https://doi.org/10.1038/s43017-023-00484-z

Jointly advancing infrastructure and biodiversity conservation

S. Kyle McKay, Seth J. Wenger, Charles B. van Rees, Brian P. Bledsoe & Todd S. Bridges

Infrastructure development and biodiversity conservation are often planned and executed in isolation. However, outcomes from these efforts are interlinked, with coordinated actions required to jointly address sustainability challenges. Natural infrastructure – encompassing a spectrum of natural to conventional solutions – is key to the infrastructure–biodiversity connection and should be brought into large-scale application.

Species extinctions continue at a pace that is orders of magnitude faster than background rates, with long-term implications for the services that sustain humanity[1]. Efforts to stem these biodiversity losses are failing – witness that none of the United Nations' 2020 Aichi biodiversity targets were met[2] – largely owing to a lack of societal investment. Indeed, in the face of competing demands for limited funds, conservation is frequently neglected over other pressing social and economic concerns. For example, annual global spending on infrastructure exceeds conservation investment by a factor of 20 (~US$2.7 trillion compared with $124–143 billion, respectively[3,4]).

In fact, infrastructure investments are currently surging. Historically, massive investments in infrastructure (for human well-being, economic development and climate resilience) would be a cause for alarm, given the connection between development and species loss and decline. However, a marked rethinking of civil infrastructure systems and nature's contributions to their performance now presents an exceptional opportunity for synergy: services provided by natural infrastructure can be harnessed to meet societal needs while also conserving or enhancing biodiversity.

Natural infrastructure refers to infrastructure systems that utilize, rehabilitate or mimic natural ecological processes, as well as ecological communities, ecosystems and habitats that perform civil infrastructure functions. Natural infrastructure, and the allied concept of nature-based solutions, have been variously defined in policies and reports globally[5]. Practically, natural infrastructure can be characterized by four properties, not all of which are met by all features: it performs engineering functions and services, it consists at least in part of biotic components, it is designed to address environmental and social concerns, and it exhibits resilience through self-organization.

Here, we outline how infrastructure investments represent a singular opportunity to chart a path to sustainability, and argue that infrastructure decisions should be intimately connected to decisions about biodiversity and ecosystem services.

An inevitable convergence

The long-term trajectories of conservation science and infrastructure practice have brought them into a surprising alignment (Fig. 1). On the conservation side, a succession of four major philosophical approaches has been chronicled[6], with the role of society increasingly acknowledged. Modern conservation began with the notion of 'nature for itself', emphasizing nature's value apart from people, progressing to 'nature despite people', recognizing and mitigating human impacts on ecosystems. The notion of 'nature for people' subsequently focused on how natural systems benefit societies, before the contemporary approach of 'people and nature' acknowledged the nuanced and dynamic relationships between human and natural systems, long understood by Indigenous peoples.

In industrialized countries, civil infrastructure underwent a parallel evolution. The predominant attitude before the mid-twentieth century was 'control of nature', wherein infrastructure was designed to modify natural systems for societal benefit. Increasing recognition of human impacts drove a shift in laws to a 'mitigation hierarchy' of avoiding, minimizing and mitigating environmental impacts of infrastructure. This approach was followed by an 'expansion of project purposes' in the late-twentieth century, viewing infrastructure projects as opportunities for multiple ancillary benefits beyond their primary design objectives. Motivated in part by twenty-first-century natural disasters, infrastructure planning now emphasizes 'resilient design' that can absorb, recover and adapt under global change.

All these paradigms remain in contemporary use. However, the historically separate communities-of-practice are increasingly aligned (Fig. 1), with conservation efforts encompassing social objectives[7] and infrastructure design embracing ecosystem services for sustainable performance[8].

Bringing natural infrastructure to scale

Capturing synergy from joint investments is only possible with an approach that brings natural infrastructure into large-scale application. Such upscaling requires coordinated effort from conservation and infrastructure practitioners, stakeholders, decision-makers and funders across the project execution process. While we provide illustrative examples for how these interdependent tasks might be accomplished, we recognize that their fulfillment will depend on local legal and cultural contexts.

Task 1: Gather additional scientific evidence. Many applications of natural infrastructure are new and still considered experimental. Uncertainty always accompanies innovation, and systematic monitoring should be conducted to maximize learning. Doing so requires substantial investment to document effectiveness in achieving social, economic and ecological outcomes. The diversity of infrastructure and ecological contexts might be problematic for monitoring approaches that emphasize replication and measurable scales, necessitating a new,

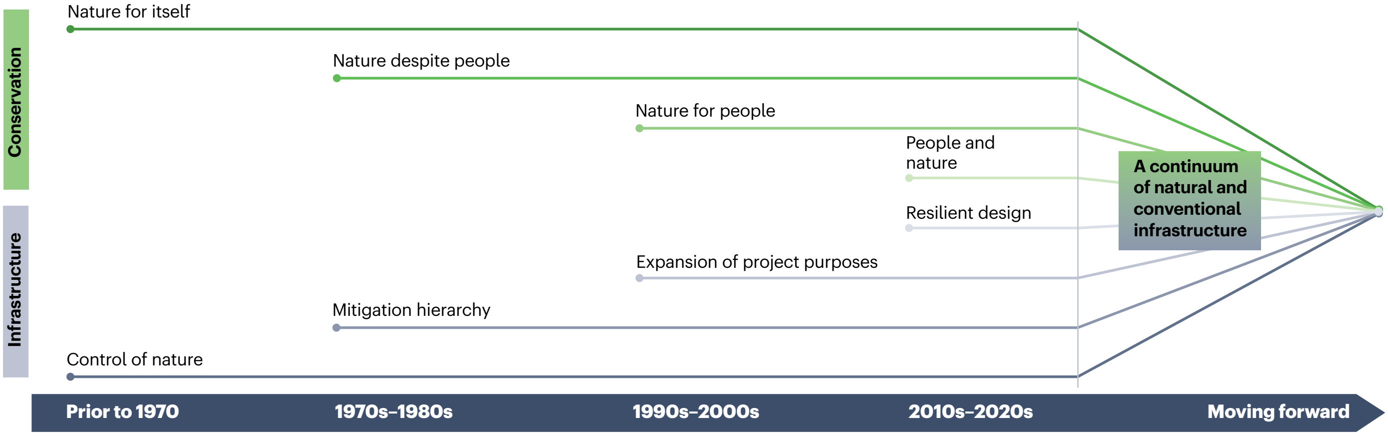

Fig. 1 | A confluence in the framing of, and approaches to, infrastructure and conservation planning. A timeline of the key framing in infrastructure (grey) and conservation (green), ultimately transitioning to a continuum of natural and conventional infrastructure.

flexible and evidence-based approach that more clearly articulates the purpose of monitoring[9].

Similarly, forecasting infrastructure performance is crucial to engineering decision-making processes. Integrated modelling tools are needed to assess coupled physical and ecological effects over larger spatiotemporal scales. In addition to biophysical knowledge, greater understanding of society's demand for natural infrastructure with respect to co-benefits, risk tolerances and acceptance of novel approaches is needed.

Task 2: Translate science into practical guidelines. There is a gap between the demand for natural infrastructure and availability of engineering methods to inform siting, planning, design and construction. Design manuals, standards of practice, operational guidelines and modelling tools are necessary to transition projects from conception to implementation. International guidelines are emerging in select applications of nature-based solutions (flood risk and stormwater management), but other domains have less guidance. Ultimately, detailed design standards comparable to those for conventional infrastructure (substrate sizing for reefs, fatigue testing of vegetation) are required. Likewise, cost estimation and real estate appraisal, common tools of conventional infrastructure planning, will require adaptation for natural infrastructure.

Natural infrastructure design also requires a suite of pragmatic tools for benefit accounting and assessing trade-offs that are usable within the constraints of normal project planning horizons. These should embrace both quantitative and qualitative outcomes and use monetary and non-monetary metrics. Two major initiatives are underway in the US Federal Government to improve natural capital accounting and assess natural assets[10], which could directly support better benefit accounting for natural infrastructure.

Task 3: Update policy to match science and practice. Infrastructure and conservation are embedded in a system of laws, policies and professional cultures that were developed for a different era (Fig. 1) and will, in some cases, need revision to accommodate new knowledge and planning paradigms. Some natural infrastructure defies traditional categorization for environmental compliance (should an oyster reef be categorized as a restoration project or a breakwater?), complicating the regulatory process and hindering application. Policy could be adapted to reduce these sources of friction and to develop expedited permitting pathways for natural infrastructure and multi-purpose projects.

Agency business processes, budget silos and project schedules also stifle innovation and limit public involvement. Currently, professionals at all levels (from policy experts to project managers to designers) must creatively navigate these systems to facilitate integrated projects. New project management tools are needed to facilitate trade-offs between urgent needs for natural infrastructure, breadth in scoping and input, and timely delivery. This challenge is particularly important for post-disaster recovery, where project planning timeframes are short and opportunities to incorporate resiliency through natural infrastructure are easily overlooked.

Task 4: Foster agility and collaboration in institutions and professionals. Conservation and infrastructure communities require new systems and culture to overcome institutional inertia. These organizations could facilitate knowledge sharing, compile best practices and case studies, develop new science or techniques, vet novel approaches into standards of practice, and serve as a clearinghouse for review expertise. There is a need to foster the development of the institutions now emerging to cross boundaries between disciplines and span sectors to facilitate the adoption of natural infrastructure.

Effective use of natural infrastructure will also require a workforce conversant in multiple disciplines and communities of practice. Consequently, educational institutions need programmes to train the next generation of boundary-spanning professionals and provide training for current practitioners. These programmes must navigate the challenge of providing interdisciplinary breadth of perspective alongside the disciplinary depth required for project execution.

A path to sustainable infrastructure

The false dichotomy of conservation versus infrastructure is antiquated. The two communities are rapidly converging, and future projects should pursue infrastructure and conservation goals in parallel. Natural infrastructure represents a critical tool for simultaneously addressing multiple key sustainability challenges. Society cannot afford to overlook the multigenerational benefits of simultaneous action with an integrative approach. What was once an opportunity is now an imperative, what was an emerging challenge is now a crisis, and what seemed possible separately is now impossible without integration.

S. Kyle McKay[1], Seth J. Wenger[2], Charles B. van Rees[2], Brian P. Bledsoe[3] & Todd S. Bridges[3]
[1]Environmental Laboratory, US Army Engineer Research and Development Center, New York, NY, USA. [2]Odum School of Ecology, University of Georgia, Athens, GA, USA. [3]College of Engineering, University of Georgia, Athens, GA, USA.
e-mail: kyle.mckay@usace.army.mil

Published online: 25 September 2023

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Acknowledgements

This work was conducted as part of the Network for Engineering With Nature (N-EWN, https://n-ewn.org/). The use of products or trade names does not represent an endorsement of these products by either the authors or the N-EWN. Opinions expressed here are those of the authors and not necessarily those of the agencies they represent or the N-EWN. The article benefited from comments by S. Altman, D. Crane, D. Hernández-Abrams, L. Dietterich, J. Hallemeier, R. Jackson, A. McKay, M. Simmons, T. Simon, B. Suedel and B. Woodson.

Competing interests

The authors declare no competing interests.