

Disentangling the complexity of human–nature interactions

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Funding information

Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences and Stanford University, Grant/Award Number: 62847978-GHEGZ; Canada Research Chairs

Handling Editor: Jacopo Baggio

Abstract

1. Human–nature interactions have been identified as an important leverage point for achieving sustainability. Processes to recognize, protect, improve and reimagine human–nature interactions will be central to shift the world to more sustainable and equitable pathways and futures.
2. In the context of the interconnected and rapidly changing Anthropocene, work on human–nature interactions must move beyond dominant linear assumptions of a relatively simple and easily and predictably manipulated world to acknowledge and engage with the complex, dynamic, asymmetrical and unequal nature of the interactions connecting people and nature.
3. Based on three key features highlighted by the study of complex social–ecological systems (SES)—that these systems are relational, open and dynamic—we propose three new directions for the study and management of human–nature interactions that can help to acknowledge and disentangle the globally intertwined and dynamic nature of these interactions.
4. These features suggest new directions and foci for sustainability science: the inseparable and relational qualities of the interactions between people and nature; the cross-scale nature of these relationships; and the continuously evolving and changing form of these relationships.
5. To bridge the gap between the theory of complex, inseparable and unequal human–nature interactions and the reductionist tendencies in research and practice, SES research raises opportunities to connect local action and global learning; to mobilize and develop new cross-scale and relational capacities to encourage synergies and avoid trade-offs; and to explore, experiment and learn our way forward onto more sustainable and equitable pathways.

KEYWORDS

complex adaptive systems, cross-scale dynamics, human–environment interactions, relational values, social–ecological systems, sustainable development, transformation

Elena M. Bennett and Belinda Reyers contributed equally to this paper.

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1 | SUSTAINABLE DEVELOPMENT AND HUMAN-NATURE INTERACTIONS IN THE ANTHROPOCENE

Human actions are profoundly changing our planet and its people (Crutzen, 2002), driven largely by efforts to increase the efficiency and reach of resource extraction and use for short-term economic gain (Folke et al., 2021). These changes have brought with them significant improvements in global average human well-being (at least until recently), as well as devastating consequences for biodiversity, climate, ecosystem services and the billions of global poor and marginalized (and future generations) who have benefited little from, and continue to incur the costs of, this dominant model of development (UNDP (United Nations Development Programme), 2020). This extractive model of development has fundamentally altered not only people and their environment but has also had profound consequences for the interactions, interdependencies and relationships connecting people and their environment (hereafter referred to as human-nature interactions). 'Nature' as we use it here is interpreted in its broadest sense as inclusive of non-human living organisms and ecosystems—wild or not (Gason & Soga, 2020).

Efforts to enhance, reconfigure and raise awareness of the interactions between people and nature have been highlighted as critical leverage points for setting the world onto more sustainable pathways (Díaz et al., 2020). Thus, these interactions have become an important area of interdisciplinary research and practice. The study of human-nature interactions has a long and interdisciplinary history, and offers many methods and theories that can be used to address the challenges of sustainability (Brondizio & Moran, 2012).

At the same time, the Anthropocene is changing how people interact with nature. One major set of changes in these interactions has been the enhanced interconnectivity, scale and rate of change driven by increased global trade, financial and information flows, which link people to each other and to environments in new ways, leading to novel and ever changing human-nature interactions (Keys et al., 2019). The global connectivity of the Anthropocene increases the potential for people's impacts on nature to be deferred, disconnected or transferred across space and time, such as when demand for biomass in one place leads to deforestation far away (Downing et al., 2021). These complex links between cause and effect result in novel and hard-to-predict vulnerabilities in groups, regions and systems (Adger et al., 2009).

Such vulnerabilities are caused and further entrenched by the profound inequalities of the Anthropocene and the growing power asymmetries in human-nature interactions across regions, scales, groups and generations (Leach et al., 2018). This 'Great Inequality' has been caused by, and has resulted in, a few regions or groups reaping the majority of the benefits from the changes wrought on the planet (Rammelt et al., 2022). It has at the same time left most other regions and groups to bear the brunt of the consequences of these impacts, such as climate change, pollution or biodiversity loss, while receiving few if any of the benefits (Biermann, 2014). These asymmetrical patterns of those who caused and have benefited most from environmental exploitation versus those who are paying the cost is increasing both between and within countries (Brondizio et al., 2019).

The way the Anthropocene has changed the world has implications for how we study, restore and reconfigure human-nature interactions. Many current scientific, policy and practical approaches to sustainability are based on (largely unstated) assumptions that the world and its human-nature interactions are mostly simple and linear, and can therefore be understood through reductionist approaches that break systems into separate social and ecological parts to be managed in a more or less piecemeal fashion. Such approaches often assume relatively predictable, spatially bounded and easily manipulated interactions, rather than a globally intertwined and dynamic system of human-nature interactions. In the best case, this mismatch between reductionist approaches and complex realities means that such assumptions will result in interventions that are ineffectual; in the worst, such assumptions will undermine recent sustainability gains, degrade important human-nature interactions and increase vulnerability (Eriksen et al., 2021).

How can we better align the study and governance of human-nature interactions with their complex and dynamic realities? Complex systems and challenges are not unknowable, insoluble or unmanageable, they just behave differently from simple or even from complicated systems (Poli, 2013). Complicated systems or problems, such as building a highway or sending a rocket to the moon, follow the rules of linear cause and effect, have outputs proportionate to inputs, can be dis- and re-assembled and are equal to the sum of their parts, which have controllable interactions and allow for permanent solutions. Complex systems, such as public health care systems or the global climate system, follow qualitatively different rules of behaviour. Preiser et al. (2018) helpfully review these different properties and behaviours from the perspective of complex social-ecological systems (SES) and distil out six key features of complex systems: (1) contextual, (2) open, (3) relational, (4) dynamic, (5) adaptive and (6) emergent (Table 1, Preiser et al., 2018; Sellberg et al., 2021). As Preiser et al. (2018) highlight in their review, accepting that these features set complex SES apart from other systems implies that we need to shift the focus of what we study and consider, choose different methods and approaches for studying these systems, and reconsider the perspective or worldview from which we approach such complex problems and systems.

In this perspective, we take the central three of these features: (1) relational, (2) open and (3) dynamic as a starting point to explore the new directions they suggest for the focus, methods and perspectives used to study and engage in human-nature interactions (Table 1).

2 | DISENTANGLING THE COMPLEXITY OF HUMAN-NATURE INTERACTIONS

2.1 | Beyond interactionalism to a focus on inseparable relationships

It is well known that failure to recognize interactions and feedbacks connecting humans and nature has led to both significant environmental problems, and even to the failure of some proposed solutions

TABLE 1 Three central features of complex social–ecological systems (drawn from Preiser et al., 2018; Sellberg et al., 2021) and new directions they suggest for the study and governance of human–nature interactions.

Feature of SES	Description of feature	New directions	Key elements of new direction
Relational	The structure and function of systems are determined more by the relationships among constituent entities than by the components themselves	Beyond interactionalism to inseparable relationships	Relationships become primary; entities secondary. Focus on the nature of the relations between system parts and between a system and its wider environment
Open	Systems are embedded and nested with porous boundaries allowing the exchange of matter, information and energy. Systems can have connections to distant places	Beyond multi-scale to globally intertwined systems	Identify and account for cross-scale dynamics shaping the system or symptoms of interest. Regularly review the boundaries of a system as connectors rather than separators
Dynamic	Amplifying and constraining feedback loops as well as periods of fast and slow change result in non-linear interactions and outcomes with potential thresholds	Beyond solutions to process navigation	A focus on processes and the ever-changing nature of human–nature interactions, combined with monitoring, learning and adaptively navigating the processes of sustainable development

to those problems (Fish et al., 2022; Gain et al., 2020). SES theory takes this one further step forward to highlight that it is the relationships themselves, rather than the human or natural parts of the system, that ultimately determine sustainable development outcomes and pathways (Table 1, Preiser et al., 2018).

In most studies of human–nature interactions, and in most policies to address human–nature interactions, the interactions between people and the environment are still depicted in linear uni- or bidirectional ways. That is, a study or policy might be focused either on the impact of people on nature, such as through pollution, land use change or climate; or one might be focused on the impact of nature on people, such as through the delivery of ecosystem services. With some studies exploring the feedback effects of such impacts (e.g. wetland restoration resulting in reversals of cropland degradation, or marine mammal recovery affecting fisheries negatively, Gregr et al., 2020; Hull et al., 2015), these approaches are now quite sophisticated, allowing the mapping of trade-offs, co-benefits and feedbacks between multiple sustainability outcomes (e.g. Nilsson et al., 2018). However, most analyses of interactions still give prominence to either the social or ecological domain, and focus on the domains rather than the interactions between them (Schlüter et al., 2019).

Recognizing that studies of human–nature interactions differ in the degree to which the social and ecological are viewed as merely linked or as part of a single integrated system, SES research uses as its departure point that any ‘delineation between social and natural systems is artificial and arbitrary’ (Berkes et al., 1992, p. 4). Instead, SES science sees social–ecological *relations*, not social or ecological *entities*, as the fundamental elements for study and action (Preiser et al., 2018; Schlüter et al., 2019). In fact, SES research has recently warned that many studies of human–nature connections, which focus on entities rather than relationships, may actually reinforce the separation of humans from their environment which runs counter to the original intent of a focus on these interactions (Cooke et al., 2016).

In this way, SES science highlights the need for the study of human–nature interactions to scrutinise the assumptions behind each study or policy effort, and clarify where on the spectrum of loosely coupled to inseparable its framing lies. SES science also provides useful examples and even templates for how to move beyond the interactionalism currently dominating the study of people–nature interactions to the more relational end of this spectrum. As Fish et al. (2022) make clear, a focus on relationships and relational approaches goes beyond the dominant scientific tendency to focus on the parts of a system, and subsequently, on their interactions (referred to as interactionalism). The difference is subtle, but important: interactions take place between entities that pre-exist those interactions; relational thinking involves ‘recognising a deeper set of entanglements’ in which ‘entities do not exist before they are in relationship; rather their separate existence at any point in time is a snapshot of a deep and dynamic set of relations with other entities over space and time’ (Fish et al., 2022). Such relational approaches, long prevalent in global south scholarship, as well as in both Indigenous and local knowledge systems, are a fundamentally different way to approach sustainability science and practice that moves away from some historic and problematic reductionist tendencies inherent in sustainability science, policy and practice (Chilisa, 2017; Fish et al., 2022; Muller et al., 2019; Ogar et al., 2020; West et al., 2020).

New avenues in the development of indicators of sustainable development is one example of how a relational focus is proving useful (Selomane et al., 2019). While most existing indicators lean either towards social factors or processes or else towards ecological factors or processes, a new set of indicators is emerging, in part from Indigenous and community monitoring systems, that feature the relationships connecting people and nature (Bennett, Baird, et al., 2021). Such indicators include measurements of the condition of the human–biodiversity relationship (Lyver et al., 2017) and indicators that monitor relationships connecting social and ecological components of a system (Thompson et al., 2020). Importantly, in these examples, the monitoring systems do not treat the social

and ecological parts as even theoretically separable, but focus instead on what connects them. The indicators measured in these cases are less focused on the sustainable extraction of nature's contributions to people (e.g. the ability to catch fish in perpetuity), and more focused on relational features such as ongoing territorial knowledge, sharing and ceremony (Thompson et al., 2020) or the proportion of community members practicing traditional activities in nature (Lyver et al., 2017). Additionally, the monitoring itself is treated not as a separate activity but as part of daily practices, such as harvesting (Thompson et al., 2020). Evidence is growing that an awareness and engagement with nature in this way can itself foster action and is therefore an important leverage point for policy and transformative change (Hajer et al., 2015; Mattijssen et al., 2020).

2.2 | Beyond multi-scale to globally intertwined systems

Chief among the challenges presented by a hyperconnected Anthropocene are the scale, and connectivity across scales, of the interactions connecting people and the environment. It is common to attempt to address global- or large-scale symptoms at the global or international level via multilateral environmental treaties among nation States (e.g. the UN Framework Convention on Climate Change) and subsequent international agreements (e.g. the Paris Agreement). However, outcomes from these international and global efforts have been much slower, less effective and less participatory than desired (de Jong, 2011; Young, 2011). A vast literature has pointed out problems with global-scale action, including powerful players and vested interests who wish to ensure that little action occurs (IPCC, 2022), the free-riding and burden-shifting that happen among nations in addressing climate change, a classic collective action dilemma given the lack of an international body in place to enforce agreements (Galaz et al., 2015). Additionally, and importantly, work on human-nature interactions at this scale is prone to overlooking the contextually determined nature of human-nature interactions (Preiser et al., 2018) and their often cascading, cross-scale nature (Keys et al., 2019).

In response to some of these shortcomings of top-down global approaches, the world has seen rapid growth in local, bottom-up actions for sustainable development (Bennett et al., 2016). Such local action is important for a number of reasons: This is often the scale at which human-nature relationships are the most obvious and direct, and action can often take place relatively quickly and be more participatory and therefore more equitable and context sensitive. The modularity of action in many different locales means that it is easier to experiment and adapt in ways that would be hard or even impossible to do at larger scales or higher levels of jurisdiction. And such experimentation improves the potential for response diversity, developing a range of different techniques that result in the same outcome, thus lending functional redundancy

to our approaches to solving environmental problems (Walker et al., 2023).

However, local action is not without its problems. Local actions that appear beneficial in one country can have spillover effects elsewhere, such as when policies to reduce deforestation in Europe were effective in Europe, but led to increased deforestation in Latin and South America, helped on by existing and entrenched power imbalances. Such sustainability blind spots or off-stage burdens (Pascual et al., 2017) are common around the world (Downing et al., 2021, Meyfroidt et al., 2018) due to the increased connectivity of the Anthropocene, and how that reinforces and entrenches inequality and unsustainability dynamics (Leach et al., 2018).

These shortcomings of both the global- and local-level study and action have led to calls for multiscale approaches to sustainability and for the study of human-nature interactions at multiple scales (Scholes et al., 2013). However, in the globally connected context of the Anthropocene, it is not safe to assume that the global outcome of multiscale efforts is the additive product of many national or sub-national efforts or outcomes. While multiscale assessments often present scales as an 'orderly pile of duplicates' (Scholes et al., 2013, p. 17), the reality is that interactions of varying strengths across scales of people-nature interactions can lead to much different outcomes than anticipated in a linear or additive system (Table 1).

SES research and practices go one step further to point to the radically open and *cross-scale* nature of human-nature interactions, meaning that it is not enough to independently attend to multiple scales but that one must also attend to the ways that actions at one scale have outcomes at other scales. Sustainable development challenges such as inequality or climate change might be driven by a collection of social and ecological processes that happen in localities, but clearly have both causes and consequences at multiple spatial, temporal and sociopolitical scales (Cash et al., 2006). In such 'radically open systems' (Preiser et al., 2018), it is no longer possible to isolate the 'local' or even the 'global'. Instead, in globally intertwined SES, sustainable development efforts need to identify, and account for, cross-scale influences on the system's behaviour, including far lying, regional and global systems which can affect, and be affected by, the system of interest (Scheffer et al., 2001). Indeed, many cross-scale interactions are linked to important threshold effects with significant consequences including tipping points, cascading crises and the risk of irreversible change. The recent global Covid-19 pandemic, its cascading social-ecological causes, responses and potentially irreversible economic and social impacts is a case in point. Ignoring cross-scale dynamics of vulnerability and climate change in current climate change adaptation projects, and focusing on addressing local-scale symptoms instead, has resulted mostly in reinforced or redistributed vulnerabilities rather than reduction in such exposures (Eriksen et al., 2021).

This understanding of SES theory helps to make clear some of the risks and assumptions implicit in the study of human-nature interactions where study or policy boundaries become separators that exclude the exchange of information, energy and material, or other important external factors from consideration. As a new direction

to the problem of scale, SES research and practice ensures that system boundaries are defined, tested, constantly reviewed and often presented as connectors with, rather than separators from, the external environment (Table 1; Preiser et al., 2018). Recent advances in methods such as systems dynamic modelling and causal loop diagrams present new methods for studying interlinkages among scales and other boundaries (Nabavi et al., 2017). For example, Downing et al. (2021) analyse the impact of reforestation programmes in China on other countries supplying forest and agricultural commodities to China using a multimethod approach linking national deforestation policies to regional impacts on sustainable development goals. From a governance perspective, a focus on cross-scale interactions and risks raises key challenges such as alternative forms of agency, law and institutions beyond the national scale and questions around access and power (Du Toit & Kotzé, 2022; Keys et al., 2019; Kotzé, 2014; Lele, 2020; Rammelt et al., 2022). Furthermore, the ability to identify cross-scalar human–nature interactions and anticipate consequences at other scales or on other sectors beyond than the focal one is a critical capacity for sustainable development practitioners (Moore et al., 2018).

In the same way that moving beyond interactionism challenges the separability of humans and their environment, this aspect of SES theory challenges the ideas of spatial boundaries and fixed scales of study. For any unit of study or action, the presence of multiple actors and perspectives will dynamically define the network or hierarchy of interest. Few units of analysis will fall into a single scale and are often so multiscale and cross-scalar as to begin to question easy distinctions of scale when it comes to the study of human–nature interactions (Manson, 2008). A study of these interactions that adopts cross-scale lenses and re-negotiates boundaries brings new approaches to the study of human–nature interactions as a network of nodes and links (Bodin et al., 2019). It further recognizes that core aspects of sustainability challenges re-occur across multiple contexts and scales, allowing the development of middle range theories and context-sensitive generalizable findings (Crona et al., 2015; Reyers et al., 2022).

2.3 | Beyond solutions to process navigation

Human–nature interactions are non-linear, dynamic, inherently unpredictable and uncontrollable, which suggests that efforts to foster sustainable and equitable human–nature interactions must involve process navigation rather than control, requiring attention to process rather than the search for permanent solutions (Poli, 2013; Preiser et al., 2018). SES theory suggests that social–ecological systems are made up of dynamic interactions between connected parts across multiple scales, which produces emergent behaviours and properties. In these systems, root causes and linear cause–effect pathways cannot be distinguished and therefore solved. Small inputs can create large outputs and vice versa, often leading to the many disproportionate and unintended outcomes seen in sustainable development efforts (Coetzee et al., 2018). Because knowledge

of the system is always be incomplete (Preiser & Woermann, 2019) and without permanent fixed endpoint solutions, SES theory suggests that sustainability challenges require navigation rather than fixing (Table 1). As interventions shape outcomes which in turn shape the system and cause new problems which in turn require navigation or as Meadows put it, we need to ‘learn to dance’ with systems (Meadows, 2001).

From this dynamics-oriented perspective, SES research suggests new directions for navigating pathways towards sustainability that mandate a shift away from focusing on reacting to events or the symptoms of complex problems such as drought or GDP declines towards processes that revitalize and reconfigure the dynamic human–nature relationships underlying so many sustainability challenges. While it is clearly important to agree on global targets such as the sustainable development goals, it is equally vital to avoid seeing these goals and targets as fixed end points that can be achieved and set aside. Instead, SES science suggests that efforts towards sustainable development must be founded on an embrace of the uncertain, and on prioritizing robust collaborations and learning centred on revealing and reimagining human–nature interactions as they shift over time. Learning and adaptively navigating the processes of sustainable development and the dynamics of human–nature interactions are key aspects of the study and management of these interactions (Hertz et al., 2020; Reyers et al., 2022).

In moving beyond a focus on solutions to navigating processes and change (both expected and surprising), SES research highlights the co-evolutionary nature of sustainable development. As humans change the environment, the environment, in turn, shapes humans, thus moulding future pathways of development (Haider et al., 2021). A coevolutionary perspective helps to specify the mechanisms that shape how relationships, processes and innovations are maintained or changed over time and thus enables sustainable development to better consider human–nature interactions and dynamics. It shifts the focus from outcomes to how interventions shape outcomes and future development pathways. Focusing on the dynamics of human–nature relationships highlights the crucial role of these relationships as the entry point for sustainable development efforts. Existing and new relationships will coevolve with each other, leading to entirely novel pathways, ultimately influencing which human–nature interactions are maintained and which are lost.

Several authors have recently pointed to the need for a move towards process ontologies as better suited to working with complex human–nature interactions (Mancilla García et al., 2020). Such ontologies (the ways in which we understand reality) are based on a world view of constant change and dynamism and have helpfully introduced concepts such as process and possibility space as the ‘sets of possible processes at any given moment in time and space’ (Hertz et al., 2020). Such perspectives and approaches appear able to overcome the challenges of dominant ontologies that feature reductionism and static approaches, towards enhancing understanding by engaging with the complexity, dynamism and intertwined nature of human–nature interactions.

3 | REIMAGINING HUMAN-NATURE RELATIONSHIPS IN THE CONTEXT OF THE ANTHROPOCENE

Human-nature interactions at all scales, and the relationships that result from them, lie at the heart of sustainable development. It is in these relationships, and our capacity to make them visible and to reimagine them, that sustainable and equitable futures lie (Moore et al., 2018). Over the past 50 years of efforts towards sustainable development, great strides have been made in recognizing that sustainability is about the interdependence of nature and people, rather than the persistence of one or the other (Mace, 2014). The fundamentally complex character of human-nature interactions implies that diverse perspectives and multiple approaches are required to further the aims of sustainable development (Stenseke, 2020; Tengo et al., 2014). SES research and practice has clarified the relational, cross-scale and dynamic nature of these interactions, and, in so doing, highlighted important new directions forward for research, practice and policy to deeply and robustly engage with the complex realities of the relationships between people and nature.

Recognizing that sustainable development is a cross-scale, dynamic and relational enterprise raises opportunities to connect local action as source of natural 'experiments' with regional and global efforts to mobilize, collect, synthesize and share the learning and knowledge gained across diverse systems (Bennett et al., 2022). It furthermore emphasizes the need for transformative capacities across all scales needed to see, and thus avoid, leakage, burden shifting and off-stage burdens, and to encourage synergies across these experiments with sustainability.

Acknowledging that human-nature relationships are complex, nonlinear and dynamic implies that global transitions to sustainability will likely emerge from the interactions among a patchwork of geographically distinct, but interacting, pathways of change (Bennett, Biggs, et al., 2021). Across regions, outcomes of actions will aggregate in a variety of different ways with markedly different outcomes. Sustainability transitions are thus likely to be emergent and therefore difficult to predict with any precision. Instead, key aspects of regional sustainability shifts and people-nature reconfigurations, and how they interact across locations, are expected to be novel, difficult to influence and unpredictable (Westley et al., 2011). Successful pathways will involve exploration and experimentation, combined with continuous assessment of outcomes (successes and failures), and a focus on learning, adapting and information sharing (Fabricius & Cundill, 2014).

Taken together, the changes needed in the study of and engagement with human-nature interactions to bridge the gap between the theory of complex, inseparable and unequal human-nature interactions and the reality of research and practice which tend to treat them as separable, static and as linear, appear daunting. It may be tempting to continue to revert to the simpler and widely accepted approaches which align well with current sustainable development research, policy and practice funding mechanisms, project designs and assumptions of siloed goals, linear trade-offs and generalizable

solutions. Such reversion not only risks missing the potential offered by the embrace of human-nature interactions, it actually risks undermining the transformative value and leverage potential that these interactions offer to sustainable development.

While daunting, it is clear that these new directions offer plausible and possible next steps, as is clear from the many practical advances seen in the application of complexity-oriented and aware theories and methods (ranging from monitoring and evaluation programmes; Hertz et al., 2021), agricultural innovation project designs (Douthwaite & Hoffecker, 2017) and the many innovations seen in the health domain (Sturmberg, 2019). The three new directions described here, as well as the many possible others in other disciplines, knowledge systems and practices (e.g. Nhemachena, 2017; Stenseke, 2020), suggest new avenues to hold and appreciate while disentangling the complexity and continuous change involved in the study of human-nature interactions.

AUTHOR CONTRIBUTIONS

Elena M. Bennett and Belinda Reyers conceived the ideas and co-wrote the paper through a series of online collaborative writing and brainstorming sessions over the course of a year. Both authors contributed equally to the manuscript.

ACKNOWLEDGEMENTS

EMB acknowledges support of a Canada Research Chair (NETGP 523374-18). BR is supported by the Beijer Institute of Ecological Economics, Royal Swedish Academy of Sciences and Stanford University, USA (Agreement number: 62847978-GHEGZ). Both authors acknowledge many conversations with colleagues and students over the years that have influenced their thinking on these topics.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

There are no data that need to be archived for this paper.

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How to cite this article: Bennett, E. M., & Reyers, B. (2024). Disentangling the complexity of human-nature interactions. *People and Nature*, 6, 402–409. <https://doi.org/10.1002/pan3.10611>