertainties are common even following engineering-based solutions like large-scale eradication. What often follows such eradication without restoration is an unintended novel trajectory towards a functionally downgraded state prone to more invasions, due to altered environmental and biological functions (Guido & Pillar, 2017; Reynolds et al., 2017). Given the high prevalence and long-term persistence of alien species in many ecosystems (Figure 1b), their interactions with native species—ranging from detrimental to facilitative (Figure 1c)—can be significant (Simberloff & Von Holle, 1999). Thus, directing mixed-species ecosystems towards desired biodiverse trajectories requires the careful activation of ecological processes, the promotion of novel feedbacks, emergent regulatory functions and the participation of local communities to mitigate the negative impacts of invasions and harness ecosystem services (McGeoch, Clarke, et al., 2024; McGeoch, Ordonez, et al., 2024). Nonetheless, directing ecosystems towards a desirable state is relatively feasible when invasions are moderate and have not disrupted all ecological interactions (Rastogi et al., 2023) (Figure 2). The decision to apply directing interventions must be weighed against multiple outcomes and local context. For example, while some herbivores, such as *Antilope cervicapra*, may facilitate the dispersal of the alien shrub *Prosopis juliflora* in Indian savannas (Jadeja et al., 2013), a functionally diverse herbivore guild—including megaherbivores—can reduce the abundance of other alien plants in these landscapes (Mungi, Jhala, et al., 2023). Thus, only when herbivores effectively diminish invasions should they be introduced as part of a direct intervention. Strategically, the success of directing approaches hinges on robust community ecology research and an understanding of community assembly processes, which remain complex and variable. As science for the management of mixed-species ecosystems is still emerging, further experimental research is essential to build evidence for the efficacy of these approaches.

3.3 | Accept and adapt

Adapting to biological invasions becomes critical when managers must accept the abundance of invasive species due to their social importance, the vast scale of invasions or limited capacity for control (Nerlekar et al., 2022; Thompson et al., 2021). Unlike resistance and direct interventions, adaptations aim to enhance biodiversity and societal benefits amidst prevalent invasions. Typically, when ecosystems are dominated by high abundances of alien species for extended periods, emergent interactions between aliens and natives can alter community structure and turnover, ultimately steering ecosystem

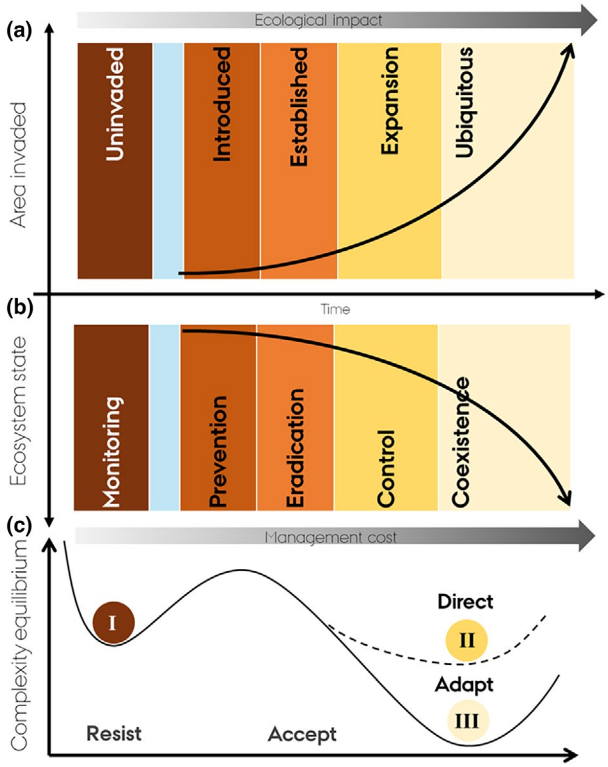

FIGURE 2 Linkage in between invasion process (a), management regime (b) and Resist–Accept–Direct/Adapt (RAD+) typology (c). (a) An alien species expands in area and in abundance over time, eventually fundamentally changing the ecosystem. (b) The management cost and ecological impacts of alien species increase with increasing abundance and the potential of restoring baseline system becomes more uncertain. (c) The invasion abundance and management options could be compared with the RAD+ framework and alternate stable state scenario, where prior to alien species introduction, a baseline state (I) comprising native species existed. Here *resisting* invasions via eradication followed by strengthening ecological processes offering resistance can help in retaining native communities. *Acceptance* of alien invasions can be imagined leading to higher expansive distribution and interactions with native species forming mixed communities. Such mixed communities can be *directed* to a desirable biodiverse state by limiting the densities of invasive species and restoring native ecological processes (II). When the invasion control is unfeasible or ineffective and have severe impacts, accepting the invaded state and assisting societal *adaptations* to harness novel ecosystem services from invaded ecosystems could guide in mitigating negative impacts of invasions (III).

trajectories under the alien species influence (Figure 1c) (Foxcroft et al., 2010; Silvério et al., 2013). Such trajectories may necessitate interventions to secure novel ecosystem services and accommodate emergent biodiversity—approaches that are inherently heuristic and require active social participation (Figure 3). We define adaptations to biological invasions as strategies designed to reduce the immediate negative impacts on human well-being, biodiversity and ecosystem services (Figure 1). These strategies are particularly important in heavily modified systems (e.g. grazing savannas and secondary forests), where societal behaviour may exacerbate the decline of native species while promoting invasive ones. Adaptations may be planned, strategized and executed via policies and institutions (Giakoumi et al., 2019), or emerge organically as individual or small group responses (autochthonous adaptations) that transform established socio-cultural practices (Howard, 2019; Howard & Pecl, 2019). We elaborate on three types of adaptations in the context of biological invasions: novel ecosystem adaptations, autochthonous adaptations and planned adaptations (Table 2).

The positive impacts of societal adaptations on biodiversity can generally be categorized into two groups: those that enhance native biodiversity and those that leverage novel ecosystem services. For instance, the involvement of local communities in managing the woody invasive plant *Prosopis juliflora* in Kenyan savannas has led to the commercial use of the charcoal made from the plant, providing renewable energy and tangible local benefits (Mwangi & Swallow, 2008). In other situations, social and management adaptations are crucial to transition livelihood practices—such as replacing the use of native plant biomass with invasive species biomass—to reduce invasion extent and protect native species (Rai & Scarborough, 2015). In India, local communities have long relied on native plant biomass for crafts and furniture; however, given the prevalence of invasive plants, several government agencies are now developing economic models in which invasive biomass substitutes native material (Figure 3). These planned adaptations often draw inspiration from autochthonous practices, where local groups have repurposed invasive biomass for small-scale production of wooden crafts (Kannan et al., 2014) (Figure 3).

4 | SYNERGIES WITH SOCIETAL CHALLENGES AND ETHICAL VALUES

A crucial aspect of NbS for biological invasions using the RAD+ framework is its alignment with a suite of global commitments and ambitions to reverse biodiversity loss, while also co-benefitting climate change mitigations (IPBES, 2023; IPCC, 2021). The resources to tackle multiple challenges threatening ecosystems and society are often limited, especially in the Global South (McGeoch, Clarke, et al., 2024; McGeoch, Ordonez, et al., 2024; Seddon et al., 2020). Investing in isolated solutions for each global challenge can exhaust these limited resources while yielding negligible impact (Turney et al., 2020). For example, smallholder pastoral communities in the Global South are increasingly affected by intensifying heat and drought, compounded by widespread invasions of woody plants that reduce native forage for livestock grazing (Bekele et al., 2018). These simultaneous stressors result in reduced grazing areas that exacerbate the negative impacts of grazing on soil carbon and plant diversity (Koerner & Collins, 2014) and result in competition with wild herbivores. In such contexts, invasive plant control must be socioeconomically feasible, and restored socio-ecological systems should remain resilient to ongoing climatic changes and invasions. Strategies, such as initially reducing the abundance of woody invasives with community participation (Nerlekar et al., 2022), followed

FIGURE 3 (a) Grassy ecosystems invaded by woody *Lantana camara* due to a legacy of historical propagation and anthropogenic land-use. Even after the anthropogenic land-use was converted to natural land-use, the invasion persisted. (b) Uprooting *Lantana camara* by the management team and involving local communities reduced the propagule pressure of the plant. (c) Assisted revegetation of native plants followed by the recovery of megafauna strengthens ecological processes that resist future invasions. This strategic use of NbS directs mixed-species communities towards native species dominance. (d) Alternatively, in areas where the restoration of ecological processes is unfeasible, local communities opt for the utilization of *Lantana camara* plant parts for making baskets and other furniture. This societal adaptation to use invasive plant biomass reduces extractive dependence on native plants and economically benefits the communities. [Photographs: (a, b) Rajat Rastogi, (c) Jayanta Bora, (d) Kannan et al. (2014)].

by restoring rotational grazing using a diverse herbivore guild (Herrik et al., 2023) and concurrently preventing fragmentation of grassy ecosystems, can serve as effective NbS. These measures not only direct ecosystems towards biodiverse grassy states but also bolster natural controls against future invasions, alleviating the adverse impacts of concentrated grazing that contributes to mitigating climate change impacts (Ren et al., 2024). While such NbS for biological invasions require integrative and participatory models, they effectively address the convergent impacts of global challenges. Failure to do so may exacerbate biodiversity loss, invasion impacts, poverty and social conflicts (McLennan, 2021). Other NbS for biological invasions can significantly align with global initiatives for mitigating climatic changes and halting biodiversity loss. For instance, protecting intact forest systems from human modification not only enhances biotic resistance to invasions (Mungi et al., 2021) but also conserves mega-herbivores that reduce invasive plants by consuming them (Mungi, Jhala, et al., 2023). Thus, declaring biodiverse forested areas as protected increases carbon sinks, stabilizes climatic patterns and provides myriad ecosystem services—an effective strategy to address multiple global challenges.

NbS for biological invasions not only have the potential to promote equitable outcomes to key stakeholders directly associated with ecosystems, such as IPLCs but also benefit from their traditional knowledge (Seebens, Niamir, et al., 2024). NbS are dependent on the meticulous knowledge about ecosystems and ecological processes that regulate biodiversity and function; however, such knowledge is often concentrated in a few well-studied regions, leaving large areas in the Global South underrepresented (McGeoch, Ordonez, et al., 2024). This gap can be bridged by collaborating with IPLCs, as their long-term traditional knowledge associated with the ecosystem proves invaluable for bottom-up planning in the development of NbS for biological invasions (Reyes-García et al., 2024). For example, in Australia, the Yellomundee Aboriginal Bushcare group uses traditional cool-burning fire regimes to suppress alien species and promote native regeneration—a method now widely adopted across northern Australia (Barber & Glass, 2015). Similar traditional practices were used by local communities in peninsular India to reduce the woody encroachment in dry savannas and improve forage production for herbivores (Ratnam et al., 2016). Suppressing these conventional practices due to colonial forestry practices has led to increased woody plant invasions in savannas and reduced ecosystem services (Shackleton et al., 2014). To avoid such undesirable outcomes while harnessing the benefits derived from local ecosystems, it is essential to strengthen the collaboration among IPLCs, scientists, and other stakeholders in devising NbS for biological invasions. For instance, New Zealand implemented a policy to strengthen community-based governance of a marine world heritage site, empowering IPLCs to proactively reduce invasion pathways and advise government agencies on suitable actions (Cunningham et al., 2019). This initiative not only improves ecological outcomes but also ensures diverse representation in ecosystem management and aligns equitable development, a win-win strategy for both ecosystem and society.

In many invasion management cases, lethal control measures can trigger ethical controversies that intensify conflicts among managers, animal welfare advocates and members of IPLCs (e.g. Bhattacharyya & Larson, 2014). Actions, such as culling and poisoning invasive animals, often generate negative perceptions because they rely on violent means and are perceived as violations of animal rights (Futhazar, 2020). In contrast, NbS for biological invasions propose using natural regulatory mechanisms, such as the introduction of natural consumers, facilitation of trophic cascades or the restoration of natural disturbance regimes, to reduce invasive populations. These approaches are seen as enacting a 'natural order' that may alleviate ethical concerns (Perry & Perry, 2008). Furthermore, NbS are viewed as acceptable forms of human intervention that ultimately aim to decouple management from continuous, heavy-handed control, thereby promoting ecological autonomy. Thus, by leveraging inherent ecological processes to achieve population control, NbS provide a more ethically and socially acceptable alternative to lethal methods. This paradigm not only addresses animal welfare concerns but also aligns with goals to restore and sustain resilient ecosystems with reduced reliance on ongoing human intervention.

5 | CHALLENGES AND OPPORTUNITIES

Although NbS for biological invasions can generate significant synergies with efforts to restore biodiversity, mitigate climate change and benefit local communities while effectively managing invasions, they are not a panacea for contemporary global challenges. The magnitude and severity of climate change and biodiversity loss far exceed what any single approach, including NbS, can achieve in isolation. Global initiatives aimed at reducing species introductions, protecting native ecosystems from degradation, cutting greenhouse gas emissions and promoting equitable benefits remain fundamental to a sustainable future (IPBES, 2018, 2023; IPCC, 2021). In regions where resources are especially scarce, particularly in the Global South, the reliance on isolated, narrow-scale, engineering-based interventions for invasion management can rapidly deplete limited funding and effort, often without delivering lasting desirable outcomes, such as invasion eradication. Such blanket applications not only risk unintended adverse impacts on ecosystems and local communities but may also exacerbate existing environmental inequities.

Engineering-based interventions remain the most popular approach to managing invasions. This popularity rests on the fact that engineering-based interventions ascertain immediate, albite temporary, removal of invasive species, whereas NbS for biological invasions demand a deeper understanding of underlying ecological processes. Unlike methods that guarantee only transient control, NbS require long-term strategies that gradually reduce invasive species and their impacts through adaptive management. Furthermore, NbS for biological invasions can hardly be generalized without rekindling context-specificity and rejecting the mechanical notion of 'one model fits all'. Hence, NbS for biological invasions are largely scale-sensitive, which can be difficult to accommodate in traditional management paradigms. Large-scale application of NbS necessitates large-scale monitoring of ecosystems, as it produces heuristic understanding of the socio-ecological dynamics vital for developing NbS. Investments are hence required for two aspects: (1) implementation of long-term large-scale monitoring of ecosystems based on scientific protocols and (2) developing experimental science to translate ecological data into management strategies.

Misinterpretations of NbS presents another major challenge. There has been growing criticism of interventions that are labelled as NbS yet fall short of the core idea of strengthening ecological mechanisms and reducing human control. For example, Miyawaki forests or tree plantations in open dry grassy areas, following invasive plant control, have been practised in Africa and South Asia under the banner of NbS. These plantations are increasingly contested due to their blanket application in ecologically unsuitable areas, the inefficacy in resisting future invasions, the resulting social injustices (Fleischman et al., 2020) and even the potential contribution to climatic warming (Rohatyn et al., 2022). NbS for biological invasions must be protected from such misinterpretations. No solution can be, by default, nature-based unless scientifically tested to have the potential to meet the desired objectives. Our study provides a flexible RAD+ framework to pick the most suitable/desired objective and implement NbS for biological solutions inspired by the local knowledge about the ecosystem.

The scale of implementing NbS for biological invasions remains a critical facet for its success. Unlike engineering-based solutions, NbS has the advantage of naturally scaling up via spontaneous ecological and social processes, and the potential of establishing ecological autonomy. However, functional biodiversity that brings most of the NbS for biological invasions is largely restricted to smaller areas (Dirzo et al., 2014), whereas biological invasions extend across broader landscapes (Seebens et al., 2024). Hence, different solutions are required for managing biological invasions in the absence of biodiversity across different land-tenure systems. For example, in a large protected areas like Mozambique's Gorongosa National Park or India's Kaziranga National Park, the restoration of a functional herbivore guild can control the abundance of invasive plants (Guyton et al., 2020; Mungi, Jhala, et al., 2023). However, the biodiversity-depauperate multiple-use areas that surround such protected areas are often densely invaded patches of alien plants, acting as a propagule for invading protected areas. Here, participatory control of invasive plant density and restoring native communities can reduce the invasion pressure on protected areas while directing the multiple-use areas towards native species dominance. Thus, NbS for biological invasions becomes a landscape strategy that requires scientific investments, policy instruments and support from society. Using RAD+ typology sequentially can be helpful in certain cases, where invasions are resisted initially to buy time for long-term efforts that direct ecosystems to a desired resilient state. The decision space is not static and might invoke uncertainty in ecosystem management; however, the optimum solution is a shifting target; what constitutes a feasible option at one time may not be so in the future (Lynch et al., 2021).

Ecological information required to design NbS for biological invasions does not alone dictate the decision on developing management actions; as with all societal decisions, cultural, policy-contextual and political factors play a role. Differences of opinion among invasion ecologists, ecosystem manager and local communities arise from a combination of scientific uncertainty along with different value systems (based on experience, culture and worldview). Uncertainties are contentious around NbS for biological invasions. But depending on the definition, such uncertainties are integral to every transforming system, particularly when the rates of transformations are unprecedented. As conservation increasingly becomes interventionist (Hobbs & Cramer, 2008), we see NbS become even more relevant to mitigate the negative outcomes of human interventions. The presence of NbS in international frameworks for biodiversity management (e.g. IPCC and CBD) has spurred their adoption in national policy instruments. As globalization increasingly mixes species from disparate parts of the planet, NbS for biological invasions holds a key role in limiting such introductions from turning into invasions. NbS for biological invasions offers opportunities to limit human control on ecosystems, while still achieving desirable outcomes in ecosystem management and aiming for ecological autonomy.

AUTHOR CONTRIBUTIONS

Ninad Avinash Mungi, Alejandro Ordonez Gloria, Rajat Rastogi and Jens-Christian Svenning conceived the idea. All authors contributed equally and wrote the first draft of the manuscript, revised subsequent versions and approved the final version.

ACKNOWLEDGEMENTS

We consider this work a contribution to the Danish National Research Foundation Center for Ecological Dynamics in a Novel Biosphere (ECONOVO) and J-CS' VILLUM Investigator project 'Biodiversity Dynamics in a Changing World'. We thank Prof. Melodie McGeoch for critically contributing to the ideas and manuscript drafts. We thank the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Invasive Alien Species Assessment for providing a platform to develop these ideas. We thank Subhashree Sahoo for reviewing our drafts. This work was supported by VILLUM Investigator project 'Biodiversity Dynamics in a Changing World' funded by VILLUM FONDEN (grant 16549 to J-CS), GLOBALI and Center for Ecological Dynamics in a Novel Biosphere (ECONOVO), funded by Danish National Research Foundation (grant: DNRF173 to J-CS). RR is supported by Deutscher Akademischer Austauschdienst (DAAD; PKZ: 91865186).

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

This article does not include any data.

ORCID

Ninad Avinash Mungi https://orcid.org/0000-0001-6502-0457

REFERENCES

Aplet, G. H., & Mckinley, P. S. (2017). A portfolio approach to managing ecological risks of global change. *Ecosystem Health and Sustainability*, *3*(2), e01261.

Averett, J. P., McCune, B., Parks, C. G., Naylor, B. J., DelCurto, T., & Mata-González, R. (2016). Non-native plant invasion along elevation and canopy closure gradients in a middle Rocky Mountain ecosystem. *PLoS One*, *11*(1), e0147826. https://doi.org/10.1371/journal.pone.0147826

Barber, D., & Glass, P. (2015). Yellomundee firesticks. In E. J. Ens, J. Fisher, & O. Costello (Eds.), *Indigenous people and invasive species: Perceptions, management, challenges and uses*. IUCN Commission on Ecosystem Management Community Report. https://ipm.ifas.ufl.edu/pdfs/ens_et_al_2015_indigenous_people_and_invasive_species_iucn_cem_ecosystems_and_invasiv.pdf

Beaury, E. M., Finn, J. T., Corbin, J. D., Barr, V., & Bradley, B. A. (2020). Biotic resistance to invasion is ubiquitous across ecosystems of the United States. *Ecology Letters*, *23*(3), 476–482. https://doi.org/10.1111/ele.13446

Bekele, K., Haji, J., Legesse, B., Shiferaw, H., & Schaffner, U. (2018). Impacts of woody invasive alien plant species on rural livelihood: Generalized propensity score evidence from *Prosopis* spp. invasion in Afar region in Ethiopia. *Pastoralism: Research, Policy and Practice*, *8*(1), 28. https://doi.org/10.1186/s13570-018-0124-6

Bellard, C., Cassey, P., & Blackburn, T. M. (2016). Alien species as a driver of recent extinctions. *Biology Letters*, *12*(2), 20150623. https://doi.org/10.1098/rsbl.2015.0623

Bergstrom, D. M., Lucieer, A., Kiefer, K., Wasley, J., Belbin, L., Pedersen, T. K., & Chown, S. L. (2009). Indirect effects of invasive species removal devastate world Heritage Island. *Journal of Applied Ecology*, *46*(1), 73–81. https://doi.org/10.1111/j.1365-2664.2008.01601.x

Bertelsmeier, C., & Ollier, S. (2020). International tracking of the COVID-19 invasion: An amazing example of a globalized scientific coordination effort. *Biological Invasions*, *22*(9), 2647–2649. https://doi.org/10.1007/s10530-020-02287-5

Bhagwat, S. A., Breman, E., Thekaekara, T., Thornton, T. F., & Willis, K. J. (2012). A battle lost? Report on two centuries of invasion and management of *Lantana camara* L. in Australia, India and South Africa. *PLoS One*, *7*(3), e32407. https://doi.org/10.1371/journal.pone.0032407

Bhattacharyya, J., & Larson, B. M. H. (2014). The need for indigenous voices in discourse about introduced species: Insights from a controversy over wild horses. *Environmental Values*, *23*(6), 663–684. https://doi.org/10.3197/096327114X13947900181031

Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P., Jarošík, V., Wilson, J. R. U., & Richardson, D. M. (2011). A proposed unified framework for biological invasions. *Trends in Ecology & Evolution*, *26*(7), 333–339. https://doi.org/10.1016/j.tree.2011.03.023

Campbell, C., Russo, L., Albert, R., Buckling, A., & Shea, K. (2022). Whole community invasions and the integration of novel ecosystems. *PLoS Computational Biology*, *18*(6), e1010151. https://doi.org/10.1371/journal.pcbi.1010151

Chen, B.-M., Li, S., Liao, H.-X., & Peng, S.-L. (2017). Do forest soil microbes have the potential to resist plant invasion? A case study in Dinghushan biosphere reserve (South China). *Acta Oecologica*, *81*, 1–9. https://doi.org/10.1016/j.actao.2017.04.003

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Maginnis, S., Maynard, S., Nelson, C. R., Renaud, F. G., Welling, R., & Walters, G. (2019). Core principles for successfully implementing and upscaling nature-based solutions. *Environmental*

Science & Policy, *98*, 20–29. https://doi.org/10.1016/j.envsci.2019.04.014
Cranston, J., Crowley, S. L., & Early, R. (2022). UK wildlife recorders cautiously welcome range-shifting species but incline against intervention to promote or control their establishment. *People and Nature*, *4*(4), 879–892. https://doi.org/10.1002/pan3.10325
Cummings, J. A., Parker, I. M., & Gilbert, G. S. (2012). Allelopathy: A tool for weed management in forest restoration. *Plant Ecology*, *213*, 1975–1989.
Cunningham, S., Teirney, L., Brunton, J., McLeod, R., Bowman, R., Richards, D., Kinsey, R., & Matthews, F. (2019). Mitigating the threat of invasive marine species to Fiordland: New Zealand's first pathway management plan. *Management of Biological Invasions*, *10*(4), 690–708. https://doi.org/10.3391/mbi.2019.10.4.07
Derham, T. T., Duncan, R. P., Johnson, C. N., & Jones, M. E. (2018). Hope and caution: Rewilding to mitigate the impacts of biological invasions. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *373*(1761), 20180127.
DeSantis, R. D., Hallgren, S. W., & Stahle, D. W. (2011). Drought and fire suppression lead to rapid forest composition change in a forest-prairie ecotone. *Forest Ecology and Management*, *261*(11), 1833–1840. https://doi.org/10.1016/j.foreco.2011.02.006
Diagne, C., Leroy, B., Vaissière, A.-C., Gozlan, R. E., Roiz, D., Jarić, I., Salles, J.-M., Bradshaw, C. J. A., & Courchamp, F. (2021). High and rising economic costs of biological invasions worldwide. *Nature*, *592*(7855), 571–576. https://doi.org/10.1038/s41586-021-03405-6
Díaz, S., Settele, J., Brondízio, E. S., Ngo, H. T., Agard, J., Arneth, A., Balvanera, P., Brauman, K. A., Butchart, S. H. M., Chan, K. M. A., Garibaldi, L. A., Ichii, K., Liu, J., Subramanian, S. M., Midgley, G. F., Miloslavich, P., Molnár, Z., Obura, D., Pfaff, A., … Zayas, C. N. (2019). Pervasive human-driven decline of life on earth points to the need for transformative change. *Science*, *366*(6471), eaax3100. https://doi.org/10.1126/science.aax3100
Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J., & Collen, B. (2014). Defaunation in the Anthropocene. *Science*, *345*(6195), 401–406.
Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Reuter, K., Smith, M., van Ham, C., Weisser, W. W., Le Roux, X., & Lamarque, P. (2015). Nature-based solutions: New influence for environmental management and research in Europe. *GAIA-Ecological Perspectives for Science and Society*, *24*(4), 243–248.
Ellison, C. A., & Cock, M. J. (2017). Classical biological control of *Mikania micrantha*: The sustainable solution. In C. A. Ellison, K. V. Sankaran, & S. T. Murphy (Eds.), *Invasive alien plants: Impacts on development and options for management* (pp. 162–190). CABI.
Essl, F., Lenzner, B., Bacher, S., Bailey, S., Capinha, C., Daehler, C., Dullinger, S., Genovesi, P., Hui, C., Jeschke, J. M., Katsanevakis, S., Kühn, I., Leung, B., Liebhold, A., Liu, C., MacIsaac, H. J., Meyerson, L. A., Nuñez, M. A., Pauchard, A., … Hulme, P. E. (2020). Drivers of future alien species impacts: An expert-based assessment. *Global Change Biology*, *26*(9), 4880–4893.
Estévez, R. A., Anderson, C. B., Pizarro, J. C., & Burgman, M. A. (2015). Clarifying values, risk perceptions, and attitudes to resolve or avoid social conflicts in invasive species management. *Conservation Biology*, *29*(1), 19–30. https://doi.org/10.1111/cobi.12359
Fleischman, F., Basant, S., Chhatre, A., Coleman, E. A., Fischer, H. W., Gupta, D., Güneralp, B., Kashwan, P., Khatri, D., Muscarella, R., Powers, J. S., Ramprasad, V., Rana, P., Solorzano, C. R., & Veldman, J. W. (2020). Pitfalls of tree planting show why we need people-centered natural climate solutions. *BioScience*, *70*(11), 947–950. https://doi.org/10.1093/biosci/biaa094
Foxcroft, L. C., Richardson, D. M., Rejmánek, M., & Pyšek, P. (2010). Alien plant invasions in tropical and sub-tropical savannas: Patterns, processes and prospects. *Biological Invasions*, *12*(12), 3913–3933. https://doi.org/10.1007/s10530-010-9823-7
Fricke, E. C., Ordonez, A., Rogers, H. S., & Svenning, J.-C. (2022). The effects of defaunation on plants' capacity to track climate change. *Science*, *375*(6577), 210–214. https://doi.org/10.1126/science.abk3510
Funk, J. L., & McDaniel, S. (2010). Altering light availability to restore invaded forest: The predictive role of plant traits. *Restoration Ecology*, *18*(6), 865–872.
Futhazar, G. (2020). The conceptual challenges of invasive alien species to non-human rights. *Journal of Human Rights and the Environment*, *11*(2), 224–243. https://doi.org/10.4337/jhre.2020.02.04
Giakoumi, S., Katsanevakis, S., Albano, P. G., Azzurro, E., Cardoso, A. C., Cebrian, E., Deidun, A., Edelist, D., Francour, P., Jimenez, C., Mačić, V., Occhipinti-Ambrogi, A., Rilov, G., & Sghaier, Y. R. (2019). Management priorities for marine invasive species. *Science of the Total Environment*, *688*, 976–982. https://doi.org/10.1016/j.scitotenv.2019.06.282
Griffiths, C. J., Jones, C. G., Hansen, D. M., Puttoo, M., Tatayah, R. V., Müller, C. B., & Harris, S. (2010). The use of extant non-indigenous tortoises as a restoration tool to replace extinct ecosystem engineers. *Restoration Ecology*, *18*(1), 1–7. https://doi.org/10.1111/j.1526-100X.2009.00612.x
Guido, A., & Pillar, V. D. (2017). Invasive plant removal: Assessing community impact and recovery from invasion. *Journal of Applied Ecology*, *54*(4), 1230–1237.
Guyton, J. A., Pansu, J., Hutchinson, M. C., Kartzinel, T. R., Potter, A. B., Coverdale, T. C., Daskin, J. H., da Conceição, A. G., Peel, M. J. S., Stalmans, M. E., & Pringle, R. M. (2020). Trophic rewilding revives biotic resistance to shrub invasion. *Nature Ecology & Evolution*, *4*(5), 712–724. https://doi.org/10.1038/s41559-019-1068-y
Heller, N. E., & Hobbs, R. J. (2014). Development of a natural practice to adapt conservation goals to global change. *Conservation Biology*, *28*(3), 696–704.
Herrik, A. L., Mogensen, N., Svenning, J.-C., & Buitenwerf, R. (2023). Rotational grazing with cattle-free zones supports the coexistence of cattle and wild herbivores in African rangelands. *Journal of Applied Ecology*, *60*(10), 2154–2166. https://doi.org/10.1111/1365-2664.14493
Hobbs, R. J., Arico, S., Aronson, J., Baron, J. S., Bridgewater, P., Cramer, V. A., Epstein, P. R., Ewel, J. J., Klink, C. A., Lugo, A. E., Norton, D., Ojima, D., Richardson, D. M., Sanderson, E. W., Valladares, F., Vilà, M., Zamora, R., & Zobel, M. (2006). Novel ecosystems: Theoretical and management aspects of the new ecological world order: Novel ecosystems. *Global Ecology and Biogeography*, *15*(1), 1–7. https://doi.org/10.1111/j.1466-822X.2006.00212.x
Hobbs, R. J., & Cramer, V. A. (2008). Restoration ecology: Interventionist approaches for restoring and maintaining ecosystem function in the face of rapid environmental change. *Annual Review of Environment and Resources*, *33*, 39–61.
Howard, P. L. (2019). Human adaptation to invasive species: A conceptual framework based on a case study metasynthesis. *Ambio*, *48*(12), 1401–1430. https://doi.org/10.1007/s13280-019-01297-5
Howard, P. L., & Pecl, G. T. (2019). Introduction: Autochthonous human adaptation to biodiversity change in the Anthropocene. *Ambio*, *48*(12), 1389–1400. https://doi.org/10.1007/s13280-019-01283-x
Hughes, K. A., Pescott, O. L., Peyton, J. M., Adriaens, T., Peyton, J., Cottier-Cook, E. J., Key, G., Rabitsch, W., Tricarico, E., Barnes, D. K. A., Baxter, N., Belchier, M., Blake, D., Convey, P., Dawson, W., Frohlich, D., Gardiner, L. M., González-Moreno, P., James, R., … Roy, H. E. (2020). Invasive non-native species likely to threaten biodiversity and ecosystems in the Antarctic peninsula region. *Global Change Biology*, *26*(4), 2702–2716. https://doi.org/10.1111/gcb.14938
IPBES. (2018). *The IPBES assessment report on land degradation and restoration*. Zenodo. https://doi.org/10.5281/zenodo.3237393

IPBES. (2023). *IPBES invasive alien species assessment: Full report*. Zenodo. https://doi.org/10.5281/zenodo.10795593

IPCC. (2021). *Climate change 2021: The physical science basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. https://doi.org/10.1017/9781009157896.001

IUCN. (2020). *Global standard for nature-based solutions. A user-friendly framework for the verification, design and scaling up of NbS*. IUCN.

Jadeja, S., Prasad, S., Quader, S., & Isvaran, K. (2013). Antelope mating strategies facilitate invasion of grasslands by a woody weed. *Oikos*, *122*(10), 1441–1452.

Kannan, R., Shackleton, C. M., & Shaanker, R. U. (2014). Invasive alien species as drivers in socio-ecological systems: Local adaptations towards use of *Lantana* in southern India. *Environment, Development and Sustainability*, *16*(3), 649–669. https://doi.org/10.1007/s10668-013-9500-y

Kerr, M. R., Ordonez, A., Riede, F., & Svenning, J.-C. (2024). A biogeographic–macroecological perspective on the rising novelty of the biosphere in the Anthropocene. *Journal of Biogeography*, *51*(4), 575–587. https://doi.org/10.1111/jbi.14762

Koerner, S. E., & Collins, S. L. (2014). Interactive effects of grazing, drought, and fire on grassland plant communities in North America and South Africa. *Ecology*, *95*(1), 98–109. https://doi.org/10.1890/13-0526.1

Kopf, R. K., Nimmo, D. G., Humphries, P., Baumgartner, L. J., Bode, M., Bond, N. R., Byrom, A. E., Cucherousset, J., Keller, R. P., King, A. J., McGinness, H. M., Moyle, P. B., & Olden, J. D. (2017). Confronting the risks of large-scale invasive species control. *Nature Ecology & Evolution*, *1*(6), 1–4. https://doi.org/10.1038/s41559-017-0172

Lampert, A., Hastings, A., Grosholz, E. D., Jardine, S. L., & Sanchirico, J. N. (2014). Optimal approaches for balancing invasive species eradication and endangered species management. *Science*, *344*(6187), 1028–1031. https://doi.org/10.1126/science.1250763

Lemoine, R. T., & Svenning, J.-C. (2022). Nativeness is not binary—A graduated terminology for native and non-native species in the Anthropocene. *Restoration Ecology*, *30*, e13636.

Lynch, A. J., Rahel, F. J., Limpinsel, D., Sethi, S. A., Engman, A. C., Lawrence, D. J., Mills, K. E., Morrison, W., Peterson, J. O., & Porath, M. T. (2022). Ecological and social strategies for managing fisheries using the resist-accept-direct (RAD) framework. *Fisheries Management and Ecology*, *29*(4), 329–345.

Lynch, A. J., Thompson, L. M., Beever, E. A., Cole, D. N., Engman, A. C., Hawkins Hoffman, C., Jackson, S. T., Krabbenhoft, T. J., Lawrence, D. J., Magill, R. T., Melvin, T. A., Morton, J. M., Newman, R. A., Peterson, J. O., Porath, M. T., Rahel, F. J., Schuurman, G. W., Sethi, S. A., Wilkening, J. L., & Limpinsel, D. (2021). Managing for RADical ecosystem change: Applying the resist-accept-direct (RAD) framework. *Frontiers in Ecology and the Environment*, *19*(8), 461–469.

McGeoch, M. A., Clarke, D. A., Mungi, N. A., & Ordonez, A. (2024). A nature-positive future with biological invasions: Theory, decision support and research needs. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *379*(1902), 20230014. https://doi.org/10.1098/rstb.2023.0014

McGeoch, M. A., Ordonez, A., Howard, P. L., Groom, Q. J., Shrestha, B. B., Fernandez, M., Brugnoli, E., Bwalya, B., Byun, C., Ksenofontov, S., Ojaveer, H., Simberloff, D., Mungi, N. A., & Rono, B. (2024). *IPBES invasive alien species assessment: Chapter 6. Governance and policy options for the management of biological invasions*. https://doi.org/10.5281/zenodo.10677227

McLennan, M. (2021). *The global risks report 2021* (16th ed.). SK Group and Zurich Insurance Group.

Mungi, N. A., Jhala, Y. V., Qureshi, Q., le Roux, E., & Svenning, J.-C. (2023). Megaherbivores provide biotic resistance against alien plant dominance. *Nature Ecology & Evolution*, *7*(10), 1645–1653. https://doi.org/10.1038/s41559-023-02181-y

Mungi, N. A., Qureshi, Q., & Jhala, Y. V. (2020). Expanding niche and degrading forests: Key to the successful global invasion of *Lantana camara* (sensu lato). *Global Ecology and Conservation*, *23*, e01080. https://doi.org/10.1016/j.gecco.2020.e01080

Mungi, N. A., Qureshi, Q., & Jhala, Y. V. (2021). Role of species richness and human impacts in resisting invasive species in tropical forests. *Journal of Ecology*, *109*(9), 3308–3321. https://doi.org/10.1111/1365-2745.13751

Mungi, N. A., Qureshi, Q., & Jhala, Y. V. (2023). Distribution, drivers and restoration priorities of plant invasions in India. *Journal of Applied Ecology*, *60*(11), 2400–2412. https://doi.org/10.1111/1365-2664.14506

Mwangi, E., & Swallow, B. (2008). *Prosopis juliflora* invasion and rural livelihoods in the Lake Baringo area of Kenya. *Conservation and Society*, *6*(2), 130–140.

Neilson, B. J., Wall, C. B., Mancini, F. T., & Gewecke, C. A. (2018). Herbivore biocontrol and manual removal successfully reduce invasive macroalgae on coral reefs. *PeerJ*, *6*, e5332. https://doi.org/10.7717/peerj.5332

Nerlekar, A. N., Mehta, N., Pokar, R., Bhagwat, M., Misher, C., Joshi, P., & Hiremath, A. J. (2022). Removal or utilization? Testing alternative approaches to the management of an invasive woody legume in an arid Indian grassland. *Restoration Ecology*, *30*(1), e13477.

Noll, S., & Davis, B. (2020). The invasive species diet: The ethics of eating lionfish as a wildlife management strategy. *Ethics, Policy & Environment*, *23*(3), 320–335. https://doi.org/10.1080/21550085.2020.1848189

Odum, E. P. (1969). The strategy of ecosystem development. *Science*, *164*(3877), 262–270. https://doi.org/10.1126/science.164.3877.262

Perry, D., & Perry, G. (2008). Improving interactions between animal rights groups and conservation biologists. *Conservation Biology*, *22*(1), 27–35. https://doi.org/10.1111/j.1523-1739.2007.00845.x

Prior, K. M., Adams, D. C., Klepzig, K. D., & Hulcr, J. (2018). When does invasive species removal lead to ecological recovery? Implications for management success. *Biological Invasions*, *20*, 267–283.

Pyšek, P., Hulme, P. E., Simberloff, D., Bacher, S., Blackburn, T. M., Carlton, J. T., Dawson, W., Essl, F., Foxcroft, L. C., Genovesi, P., Jeschke, J. M., Kühn, I., Liebhold, A. M., Mandrak, N. E., Meyerson, L. A., Pauchard, A., Pergl, J., Roy, H. E., Seebens, H., … Richardson, D. M. (2020). Scientists' warning on invasive alien species. *Biological Reviews*, *95*(6), 1511–1534. https://doi.org/10.1111/brv.12627

Rai, R. K., & Scarborough, H. (2015). Understanding the effects of the invasive plants on rural forest-dependent communities. *Small-Scale Forestry*, *14*(1), 59–72. https://doi.org/10.1007/s11842-014-9273-7

Rastogi, R., Qureshi, Q., Shrivastava, A., & Jhala, Y. V. (2023). Multiple invasions exert combined magnified effects on native plants, soil nutrients and alters the plant-herbivore interaction in dry tropical forest. *Forest Ecology and Management*, *531*, 120781.

Ratajczak, Z., Collins, S. L., Blair, J. M., Koerner, S. E., Louthan, A. M., Smith, M. D., Taylor, J. H., & Nippert, J. B. (2022). Reintroducing bison results in long-running and resilient increases in grassland diversity. *Proceedings of the National Academy of Sciences of the United States of America*, *119*(36), e2210433119. https://doi.org/10.1073/pnas.2210433119

Ratnam, J., Tomlinson, K. W., Rasquinha, D. N., & Sankaran, M. (2016). Savannahs of Asia: Antiquity, biogeography, and an uncertain future. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *371*(1703), 20150305. https://doi.org/10.1098/rstb.2015.0305

Ren, S., Terrer, C., Li, J., Cao, Y., Yang, S., & Liu, D. (2024). Historical impacts of grazing on carbon stocks and climate mitigation opportunities. *Nature Climate Change*, *14*(4), 380–386. https://doi.org/10.1038/s41558-024-01957-9

Reyes-García, V., Arnold, C., & Graham, S. (2024). Indigenous peoples provide alternative approaches to managing biological invasions. *Trends in Ecology & Evolution*, *39*(9), 790–792. https://doi.org/10.1016/j.tree.2024.07.008

Reynolds, P. L., Glanz, J., Yang, S., Hann, C., Couture, J., & Grosholz, E. (2017). Ghost of invasion past: Legacy effects on community disassembly following eradication of an invasive ecosystem engineer. *Ecosphere*, *8*(3), e01711. https://doi.org/10.1002/ecs2.1711

Rohatyn, S., Yakir, D., Rotenberg, E., & Carmel, Y. (2022). Limited climate change mitigation potential through forestation of the vast dryland regions. *Science*, *377*(6613), 1436–1439. https://doi.org/10.1126/science.abm9684

Roy, H. E., Pauchard, A., Stoett, P. J., Renard Truong, T., Meyerson, L. A., Bacher, S., Galil, B. S., Hulme, P. E., Ikeda, T., Kavileveettil, S., McGeoch, M. A., Nuñez, M. A., Ordonez, A., Rahlao, S. J., Schwindt, E., Seebens, H., Sheppard, A. W., Vandvik, V., Aleksanyan, A., … Ziller, S. R. (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

Sample, M., Aslan, C. E., Policelli, N., Sanford, R. L., Nielsen, E., & Nuñez, M. A. (2019). Increase in nonnative understorey vegetation cover after nonnative conifer removal and passive restoration. *Austral Ecology*, *44*(8), 1384–1397. https://doi.org/10.1111/aec.12812

Sankaran, K., Schwindt, E., Sheppard, A. W., Foxcroft, L. C., Vanderhoeven, S., Egawa, C., Peacock, L., Castillo, M. L., Zenni, R. D., Müllerová, J., González-Martínez, A. I., Bukombe, J. K., Wanzala, W., & Mangwa, D. C. (2024). *IPBES invasive alien species assessment: Chapter 5. Management; challenges, opportunities and lessons learned*. Zenodo. https://doi.org/10.5281/zenodo.11437851

Schuurman, G. W., Cole, D. N., Cravens, A. E., Covington, S., Crausbay, S. D., Hoffman, C. H., Lawrence, D. J., Magness, D. R., Morton, J. M., O'Malley, R., & Nelson, E. A. (2022). Navigating ecological transformation: Resist–accept–direct as a path to a new resource management paradigm. *BioScience*, *72*(1), 16–29.

Schwab, S. T., Jenerette, G. D., & Larios, L. (2023). Prescribed burning may produce refugia for invasive forb, *Oncosiphon pilulifer*. *Restoration Ecology*, *31*(7), e13922. https://doi.org/10.1111/rec.13922

Schwarzländer, M., Hinz, H. L., Winston, R. L., & Day, M. D. (2018). Biological control of weeds: An analysis of introductions, rates of establishment and estimates of success, worldwide. *BioControl*, *63*(3), 319–331. https://doi.org/10.1007/s10526-018-9890-8

Seddon, N., Chausson, A., Berry, P., Girardin, C. A., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *375*(1794), 20190120.

Seddon, N., Smith, A., Smith, P., Key, I., Chausson, A., Girardin, C., House, J., Srivastava, S., & Turner, B. (2021). Getting the message right on nature-based solutions to climate change. *Global Change Biology*, *27*(8), 1518–1546. https://doi.org/10.1111/gcb.15513

Seebens, H., Bacher, S., Blackburn, T. M., Capinha, C., Dawson, W., Dullinger, S., Genovesi, P., Hulme, P. E., van Kleunen, M., Jeschke, J. M., Lenzner, B., Liebhold, A. M., Pattison, Z., Pergl, J., Pyšek, P., Winter, M., Essl, F., & Kühn, I. (2021). Projecting the continental accumulation of alien species through to 2050. *Global Change Biology*, *27*(5), 970–982.

Seebens, H., Blackburn, T. M., Dyer, E. E., Genovesi, P., Hulme, P. E., Jeschke, J. M., 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., … Essl, F. (2017). No saturation in the accumulation of alien species worldwide. *Nature Communications*, *8*(1), 14435. https://doi.org/10.1038/ncomms14435

Seebens, H., Meyerson, L. A., Rahlao, S. J., Lenzner, B., Tricarico, E., Aleksanyan, A., Courchamp, F., Keskin, E., Saeedi, H., Tawake, A., & Pyšek, P. (2024). *IPBES invasive alien species assessment: Chapter 2. Trends and status of alien and invasive alien species*. Zenodo. https://doi.org/10.5281/zenodo.10677067

Seebens, H., Niamir, A., Essl, F., Garnett, S. T., Kumagai, J. A., Molnár, Z., Saeedi, H., & Meyerson, L. A. (2024). Biological invasions on indigenous peoples' lands. *Nature Sustainability*, *7*(6), 737–746. https://doi.org/10.1038/s41893-024-01361-3

Shackleton, R. T., Le Maitre, D. C., Pasiecznik, N. M., & Richardson, D. M. (2014). *Prosopis*: A global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. *AoB Plants*, *6*, plu027. https://doi.org/10.1093/aobpla/plu027

Sharma, K., Mathur, M., Hiremath, A. J., Vanak, A. T., Ravi, R., Niphadkar, M., Thorat, O., & Jagdish, N. (2024). Modelling the Banni social-ecological system using participatory system dynamics for building insights on invasive species management and stakeholder engagement. *Journal of Environmental Management*, *371*, 122899. https://doi.org/10.1016/j.jenvman.2024.122899

Silvério, D. V., Brando, P. M., Balch, J. K., Putz, F. E., Nepstad, D. C., Oliveira-Santos, C., & Bustamante, M. M. C. (2013). Testing the Amazon savannization hypothesis: Fire effects on invasion of a neotropical forest by native cerrado and exotic pasture grasses. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *368*(1619), 20120427. https://doi.org/10.1098/rstb.2012.0427

Simberloff, D. (2014). The "balance of nature"—Evolution of a Panchreston. *PLoS Biology*, *12*(10), e1001963. https://doi.org/10.1371/journal.pbio.1001963

Simberloff, D., & Von Holle, B. (1999). Positive interactions of nonindigenous species: Invasional meltdown? *Biological Invasions*, *1*(1), 21–32. https://doi.org/10.1023/A:1010086329619

Sitzia, T., Campagnaro, T., Kotze, D. J., Nardi, S., & Ertani, A. (2018). The invasion of abandoned fields by a major alien tree filters understory plant traits in novel forest ecosystems. *Scientific Reports*, *8*(1), 8410. https://doi.org/10.1038/s41598-018-26493-3

Suarez-Menendez, M., Planes, S., Garcia-Vazquez, E., & Ardura, A. (2020). Early alert of biological risk in a coastal lagoon through eDNA metabarcoding. *Frontiers in Ecology and Evolution*, *8*, 9. https://doi.org/10.3389/fevo.2020.00009

Svenning, J.-C., Buitenwerf, R., & Le Roux, E. (2024). Trophic rewilding as a restoration approach under emerging novel biosphere conditions. *Current Biology*, *34*(9), R435–R451. https://doi.org/10.1016/j.cub.2024.02.044

Te Beest, M., Cromsigt, J. P., Ngobese, J., & Olff, H. (2012). Managing invasions at the cost of native habitat? An experimental test of the impact of fire on the invasion of *Chromolaena odorata* in a south African savanna. *Biological Invasions*, *14*, 607–618.

Thompson, B. K., Olden, J. D., & Converse, S. J. (2021). Mechanistic invasive species management models and their application in conservation. *Conservation Science and Practice*, *3*(11), e533. https://doi.org/10.1111/csp2.533

Turner, M. G. (2010). Disturbance and landscape dynamics in a changing world. *Ecology*, *91*(10), 2833–2849.

Turney, C., Ausseil, A.-G., & Broadhurst, L. (2020). Urgent need for an integrated policy framework for biodiversity loss and climate change. *Nature Ecology & Evolution*, *4*(8), 996.

United Nations Environment Programme [UNEP]. (2019). *Making EbA an effective part of balanced adaptation strategies: Introducing the UNEP EbA briefing notes*. https://wedocs.unep.org/bitstream/handle/20.500.11822/28174/EBA1.pdf?sequence=1&isAllowed=y

United Nations Environment Programme [UNEP], & Food and Agriculture Organization of the United Nations. (2022). *The UN decade on ecosystem restoration (2021–2030): Flagship initiatives*. https://wedocs.unep.org/20.500.11822/37848

Van Meerbeek, K., Jucker, T., & Svenning, J.-C. (2021). Unifying the concepts of stability and resilience in ecology. *Journal of Ecology*, *109*(9), 3114–3132. https://doi.org/10.1111/1365-2745.13651

Vimercati, G., Probert, A. F., Volery, L., Bernardo-Madrid, R., Bertolino, S., Céspedes, V., Essl, F., Evans, T., Gallardo, B., Gallien, L., González-Moreno, P., Grange, M. C., Hui, C., Jeschke, J. M., Katsanevakis, S., Kühn, I., Kumschick, S., Pergl, J., Pyšek, P., … Bacher, S. (2022). The EICAT+ framework enables classification of positive impacts of alien taxa on native biodiversity. *PLoS Biology*, *20*(8), e3001729. https://doi.org/10.1371/journal.pbio.3001729

Vitali, A., Vázquez, D. P., Miguel, M. F., Sasal, Y., & Rodríguez-Cabal, M. A. (2022). A keystone mutualism promotes resistance to invasion. *Journal of Animal Ecology*, *91*(1), 74–85. https://doi.org/10.1111/1365-2656.13597

Wagh, V. V., & Jain, A. K. (2018). Status of ethnobotanical invasive plants in western Madhya Pradesh, India. *South African Journal of Botany*, *114*, 171–180. https://doi.org/10.1016/j.sajb.2017.11.008

Wanger, T. C., Wielgoss, A. C., Motzke, I., Clough, Y., Brook, B. W., Sodhi, N. S., & Tscharntke, T. (2011). Endemic predators, invasive prey and native diversity. *Proceedings of the Royal Society B: Biological Sciences*, *278*(1706), 690–694.

Wilkinson, D. M. (2004). The parable of Green Mountain: Ascension Island, ecosystem construction and ecological fitting. *Journal of Biogeography*, *31*(1), 1–4. https://doi.org/10.1046/j.0305-0270.2003.01010.x

Williamson, M., & Fitter, A. (1996). The varying success of invaders. *Ecology*, *77*(6), 1661–1666. https://doi.org/10.2307/2265769

Zavaleta, E. S., Hobbs, R. J., & Mooney, H. A. (2001). Viewing invasive species removal in a whole-ecosystem context. *Trends in Ecology & Evolution*, *16*(8), 454–459. https://doi.org/10.1016/S0169-5347(01)02194-2

How to cite this article: Mungi, N. A., Gloria, A. O., Rastogi, R., & Svenning, J.-C. (2025). Expanding the Resist–Accept–Direct framework for developing nature-based solutions and societal adaptations to biological invasions. *People and Nature*, *7*, 1505–1520. https://doi.org/10.1002/pan3.70073