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Thematic Section: Biodiversity Revisited

Transdisciplinary science for improved conservation outcomes

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Summary

Major advances in biology and ecology have sharpened our understanding of what the goals of biodiversity conservation might be, but less progress has been made on how to achieve conservation in the complex, multi-sectoral world of human affairs. The failure to deliver conservation outcomes is especially severe in the rapidly changing landscapes of tropical low-income countries. We describe five techniques we have used to complement and strengthen long-term attempts to achieve conservation outcomes in the landscapes and seascapes of such regions; these are complex social-ecological systems shaped by interactions between biological, ecological and physical features mediated by the actions of people. Conservation outcomes occur as a result of human decisions and the governance arrangements that guide change. However, much conservation science in these countries is not rooted in a deep understanding of how these social-ecological systems work and what really determines the behaviour of the people whose decisions shape the future of landscapes. We describe five scientific practices that we have found to be effective in building relationships with actors in landscapes and influencing their behaviour in ways that reconcile conservation and development. We have used open-ended inductive enquiry, theories of change, simulation models, network analysis and multi-criteria analysis. These techniques are all widely known and well tested, but seldom figure in externally funded conservation projects. We have used these techniques to complement and strengthen existing interventions of international conservation agencies. These five techniques have proven effective in achieving deeper understanding of context, engagement with all stakeholders, negotiation of shared goals and continuous learning and adaptation.

Introduction

The economic growth and prosperity of the second half of the twentieth century depleted the world's natural resources. A powerful scientific response ensued in an effort to stem the decline of biodiversity (Soulé 1985, Sarkar 1998). A proliferation of programmes and policies emerged, which culminated in the negotiation of the Convention on Biological Diversity (CBD) in Rio de Janeiro in 1992. Yet, biodiversity continues to decline, especially in the rapidly changing landscapes of tropical developing countries. Conservation biology, as a discipline, emerged with the explicit aim of tackling that decline. However, by focusing on biology and ecology, it has tended to overlook the complex social, economic and political context within which conservation actions take place. Pressey et al. (2017) identified this problem, accusing conservation biologists of a collective form of displacement activity, advocating irrelevant responses to what on the face of it seem like the incompatible goals of protecting biodiversity and supporting human development. More attention to the human behaviours and attitudes behind drivers of environmental decline might lead to a broader, more inclusive conservation science (Byerly et al. 2018).

Successful conservation needs to influence the behaviour of the people who live in, and depend upon, the resources of the landscapes and seascapes where conservation actions take place (McNie 2007, Knight et al. 2008). Conservation efforts have frequently sought to restrict income-generating activities, portraying them as negative and harmful (Kamoto et al. 2013). When conservationists seek to lock up nature, conservation has too often been seen by local people as locking up vital assets in ways that obstruct their entry into the cash economy, hinder

their access to education and health services and disrupt the provision of roads and other infrastructure (Feintrenie et al. 2010, Colfer 2011, Levang et al. 2016, Sayer & Margules 2017, Boedhihartono et al. 2018). Conservation has struggled to link biological fundamentals with the messy reality of human behaviour, economic growth and politics (Boedhihartono et al. 2018). Land-use conflicts, civil and military disorder, donor fatigue and narrow sectoral approaches to governance – what Indonesians colourfully call 'egosectoral' approaches – all conspire to thwart conservation actions. Here, we reflect upon broader conservation science and endorse a set of practices that embrace multiple disciplines to explicitly address the complex human activity that conservation has become.

Arguments for integrating conservation and development were articulated in the World Conservation Strategy 40 years ago (IUCN & WWF 1980), but the logic of sustainable development has still not been mainstreamed into the conservation research agenda. A recent response has been the development of an updated framework for conservation science (Kareiva & Marvier 2012) that acknowledges the role people must play if the protection of biodiversity is to succeed. The publication of that framework generated unnecessary controversy between its proponents and many traditional conservation biologists (Kloor 2015). Williams et al. (2020) have documented the persistent failure of much conservation science to deliver conservation outcomes. Recognition by practitioners of the need for people to own and drive conservation is not new. Integrated conservation and development projects (ICDPs) have been widely implemented since the late 1960s (Sayer & Campbell 2004). ICDPs have generally not succeeded for a range of reasons, notably the assumption that global environmental values had primacy over local development needs (Sayer & Wells 2004, Sunderland et al. 2007). ICDPs were often just attempts by aid agencies and international non-governmental organizations to reduce the impact of conservation interventions on local people living in poverty. Many conservation interventions from this period suffered from a failure to recognize that the geographical locations in which they were taking place were governed in complex, polycentric, multi-sectoral ways, and that changes occurring outside of the project area would determine outcomes (e.g., climate change, fluctuating global markets, etc.) (Sayer et al. 2016a).

Conservation actions take place on the ground, in geographically defined areas consisting of landscapes and seascapes. Landscapes are linked social-ecological systems (Walker & Salt 2006). They are shaped by interactions between biological, ecological and physical processes mediated by the interventions of people (Opdam et al. 2018). Scientists and conservation practitioners often seek transformational change in landscapes. They want problems solved – preferably within the short time frames of donor funding. Our experience is that change is usually gradual and incremental, but is punctuated by transformational events often triggered by major external drivers, such as infrastructure and other major investments. Understanding and influencing change requires long-term commitments *in situ*, drawing on and linking different sources of knowledge from different disciplines.

Conservation problems are societal constructions; they cannot be separated from broader aspects of well-being, relational values, politics and global change. Conservation science would benefit from gathering evidence on how these complex systems work and identifying processes that might influence change. Evidence in this sense is not only social and environmental data, but the knowledge of multiple actors all with different 'ways of knowing', political interests and sources of information (Evans et al. 2017). Conflicts are inevitable; epistemological differences between disciplines often result in incompatible methods and approaches, resulting in cultural and practical barriers (Hicks et al. 2010, Filer 2011). For example, social-ecological systems approaches have been seen to offer a neutral template for contextualized problem-solving in sustainability science, but they are criticized for not addressing more socially interpretive aspects of dynamically coupled human–natural systems (Agrawal 2001, Kates et al. 2001, Ostrom 2009). Science deployed in landscapes to solve conservation problems can draw from the expansive interpretations of systems approaches to ensure that the generation of knowledge is meeting the diversity of values and users. Stronger emphasis could be placed on understanding 'predictably irrational' human behaviour and on how to influence the decisions of those who shape the landscape (Thaler & Sunstein 2003, Osbaldiston & Schott 2012, Veríssimo 2013). Many conservation scientists have argued for this agenda (Brown 2002, Ghazoul 2007, Lynam et al. 2007, Milner-Gulland 2012, Bennett et al. 2017), but few have been able to engage for the long term in carrying out these activities *in situ*, with the people whose decisions conservation scientists wish to influence.

We report here on lessons learned for achieving conservation outcomes from our engagement in long-term landscape-scale projects, which have tried to balance local aspirations with global environmental values. We draw on attempts by the Center for International Forestry Research (CIFOR), the International Union for Conservation of Nature (IUCN), World Wildlife Fund (WWF) and Conservation International (CI) to establish 'learning' or 'sentinel' landscapes (IUCN 2008). We have monitored changes in these landscapes over periods of 5–25 years (Sayer et al. 2016a), and have developed approaches for assessing the performance of landscapes in delivering conservation and development benefits (Endamana et al. 2010, Sayer et al. 2016b). We have not conducted controlled experiments or randomized controlled trials at landscape scale and doubt the feasibility of doing so. We positioned ourselves as 'peripheral agents' in these landscapes, seeking to understand change and influence – nudge – the decision-making process to achieve continuous learning and adaptation (Thaler & Sunstein 2009). Our intention was to practice and learn from the different ways science can be organized to solve conservation problems. We document attempts to balance conservation and development in tropical landscapes where iconic biodiversity overlaps with urgent issues of human poverty (Campbell et al. 2010, Langston et al. 2020).

We drew from a broad range of methods (Lynam et al. 2007), but five practices were particularly effective in gathering evidence and improving decision-making. These are: understanding the social-ecological context; theories of change; network analysis; scenario development and simulation modelling; and multi-criteria analysis (MCA). Our experience with projects applying these practices shares many of the features of what has been described as transdisciplinary research and sustainability science (Clark 2007) – what we call 'embedded science' (Langston et al. 2019). Conservation actions have to align with and work through governance arrangements in the places where conservation is needed. The practices identified in this paper were agreed upon by the authors because of their useful attributes for situating conservation actions within a broader process of transdisciplinary science and for meeting the principles of knowledge co-production practiced in sustainability science (Norström et al. 2020).

Background to the review

Information on the landscapes that inspired this review is given in Table 1. We were never in control of conservation in these

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Table 1. Long-term landscape conservation initiatives that inspired the ideas expressed in this paper.

Landscape location	Key reference	Period authors engaged	International organizations involved	Local partners	Principle practices employed
Sangha Tri-National, Congo Basin	Sayer et al. (2016a)	2000–continuing	WWF, IUCN, CIFOR, Wildlife Conservation Society	Local government and forest authorities, local NGOs and communities	Inductive research, simulation modelling, scenarios, participatory visualization
Sintang landscape, West Kalimantan, Indonesia	Langston et al. (2017)	2015–2020	WWF, James Cook University	Local communities, local oil palm cooperative	Inductive research, simulation modeling, scenarios
Malinau landscape, North Kalimantan, Indonesia	Boedhihartono et al. (2007)	1994–continuing	CIFOR, Indonesian Ministry of Forestry, WWF, Tanah Air Beta (an Indonesian NGO)	Local government, Ministry of Forestry, local communities	Inductive research, simulation modelling, scenarios
Merauke landscape, Papua, Indonesia	Sarkar et al. (2016)	2000–2005	Conservation International, Medco	Medco estate crops company, local communities, local government	Inductive research, multi-criteria analysis
Lombok landscape, Nusa Tenggara Barat, Indonesia	Riggs et al. (2018)	2014–continuing	JCU, Tanah Air Beta	Local government, Mataram University, Forest Management Unit, local NGOs and communities	Inductive research, network and discourse analysis, theory of change
Seram landscape and seascape, Maluku, Indonesia	Langston et al. (2020)	2015–continuing	Birdlife International, JCU, University of British Columbia, Tanah Air Beta	Local government, Pattimura University, Ambon, local NGOs and communities	Inductive research, network analysis, theory of change, participatory visualization
Sumatra landscapes, Indonesia	Sari et al. (2019)	2014–continuing	Zoological Society of London, JCU, WWF, Bogor Agricultural University, University of Indonesia	Local government, local NGOs, pulp and paper companies	Network analysis, scenarios
Durazno landscape, Uruguay	Boedhihartono and Sayer (2012)	2006–2012	WWF, IUCN, Stora Enzo	Local communities, local government, Stora Enzo plantation company	Participatory visualization

NGO = non-governmental organization.

landscapes and we did not have the resources to apply all five practices in all of the landscapes. In each of the landscapes, the deployment of a subset of these practices led to better shared understanding of change processes amongst scientists from different disciplines and between the scientists and resource users.

We review recent empirical and conceptual advances in each of the five practices, focusing on the contribution of each practice to a broader process of collaboration and change. It is not our intention to provide full methodological details of these practices, but rather to demonstrate how conservation science can use them to engage more effectively with the broader social context in which conservation actions take place. We sought to find practical applications for the theoretical and philosophical tenets of transdisciplinary science and to adhere to the principles of knowledge co-production in sustainability research. As researchers we sought to experience and learn from the consequences of our actions in pursuing conservation goals (Reyers et al. 2010, Lang et al. 2012, Taleb 2018).

Social-ecological context and inductive research

Understanding the social-ecological context within which conservation actions take place can be achieved through inductive research (Goddard & Melville 2004), which involves researchers engaging with end users in a highly flexible manner to shape hypotheses about how decision-making might be influenced. Inductive methods encourage what has been called 'appreciative enquiry' (Cooperrider & Srivastva 1987), in which scientists engage with and learn from other people and organizations active in the landscape seeking to solve problems. Transdisciplinary problem-framing provides a starting point whereby science targets the existing strengths and capabilities within the system instead of imposing externally designed solutions (Brondizio 2017). For example, deciding what natural components that make up biodiversity merit conservation, and to what extent, reflects contextual cultural values (Boedhihartono et al. 2007, Sarkar 2019).

Inductive research draws from a diversity of anthropological perspectives that have contributed to biodiversity conservation, including cultural ecology, ethnobiology, political economy and interpretative anthropology (Orlove & Brush 1996). Anthropological techniques can be used to explore local knowledge and to ensure collective understandings and embedded norms and values amongst resource users and governance agencies are not underestimated (Boedhihartono 2012, Bernard 2017). More pertinently, these techniques can help to determine how knowledge is produced and who is empowered to produce it, how knowledge is shared and the impacts of power asymmetries (Brosius 2006). Historical trends analysis, debates concerning strengths, weaknesses, opportunities and threats (SWOT) confronting a landscape and a broad range of other participatory activities can help to engage local stakeholders in knowledge-sharing and scenario exploration. Drawing rich pictures can elicit information on the values that people attach to landscape attributes (Bell & Morse 2013).

All of the above issues determine the context in which conservation research is conducted and the ways in which resource-use decisions are made. Unstructured, inductive research methods are often more effective at unravelling the complexity of these issues than rigid, pre-planned conceptual and analytical frameworks. Social scientists have led our engagement in each of the landscapes in Table 1. The task of the initial social science engagement has

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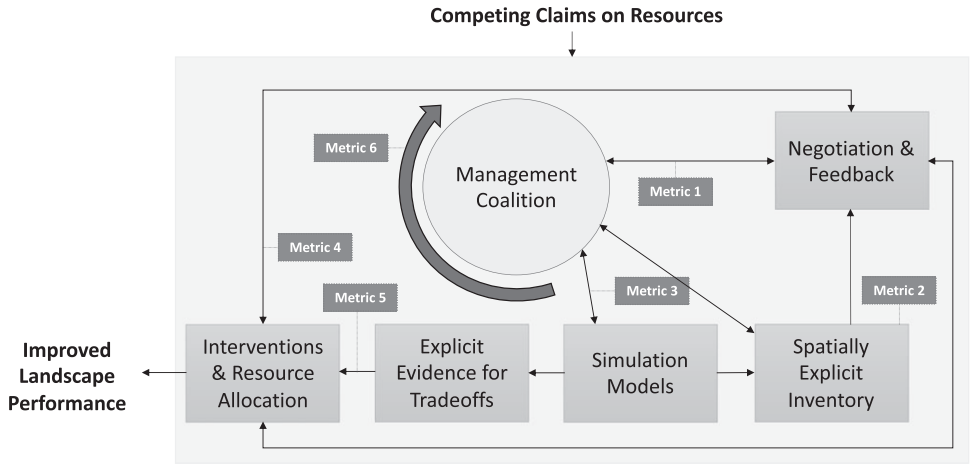


Fig. 1. Generic theory of change for social-ecological systems in landscapes, adapted from Sayer et al. (2016a). A management coalition drives progress towards improved landscape performance. Arrows show the direction of progress in changing the system. Competing claims provide the justification for the process. Metrics for tracking progress correspond to the critical processes, which are shown as numbered boxes: (1) negotiation and communication of clear goals; (2) a clear and agreed theory of change; (3) a rigorous and equitable process for continuing stakeholder engagement; (4) connection to policy processes and key actors; (5) effectiveness of governance; and (6) transparency.

been to build relationships by living in the communities and sharing their lives (Boedhihartono 2004).

Theories of change

Theories of change consist of models that show how initiatives (e.g., a policy, strategy or project) might contribute through a sequence of outcomes to an intended goal (Serrat 2017). Such theories help us to navigate through the complexity of social change. Theories of change are conceptually different from the linear logical frameworks that have guided conservation projects in the past (Prinsen & Nijhof 2015). Rather than accounting for inputs and outputs, they are designed to account for broader systems processes along non-linear pathways that enable continual learning to achieve accepted goals. Theories of change are transparent and account for trade-offs and make assumptions explicit, thus enabling buy-in from a wide range of stakeholders (Biggs et al. 2016). There is no single definition of, or fixed methodology for, a theory of change; rather, the approach allows flexibility according to the needs of the implementers (Vogel 2012). The utility of a theory of change is therefore limited by its application, by how rigorous and genuinely collaborative it is and by how it impacts on decisions that determine outcomes. Reinforced by Forsyth (2018), theories of change risk perpetuating exclusionary practices if they fail to make assumptions explicit and include a diversity of perspectives.

Theories of change can provide conservation scientists with a method for mainstreaming conservation into the development process. We have built theories of change in landscapes with local partners by collaboratively framing why goals and desired futures are what they are, what the details of those goals are, who enables and hinders the achievement of those goals and how they might be achieved (Fig. 1). Doing this effectively means laying all change logic assumptions bare. Theories of change built with local partners enable conservation scientists to contribute to developing a common understanding of the challenges and building a common commitment to deciding how to allocate resources and how and when to trigger interventions. Theories of change built at the start of interventions or retrospectively can also form the basis of evaluating the effectiveness of interventions, serving as a focus for learning and adaptive management (Belcher et al. 2020). In our experience, theories of change are most useful as consensus-building and societal learning tools (Brondizio et al. 2016). As part of an inductive research process, historical trends analysis, scenario visualization, simulation analysis, network analysis and discourse analysis have all proven useful in contributing to a theory of change (Boedhihartono 2012, van Noordwijk et al. 2015, Amaruzaman et al. 2017). Agreeing on a conceptual understanding of an issue and a way forward can be a significant step towards building commitment to conservation partnerships.

Theories of change are increasingly being used by agencies working to steer complex systems towards more sustainable trajectories (Thornton et al. 2017). The rate of change in social-ecological systems is accelerating to the point where the past is not necessarily a good indicator of the future (Steffen et al. 2015). Theories of change must account for temporal and spatial feedback throughout the entire system. Local knowledge, judgement and quantitative data are all required to build theories of change. In developing a theory of change, key milestones and processes to achieve goals have to be identified. Process and outcome metrics should be identified and interventions adapted based on progress towards those milestones and goals (Sayer et al. 2016b).

Network analysis

Conservation policy and conservation management are embedded in networks. Emerging from network science, network analysis describes the relationships between societal actors within networks, including individuals, organizations and government agencies. The analysis can identify who and what has influence, the degree of influence and where the linkages between actors can be improved for better overall management of complex systems (Prell et al. 2009, Gallemore et al. 2015). Network science is prominent in sociology and political sciences, where social network analysis (SNA) and policy network analysis (PNA) have been applied to natural resource management in a variety of circumstances (Marin & Mayntz 1991, Bodin & Prell 2011, Scott & Carrington 2011). Network analysis is distinct from actor network theory, which emphasizes relationality among entities rather than relationships between individual actors (Latour 1996). For the purposes of conservation, network analysis can help us to identify who to work with and where to leverage support for building consensus. An accompanying discourse analysis applied to those networks enables a better understanding of the subjective and political vantage points of influential people and institutions (Carmenta et al. 2017).

Network analysis can uncover hidden alliances and conflicts. Paired network and discourse analysis can show where knowledge

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might be co-generated to influence the narratives upon which decisions are made (Berkes 2009, Huitema & Turnhout 2009, Nel et al. 2016). Because governance of natural resources requires cross-sectoral collaboration, bridging institutions are necessary to coordinate the actions of the multiple actors that exist in landscapes (Berkes 2009, Kowalski & Jenkins 2015). Network analysis can help identify where those bridging institutions should apply their relationship-building efforts (Clark et al. 2011, Nel et al. 2016). Network analyses can be used as a diagnostic tool, but its real strength lies in enabling a living and evolving representation of actors and their relationships so that interventions can be adapted to deal with changing realities. Network analyses should not be undertaken by scientists alone; co-produced network analysis, with local people and practitioners, enables a shared understanding of the networks of influence and knowledge sharing, to better manage conservation and development trade-offs (Langston et al. 2019, Sari et al. 2019). Various methods can be employed to create networks, including participatory activities (Schiffer & Hauck 2010), interview-based data collection (Hogan et al. 2007) and content-based analysis.

We used participatory activities at a locally held workshop to gather information on network dynamics in the landscape at the district level in East Lombok, Indonesia (Riggs et al. 2018). The intent of the workshop was to connect local forestry officials and researchers in order to develop an understanding of the challenges and opportunities of integrated landscape management in the district. The network was first mapped on paper, with participants identifying the actors that affect, or are affected by, forest management decisions, including power, influence and relationships. As the network activity was conducted with the local forest authorities, it created an opportunity to discuss power distribution within the landscape and the diversity of objectives of different actors. The network activity incentivized local actors that participated in the workshop to give more attention to stakeholder needs and relationships and to seek partnership opportunities for improved landscape management.

Scenario development and simulation modelling

We have developed scenarios employing simple visual techniques or simulation modelling using the methods of Sandker et al. (2010) and Boedhihartono (2012). Scenarios based initially upon drawings and later formalized with models were used as a basis for a long-term initiative to monitor the performance of a Congo Basin forest landscape (Endamana et al. 2010). Scenarios for best-case and worst-case future situations were developed in all of the landscapes where we worked. Scenario exercises encouraged debate about conservation decision-making and built consensus on desirable future situations. For example, to visualize two possible future scenarios seen by local people and other stakeholders in La Paloma (Uruguay), we facilitated negotiations in Paloma between local Gaucho communities and outside investors who proposed to construct a pulp mill (Boedhihartono & Sayer 2012). Participants were asked to illustrate their preferred balance between mixed crops, plantations, cattle grazing and forest. These visualizations helped with the exchange of information, as well as helping to reduce tensions and move towards an acceptable compromise at the landscape scale.

Simulation modelling can be an effective way of creating and analysing a formal abstraction of an actual social-ecological system to predict its performance in the real world (Sandker et al. 2010). Simulation modelling can be used to assess alternative performance outcomes by varying the parameters of the model, its stocks and flows and the weights they are given. It can help users understand whether, under what conditions and in which ways desired or perverse outcomes might be achieved (Collier et al. 2011). For example, in Malinau District (North Kalimantan, Indonesia), government officials, local communities and researchers from CIFOR conducted participatory modelling to simulate potential scenarios for the impact of oil palm on the landscape (Sandker et al. 2007). We also used these techniques in East Lombok (Indonesia) to work with local forestry officials in order to explore scenarios for restoring degraded land (Riggs et al. 2018). The purpose of the model was not to make accurate predictions of restoration, but to generate discussion on the long-term impact of different restoration options for the land and for the local community. Models have limited power to make accurate predictions about complex outcomes of land-use change, but in these cases they were used to promote dialogue on different possible trajectories of change.

Multi-criteria analysis

The allocation of areas of land to different uses requires the simultaneous consideration of multiple goals and choices on the trade-offs between those goals (Lai & Hopkins 1989, Malczewski 2006, Moffett & Sarkar 2006, Sarkar & Illoldi-Rangel 2010). Measuring suitability for agriculture is a function of climate, soil type, market access, etc. Identifying areas for the protection of biodiversity often involves incorporating opportunities and constraints such as economic and social benefits and costs, as well as species distribution patterns and the viability of populations.

Incorporating multiple criteria into land-use decisions is challenging. It requires explicit attention to values that may be in conflict and the trade-offs between them. In formal MCAs, each value is modelled by a criterion, and the potential performance of each alternative outcome is assessed against each criterion. These assessments can then be integrated by various MCA methods to provide a final ranking of the outcomes that takes into account the trade-offs between the criteria. We used the MCA methodology of multi-attribute value theory (MAVT) to explore land-use options in an area allocated for estate crops near Merauke in Indonesian Papua (Sarkar et al. 2016). This methodology required the explicit formulation of the problem to be solved, what the available options or alternatives were, what socioeconomic, biological and other factors or criteria needed to be taken into account, how they should be measured and a step-by-step protocol for making choices. The core of this methodology was to elucidate all of the relevant factors and to order them by perceived importance in an objectives hierarchy of values modelled by the criteria (Keeney 1996). We constructed such hierarchies and assigned weights to the relevant criteria through consultations with all stakeholders. The processes of inductive research and the development of theories of change described earlier enriched this preference elicitation stage.

The structured explicit approach of the MCA has four important advantages (Sarkar et al. 2016):

(1) The analysis is transparent, with all objectives and methods available for scrutiny.
(2) The analysis, repeated by others with the same data, will yield the same results.
(3) Because it is explicit, the method of analysis is easily transported from one scenario to another.

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Table 2. Two solutions, shown in Fig. 2 as Scenario A and Scenario B, and the criteria used in trading off biodiversity protection with production opportunities in a concession for growing wood pulp near Merauke, Papua Province, Indonesia.

Solution 1	Solution 2
• Represents at least 30% of the area of all habitat types • Includes all sacred sites • Excludes villages and village buffers • Minimizes the number of selected cells (leaving as many as possible for production) • Minimizes shape (high area to edge ratio for clusters of selected grid cells)	• Meets the 30% habitat representation target • Gets as close as possible to a 40% habitat representation target • Includes all sacred sites • Excludes villages and buffer zones • Minimizes the number of cells rated 4 and 5, the most suitable for production • Minimizes shape • Maximizes hydrological connectivity • Maximizes the amount of community land identified by communities for traditional uses

(4) The structured protocol enables the development of computer-based decision support tools, making the rapid exploration of the costs and benefits of a large number of decision choices feasible.

Typically, a number of alternative solutions will be found based on the different weightings and preferences of stakeholders. For example, one solution might show the cost in foregone production opportunities of achieving a high-biodiversity conservation goal. By contrast, another might show the cost to biodiversity protection of reaching a high-production target. The idea is to find a compromise balancing both production and protection that all stakeholders can live with, even though it may not satisfy their highest aspirations.

A large number of methods have been applied to MCAs (e.g., Figueira et al. 2005, Moffett & Sarkar 2006). MAVT (Dyer 2005) was the methodology used for our work in Merauke because, in the absence of explicit consideration of uncertainties in outcomes, it is the simplest form of analysis consistent with standard microeconomic theory (Moffett & Sarkar 2006).

MCA was used to identify areas that might be protected for their biodiversity value within the concession for growing wood for pulp near Merauke (Sarkar et al. 2016). The result also simultaneously incorporates areas that protect hydrological processes and access for local communities to practice traditional uses such as hunting and gathering food and medicines, extracting sago from sago palm groves and maintaining important cultural sites.

A very simple solution and a more complex solution are contrasted here to illustrate how MCA was used (Table 2). In each solution, the following question was asked: 'What is the set of grid cells to be protected that . . . ?'

More total area is required to satisfy the goals of the second, more complex solution. Figure 2 illustrates the impact on potential wood pulp production.

Both solutions require that some of the grid cells rated as most suitable for growing wood pulp be allocated to biodiversity protection, ongoing community use and maintaining hydrological connectivity. What is important here is that all stakeholders can see just what the opportunity costs for production are when a different goal – in this case, biodiversity protection – is satisfied. The analysis provides evidence upon which to base decisions. Stakeholders

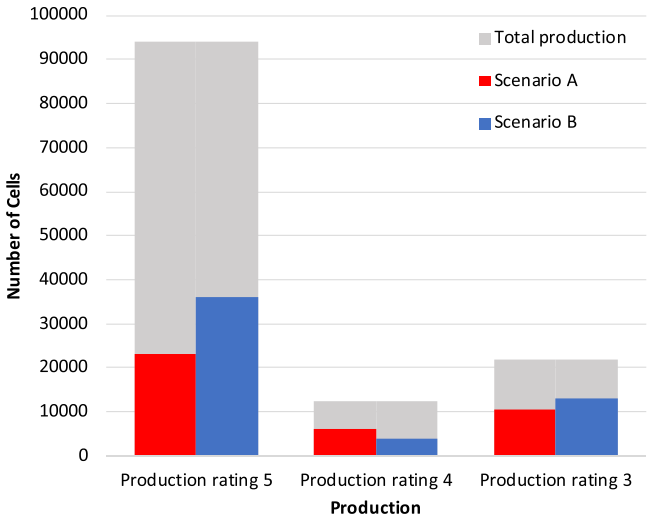


Fig. 2. The number of grid cells rated 5, 4 and 3 (the highest ratings, respectively) for growing wood pulp (grey area) and the number required to satisfy the two solutions outlined in the main text. Red is the first, simpler solution and blue the second.

may well want to see the results of other solutions, such as the impact on biodiversity of higher-production goals, before deciding on one or another, and this can be done quickly with computer-based decision support tools of this kind.

Process integration

The five practices described above can be used interactively and with continual feedback. They complement and do not replace other scientific studies that may be needed to understand specific conservation and development challenges. For example, the first stage in Seram, Lombok and Malinau consisted of understanding landscape context through inductive research. Then, with a sufficiently rich understanding of the decision context, actors and values available, it became possible to formulate and use theories of change that make stage-wise predictions of outcomes leading towards goals. Network analysis complemented these stages by identifying the relevant actors in the system in which conservation decisions were to be implemented and how these actors interacted with each other. Established partnerships created an opportunity to use scenarios and simulation modelling to predict and explore possible outcomes. MCA was used before the other tasks were completed. Once the societal values, constraints and opportunities had been identified, it became possible to identify feasible decisions that could potentially be implemented. Effectively integrating these practices and tools required a multidisciplinary team of people with strong 'epistemological agility' (Haider et al. 2018), who are sensitive to their positionality, value inclusivity and have complementary skillsets. The difficulties of knowledge co-production through transdisciplinary research, such as managing power relations or working with limited time and funding, can be prohibitive to many organizations and academic researchers (Langston et al. 2019, Turnhout et al. 2020). However, with minimal resources, the practices we outlined here have been integrated and incorporated into long-term processes of understanding and influencing change. These approaches often fail to meet the criteria against which the performance of academic researchers is assessed, and this rather open-ended research rarely meets the requirements of research funding agencies. We argue that more scientific

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resources should be deployed to support long-term place-based transdisciplinary science as a foundation within which targeted studies can identify technical solutions.

Discussion and conclusions

Knowledge of the biology and ecology of species and habitats is clearly important for conservation, but this knowledge increases enormously in value if it is embedded within a broader understanding of social-ecological systems and cultural context. What can be done in the biophysical realm is constrained by social, economic and political processes. Methods are needed to analyse complex multi-sectoral situations, drawing from empirical knowledge and from diverse disciplines to explore pathways for change (Kidd et al. 2019). Most importantly, these methods should embrace complexity and support the co-generation of knowledge by practicing science within landscapes, working with people, not on or for them (Boedhihartono et al. 2018).

We have deployed the tools described in this paper opportunistically in landscapes where our organizations were seeking to achieve conservation outcomes. The tools were not used in a planned, sequential manner. The use of the tools helped coalesce a community of practice within the landscapes; it fostered the emergence of a conservation narrative that was shared by the networks of actors who had a stake in the use of resources in the landscape. The benefits that came from the use of these techniques were incremental rather than transformational. Impact could not be measured against short-term biophysical indicators, but rather in improvements in governance of the social-ecological system. The approaches advocated here are by their nature intrusive. They assume the legitimacy of an outside agent to seek to influence conservation and development outcomes. In our actions, we are deliberately reflexive – we are influenced by local actors and we seek to influence them. There is increasing resistance in some quarters to what is perceived to be conservation colonialism (Agrawal 1997). The practice of protecting biodiversity has often created and reinforced social hierarchies adverse to marginalized groups. Any outside agent seeking to pursue an agenda of the kind outlined above would need to establish its acceptance and legitimacy with local stakeholders. This might appear to be self-evident, yet conventional conservation biology often lacks local legitimacy. Recognition of diverse understandings of what conservation and environment mean to different people, and of approaches to bridging these understandings, is creating new pathways for legitimate and inclusive conservation (Sheil 2017, Norström et al. 2020). The phase of inductive research that we propose is in line with these approaches, but even before this, any conservation organization should reflect upon what it is that gives it the right to seek to influence people's lives. In many tropical situations, the people concerned are amongst the world's poorest. All conservationists have to reflect upon the ethics of attempting to modify the lives of people who already live in very precarious conditions.

Transdisciplinary science is a collaborative process bringing together scientists from different disciplines with practitioners and local people to co-generate knowledge for solving practical problems (Hadorn et al. 2008, Popa et al. 2015). Societal challenges require integrated approaches, drawing from different types of knowledge and disciplines to solve complex problems. Transdisciplinary science emphasizes participation and process; it is a commitment to respecting and learning from contrasting perspectives and values (Stokols 2006). The co-generation of knowledge extends from collaborative problem-framing to impact, encompassing a diverse set of activities and understandings (Norström et al. 2020). There is now strong recognition that knowledge co-generation should be attentive to inclusivity, power, process and reflexivity (Miller & Wyborn in press). Transdisciplinary science is not just about creating new knowledge with new people, but embraces a deeper philosophy of how knowledge is held, created, shared and used.

Conservation scientists should be exposed to the consequences of the solutions that they advocate. Taleb (2018) argues that scientists have a moral responsibility for the implications of their research findings. They have to be actors engaged in the broader processes of societal change and assert their influence from within those processes. The practices and their tools and methods that are outlined above enable scientists to understand and engage with broader development processes and seek to influence those processes to achieve better outcomes for conservation and for people. We do not seek to impose any particular model of development, but rather to enrich the processes through which local actors define their own futures. At present, conservation science is not investing enough in engaging with the people who will experience the immediate consequences of conservation interventions. It is not sufficient to theorize about conceptual frameworks for transdisciplinary research, nor to understand how social systems function, who influences that functionality and what alternative scenarios might exist, as useful as this is. A further step is necessary, which is to learn from practices and to share the understanding gained with the people whose livelihoods are impacted. When conservation scientists engage actively with the processes of change, better outcomes for biodiversity have been achieved.

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References

Agrawal A (1997) The politics of development and conservation: legacies of colonialism. *Peace & Change* 22: 463–482.

Agrawal A (2001) Common property institutions and sustainable governance of resources. *World Development* 29: 1649–1672.

Amaruzaman S, Leimona B, van Noordwijk M, Lusiana B (2017) Discourses on the performance gap of agriculture in a green economy: a Q-methodology study in Indonesia. *International Journal of Biodiversity Science, Ecosystem Services & Management* 13: 233–247.

Belcher BM, Davel R, Claus R (2020) A refined method for theory-based evaluation of the societal impacts of research. *MethodsX* 7: 100788

Bell S, Morse S (2013) Rich pictures: a means to explore the 'sustainable mind'? *Sustainable Development* 21: 30–47.

https://doi.org/10.1017/S0376892920000338 Published online by Cambridge University Press

Bennett NJ, Roth R, Klain SC, Chan K, Christie P, Clark DA et al. (2017) Conservation social science: understanding and integrating human dimensions to improve conservation. *Biological Conservation* 205: 93–108.

Berkes F (2009) Evolution of co-management: role of knowledge generation, bridging organizations and social learning. *Journal of Environmental Management* 90: 1692–1702.

Bernard HR (2017) *Research Methods in Anthropology: Qualitative and Quantitative Approaches*. Lanham, MD, USA: Rowman & Littlefield.

Biggs D, Cooney R, Roe D, Dublin HT, Allan JR, Challender DW, Skinner D (2016) Developing a theory of change for a community-based response to illegal wildlife trade. *Conservation Biology* 31: 5–12

Bodin Ö, Prell C (2011) Social network analysis in natural resource governance: summary and outlook. In: *Social Networks and Natural Resource Management: uncovering the Social Fabric of Environmental Governance*, eds Ö Bodin, C Prell, pp. 347–373. Cambridge, UK: Cambridge University Press.

Boedhihartono A (2004) Dilemme à Malinau, Borneo: être ou ne pas être un chasseur-cueilleur Punan. Unpublished doctoral dissertation. Paris, France: Université Paris VII.

Boedhihartono AK (2012) *Visualizing Sustainable Landscapes: Understanding and Negotiating Conservation and Development Trade-offs Using Visual Techniques*. Gland, Switzerland: IUCN.

Boedhihartono AK, Bongers F, Boot RGA, van Dijk J, Jeans H, van Kuijk M et al. (2018) Conservation science and practice must engage with the realities of complex tropical landscapes. *Tropical Conservation Science* 11: 1–7.

Boedhihartono AK, Gunarso P, Levang P, Sayer J (2007) The principles of conservation and development: do they apply in Malinau? *Ecology and Society* 12: 2.

Boedhihartono AK, Sayer J (2012) Forest landscape restoration: restoring what and for whom? In: *Forest Landscape Restoration*, eds J Stanturf, D Lamb, P Madsen, pp. 309–323. Berlin, Germany: Springer Science+Business Media.

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, Shirk J (2009) Citizen science: a developing tool for expanding science knowledge and scientific literacy. *BioScience* 59: 977–984.

Brondizio ES (2017) Interdisciplinarity as Collaborative Problem Framing. ITEMS: Insights from the Social Sciences (Social Science Research Council) [www document]. URL https://items.ssrc.org/interdisciplinarity/interdisciplinarity-as-collaborative-problem-framing/

Brondizio ES, O'Brien K, Bai X, Biermann F, Steffen W, Berkhout F et al. (2016) Re-conceptualizing the Anthropocene: a call for collaboration. *Global Environmental Change* 39: 318–327.

Brosius JP (2006) Common ground between anthropology and conservation biology. *Conservation Biology* 20: 683–685.

Brown K (2002) Innovations for conservation and development. *Geographical Journal* 168: 6–17.

Byerly H, Balmford A, Ferraro PJ, Hammond Wagner C, Palchak E, Polasky S et al. (2018) Nudging pro-environmental behavior: evidence and opportunities. *Frontiers in Ecology and the Environment* 16: 159–168.

Campbell BM, Sayer JA (2003) *Integrated Natural Resource Management: Linking Productivity, the Environment and Development*. Wallingford, UK: CABI Publishing.

Campbell BM, Sayer JA, Walker B (2010) Navigating trade-offs: working for conservation and development outcomes. *Ecology and Society* 15: 16.

Carmenta R, Zabala A, Daeli W, Phelps J (2017) Perceptions across scales of governance and the Indonesian peatland fires. *Global Environmental Change* 46: 50–59.

Clark WC (2007) Sustainability science: a room of its own. *Proceedings of the National Academy of Sciences of the United States of America* 104: 1737–1738.

Clark WC, Tomich TP, van Noordwijk M, Guston D, Catacutan D, Dickson NM, McNie E (2011) Boundary work for sustainable development: natural resource management at the Consultative Group on International Agricultural Research (CGIAR). *Proceedings of the National Academy of Sciences of the United States of America* 1113: 4615–4612

Colfer CJP (2011) Marginalized forest peoples' perceptions of the legitimacy of governance: an exploration. *World Development* 39: 2147–2164.

Collier N, Campbell BM, Sandker M, Garnett ST, Sayer J, Boedhihartono AK (2011) Science for action: the use of scoping models in conservation and development. *Environmental Science & Policy* 14: 628–638.

Cooperrider DL, Srivastva S (1987) Appreciative inquiry in organizational life. *Research in Organizational Change and Development* 1: 129–169.

Dyer JS (2005) MAUT – multiattribute utility theory. In: *Multiple Criteria Decision Analysis: State of the Art Surveys*, pp. 265–292. Berlin, Germany: Springer Science+Business Media.

Endamana D, Boedhihartono A, Bokoto B, Defo L, Eyebe A, Ndikumagenge C et al. (2010) A framework for assessing conservation and development in a Congo Basin forest landscape. *Tropical Conservation Science* 3: 262–281.

Evans MC, Davila F, Toomey A, Wyborn C (2017) Embrace complexity to improve conservation decision making. *Nature Ecology & Evolution* 1: 1588.

Feintrenie L, Chong WK, Levang P (2010) Why do farmers prefer oil palm? Lessons learnt from Bungo District, Indonesia. *Small-Scale Forestry* 9: 379–396.

Figueira J, Greco S, Ehrgott M (2005) *Multiple Criteria Decision Analysis: State of the Art Surveys*. Berlin, Germany: Springer Science+Business Media.

Filer C (2011) Interdisciplinary perspectives on historical ecology and environmental policy in Papua New Guinea. *Environmental Conservation* 38: 256–269.

Forsyth T (2018) Is resilience to climate change socially inclusive? Investigating theories of change processes in Myanmar. *World Development* 111: 13–26.

Gallemore C, Di Gregorio M, Moeliono M, Brockhaus M, Prasti HRD (2015) Transaction costs, power, and multi-level forest governance in Indonesia. *Ecological Economics* 114: 168–179.

Ghazoul J (2007) Placing humans at the heart of conservation. *Biotropica* 39: 565–566.

Goddard W, Melville S (2004) *Research Methodology: An Introduction*. Cape Town, South Africa: Juta and Company Ltd.

Hadorn GH, Biber-Klemm S, Grossenbacher-Mansuy W, Hoffmann-Riem H, Joye D, Pohl C et al. (2008) *Handbook of Transdisciplinary Research*. Berlin, Germany: Springer Science+Business Media.

Haider LJ, Hentati-Sundberg J, Giusti M, Goodness J, Hamann M, Masterson VA et al. (2018) The undisciplinary journey: early-career perspectives in sustainability science. *Sustainability Science* 13: 191–204.

Hicks CC, Fitzsimmons C, Polunin NVC (2010) Interdisciplinarity in the environmental sciences: barriers and frontiers. *Environmental Conservation* 37: 464–477.

Hogan B, Carrasco JA, Wellman B (2007) Visualizing personal networks: working with participant-aided sociograms. *Field Methods* 19: 116–144.

Huitema D, Turnhout E (2009) Working at the science–policy interface: a discursive analysis of boundary work at the Netherlands Environmental Assessment Agency. *Environmental Politics* 18: 576–594.

IUCN (2008) Learning from landscapes. *Arborvitae Special Edition* [www document]. URL https://www.iucn.org/content/arborvitae-special-issue-learning-landscapes

IUCN, WWF (1980) *World Conservation Strategy: Living Resource Conservation for Sustainable Development*. Gland, Switzerland: IUCN.

Kamoto J, Clarkson G, Dorward P, Shepherd D (2013) Doing more harm than good? Community based natural resource management and the neglect of local institutions in policy development. *Land Use Policy* 35: 293–301.

Kareiva P, Marvier M (2012) What is conservation science? *BioScience* 62: 962–969.

Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, Lowe I et al. (2001) Sustainability science. *Science* 292: 641–642.

Keeney RL (1996) *Value-Focused Thinking*. Cambridge, MA, USA: Harvard University Press.

Kidd LR, Garrard GE, Bekessy SA, Mills M, Camilleri AR, Fidler F et al. (2019) Messaging matters: a systematic review of the conservation messaging literature. *Biological Conservation* 236: 92–99.

Kloor K (2015) The battle for the soul of conservation science. *Issues in Science and Technology* 31: 74–79.

Knight AT, Cowling RM, Rouget M, Balmford A, Lombard AT, Campbell BM (2008) Knowing but not doing: selecting priority conservation areas and the research–implementation gap. *Conservation Biology* 22: 610–617.

Kowalski AA, Jenkins LD (2015) The role of bridging organizations in environmental management: examining social networks in working groups. *Ecology and Society* 20: 16.

Lai S-K, Hopkins LD (1989) The meanings of trade-offs in multiattribute evaluation methods: a comparison. *Environment and Planning B: Planning and Design* 16: 155–170.

https://doi.org/10.1017/S0376892920000338 Published online by Cambridge University Press

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P et al. (2012) Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science* 7: 25–43.

Langston JD, Riggs RA, Boedhihartono AK, Kastanya A, Sayer J (2020) An island in transition: governing conservation and development in Seram, Indonesia. *Singapore Journal of Tropical Geography* doi: 10.1111/sjtg.12336.

Langston JD, Riggs RA, Kastanya A, Sayer J, Margules C, Boedhihartono AK (2019) Science embedded in local forest landscape management improves benefit flows to society. *Frontiers in Forests and Global Change* 2: 3.

Langston JD, Riggs RA, Sururi Y, Sunderland T, Munawir M (2017) Estate crops more attractive than community forests in west Kalimantan, Indonesia. *Land* 6: 12.

Latour B (1996) On actor-network theory: a few clarifications. *Soziale Welt* 47: 369–381.

Levang P, Riva WF, Orth MG (2016) Oil palm plantations and conflict in Indonesia: Evidence from West Kalimantan. In: *The Oil Palm Complex: Smallholders, Agribusiness and the State in Indonesia and Malaysia*, eds R Cramb, JF McCarthy, pp. 283–300. Singapore: NUS Press.

Lynam T, De Jong W, Sheil D, Kusumanto T, Evans K (2007) A review of tools for incorporating community knowledge, preferences, and values into decision making in natural resources management. *Ecology and Society* 12: 5.

Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science* 20: 703–726.

Marin B, Mayntz R (1991) *Policy Networks: Empirical Evidence and Theoretical Considerations*. *Frankfurt am Main*, Germany: Campus Verlag.

McNie EC (2007) Reconciling the supply of scientific information with user demands: an analysis of the problem and review of the literature. *Environmental Science & Policy* 10: 17–38.

Miller CA, Wyborn C (in press) Co-production in global sustainability: histories and theories. *Environmental Science & Policy*.

Milner-Gulland E (2012) Interactions between human behaviour and ecological systems. *Philosophical Transactions of the Royal Society B: Biological Sciences* 367: 270–278.

Moffett A, Sarkar S (2006) Incorporating multiple criteria into the design of conservation area networks: a minireview with recommendations. *Diversity and Distributions* 12: 125–137.

Nel JL, Roux DJ, Driver A, Hill L, Maherry AC, Snaddon K et al. (2016) Knowledge co-production and boundary work to promote implementation of conservation plans. *Conservation Biology* 30: 176–188.

Norström AV, Cvitanovic C, Löf MF, West S, Wyborn C, Balvanera P et al. (2020) Principles for knowledge co-production in sustainability research. *Nature Sustainability* 3: 182–190.

Norton BG (1991) Thoreau's insect analogies: or why environmentalists hate mainstream economists. *Environmental Ethics* 13: 235–251.

Opdam P, Luque S, Nassauer J, Verburg PH, Wu J. (2018) How can landscape ecology contribute to sustainability science? *Landscape Ecology* 33: 1–7.

Orlove BS, Brush SB (1996) Anthropology and the conservation of biodiversity. *Annual Review of Anthropology* 25: 329–352.

Osbaldiston R, Schott JP (2012) Environmental sustainability and behavioral science: meta-analysis of proenvironmental behavior experiments. *Environment and Behavior* 44: 257–299.

Ostrom E (2009) A general framework for analyzing sustainability of social-ecological systems. *Science* 325: 419–422.

Popa F, Guillermin M, Dedeurwaerdere T (2015) A pragmatist approach to transdisciplinarity in sustainability research: from complex systems theory to reflexive science. *Futures* 65: 45–56.

Prell C, Hubacek K, Reed M (2009) Stakeholder analysis and social network analysis in natural resource management. *Society and Natural Resources* 22: 501–518.

Pressey RL, Weeks R, Gurney GG (2017) From displacement activities to evidence-informed decisions in conservation. *Biological Conservation* 212: 337–348.

Prinsen G, Nijhof S (2015) Between logframes and theory of change: reviewing debates and a practical experience. *Development in Practice* 25: 234–246.

Reyers B, Roux DJ, Cowling RM, Ginsburg AE, Nel JL, Farrell PO (2010) Conservation planning as a transdisciplinary process. *Conservation Biology* 24: 957–965.

Riggs RA, Langston JD, Margules C, Boedhihartono AK, Lim HS, Sari DA et al. (2018) Governance challenges in an eastern Indonesian forest landscape. *Sustainability* 10: 169.

Sandker M, Campbell BM, Ruiz-Perez M, Sayer JA, Cowling R, Kassa H, Knight AT (2010) The role of participatory modeling in landscape approaches to reconcile conservation and development. *Ecology and Society* 15: 13.

Sandker M, Suwarno A, Campbell BM (2007) Will forests remain in the face of oil palm expansion? Simulating change in Malinau, Indonesia. *Ecology and Society* 12: 37.

Sari DA, Sayer J, Margules C, Boedhihartono AK (2019) Determining the effectiveness of forest landscape governance: a case study from the Sendang landscape, south Sumatra. *Forest Policy and Economics* 102: 17–28.

Sarkar S (1998) Restoring wilderness or reclaiming forests. *Terra Nova* 3: 35–52.

Sarkar S (2012) *Environmental Philosophy: From Theory to Practice*. Hoboken, NJ, USA: John Wiley & Sons.

Sarkar S (2019) What should 'biodiversity' be? In: *From Assessing to Conserving Biodiversity*, pp. 375–399. Berlin, Germany: Springer Science+Business Media.

Sarkar S, Dyer JS, Margules C, Ciarleglio M, Kemp N, Wong G et al. (2016) Developing an objectives hierarchy for multicriteria decisions on land use options, with a case study of biodiversity conservation and forestry production from Papua, Indonesia. *Environment and Planning B: Urban Analytics and City Science* 44: 464–485.

Sarkar S, Illoldi-Rangel P (2010) Systematic conservation planning: an updated protocol. *Natureza & Conservação* 8: 19–26.

Sayer J, Campbell BM (2004) *The Science of Sustainable Development: Local Livelihoods and the Global Environment*. Cambridge, UK: Cambridge University Press.

Sayer J, Endamana D, Boedhihartono A, Ruiz Pérez M, Breuer T (2016a) Learning from change in the Sangha Tri-national landscape. *International Forestry Review Special Issue: Valuing the Cameroonian Forest* 18: 130–139

Sayer J, Margules C (2017) Biodiversity in locally managed lands. *Land* 6: 41.

Sayer JA, Margules C, Boedhihartono AK, Sunderland T, Langston JD, Reed J et al. (2016b) Measuring the effectiveness of landscape approaches to conservation and development. *Sustainability Science* 12: 465–476.

Sayer J, Margules C, Bohnet I, Boedhihartono AK, Pierce R, Dale A, Andrews K (2015) The role of citizen science in landscape and seascape approaches to integrating conservation and development. *Land* 4: 1200–1212.

Sayer J, Wells MP (2004) The pathology of projects. In: *Getting Biodiversity Projects to Work: Towards More Effective Conservation and Development*, eds To McShane, MP Wells, pp. 35–48. New York, NY, USA: Columbia University Press.

Schiffer E, Hauck J (2010) Net-Map: collecting social network data and facilitating network learning through participatory influence network mapping. *Field Methods* 22: 231–249.

Scott J, Carrington PJ (2011) *The SAGE Handbook of Social Network Analysis*. Thousand Oaks, CA, USA: SAGE Publications.

Serrat O (2017) *Knowledge Solutions*. Singapore: Springer.

Sheil D (2017) Exploring local perspectives and preferences in forest landscapes: towards democratic conservation. In: *Tropical Forest Conservation: Long-Term Processes of Human Evolution, Cultural Adaptations and Consumption Patterns*, eds N Sanz, RC Lewis, JP Mata, C Connaughton, pp. 262–283. Mexico City, Mexico: UNESCO.

Soulé ME (1985) What is conservation biology? *BioScience* 35: 727–734.

Steffen W, Broadgate W, Deutsch L, Gaffney O, Ludwig C (2015) The trajectory of the Anthropocene: the great acceleration. *The Anthropocene Review* 2: 81–98.

Stokols D (2006) Toward a science of transdisciplinary action research. *American Journal of Community Psychology* 38: 79–93.

Sunderland TC, Ehringhaus C, Campbell B (2007) Conservation and development in tropical forest landscapes: a time to face the trade-offs? *Environmental Conservation* 34: 276–279.

Taleb NN (2018) *Skin in the Game: Hidden Asymmetries in Daily Life*. New York, NY, USA: Random House.

Thaler RH, Sunstein CR (2003) Libertarian paternalism. *American Economic Review* 93: 175–179.

https://doi.org/10.1017/S0376892920000338 Published online by Cambridge University Press

Thaler RH, Sunstein CR (2009) *Nudge: Improving Decisions about Health, Wealth, and Happiness*. London, UK: Penguin.

Thornton PK, Schuetz T, Förch W, Cramer L, Abreu D, Vermeulen S, Campbell BM (2017) Responding to global change: a theory of change approach to making agricultural research for development outcome-based. *Agricultural Systems* 152: 145–153.

Turnhout E, Metze T, Wyborn C, Klenk N, Louder E (2020) The politics of co-production: participation, power, and transformation. *Current Opinion in Environmental Sustainability* 42: 15–21

van Noordwijk M, Minang PA, Freeman OE, Mbow C, de Leeuw J (2015) The future of landscape approaches: interacting theories of place and change. In: *Climate-Smart Landscapes: Multifunctionality in Practice*, eds PA Minang, M van Noordwijk, OE Freeman, C Mbow, J de Leeuw, D Catacutan, pp. 375–386. Nairobi, Kenya: World Agroforestry Centre, ICRAF.

Veríssimo D (2013) Influencing human behaviour: an underutilised tool for biodiversity management. *Conservation Evidence* 10: 29–31.

Vogel I (2012) *Review of the Use of 'Theory of Change' in International Development*. London, UK: Department for International Development (DFID).

Walker B, Salt D (2006) *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Washington, DC, USA: Island Press.

Williams DR, Balmford A, Wilcove DS (2020) The past and future role of conservation science in saving biodiversity. *Conservation Letters* doi: 10.1111/conl.12720.

https://doi.org/10.1017/S0376892920000338 Published online by Cambridge University Press