Annual Review of Environment and Resources

The Impact of Systematic Conservation Planning

Emma J. McIntosh,1 Robert L. Pressey,2 Samuel Lloyd,3,4 Robert J. Smith,5 and Richard Grenyer1

1School of Geography and the Environment, University of Oxford, Oxford OX1 3QY, United Kingdom; email: emma.mcintosh@ouce.ox.ac.uk, richard.grenyer@ouce.ox.ac.uk
2Australian Research Council Centre of Excellence for Coral Reef Studies, James Cook University, Townsville QLD 4811, Australia; email: bob.pressey@jcu.edu.au
3Department of Life Sciences, Imperial College London, Silwood Park Campus, Ascot SL5 7PY United Kingdom; email: slloyd13@imperial.ac.uk
4Department of Zoology, University of Oxford, Oxford, OX1 3PS, United Kingdom
5Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Kent CT2 7NR, United Kingdom; email: r.j.smith@kent.ac.uk

Keywords
systematic conservation planning, biodiversity conservation, spatial prioritization, protected area, conservation impact evaluation, reserve design

Abstract
Systematic conservation planning (SCP) is a rapidly advancing discipline aimed at providing decision support for choices between alternate conservation actions. SCP is often used to inform choices about areas to protect, in order to optimize outcomes for biodiversity while minimizing societal costs. Despite the widespread application of SCP approaches, there is limited understanding of the types of impacts resulting from related projects, and when and where it is most effective. This is compounded by the absence of a standardized approach to evaluating and reporting on the outcomes of SCP projects. We highlight the challenges of undertaking evaluations of complex planning processes, the current state of knowledge about the outcomes of SCP projects, and emerging opportunities to improve evaluation. There is a need for clarity around theories of change, definitions of SCP and impact, and standardized reporting and information sharing across the discipline.
Objective: quantitative interpretation of broader conservation goals for each spatial feature (e.g., 1,000 ha of a particular vegetation type)

Systematic conservation planning (SCP): a process for choosing between, locating, and implementing conservation actions

Impact: the difference between the outcome of an intervention and the counterfactual outcome arising from no intervention or a different intervention

Impact evaluation: identifying the intended and unintended consequences of an intervention

1. INTRODUCTION

Determining how best to allocate scarce resources between several policy or management options is extremely challenging, because of high uncertainty in the face of incomplete information, the need to engage with multiple stakeholders, and the likelihood of conflicting values and objectives. Such decision making is perhaps most commonly associated with conflict situations, social policy, and medical triage (1); however, it is essential for conservation biology, given the protection of vulnerable species and ecosystems often conflicts with expanding human needs (2).

Systematic conservation planning (SCP) is a discipline focused on providing decision support around the allocation of resources for biodiversity conservation (3). Among the best known applications of SCP are the rezoning of the Great Barrier Reef Marine Park (4) and a series of conservation plans in South Africa (5, 6). SCP has strongly influenced the conservation planning policies of large conservation organizations such as the World Wildlife Fund (7) and The Nature Conservancy (8), as well as national and regional governments (4, 9, 10). The ecological principles and specific objectives underpinning SCP mean that it is regarded as one of the most rigorous and defensible paradigms for conservation planning today (11–13).

The premise of SCP is that evidence-based advice promotes transparency and accountability when managing difficult and value-laden decisions. Following this line of logic, our interest lies in the degree to which SCP is actually aiding decision makers and how, when, and where it is most likely to lead to conservation impact.

SCP projects can be costly and time consuming to develop (12), and in situations requiring rapid action, queries have been raised about when and in which contexts the delay and cost required for additional data gathering and planning are justifiable (14). Perhaps most concerning are questions surrounding the degree to which SCP projects influence real-world decisions and concerns about the feasibility of their recommendations being adopted and implemented (15). One explanation for these uncertainties is the lack of information about the outcomes of SCP projects and a shortage of rigorous impact evaluations (16). Without such evidence, conservation organizations and government agencies will not only struggle to argue for investment...
Figure 1
Great Barrier Reef (GBR) Marine Park Zoning resulting from the 2003 Zoning Plan, one of the best known examples of SCP on a large scale. The Representative Area Program (90) was led by the GBR Marine Park Authority over several years and involved the collection of large biophysical and social datasets across the 344,400 km² region, as well as extensive stakeholder consultation (4, 90). The final plan, enacted by the Australian Parliament in 2004, increased the total area of no-take marine reserves (referred to as Marine National Park or “green zones”) from 4.6% to 33.3% of the total marine park, meeting important objectives that included at least 20% protection for each of 70 bioregions (4). The application of specific, quantifiable objectives during planning is widely acknowledged as having provided a structured process for intense political and social negotiations around changes to commercial and recreational fishing zones (E.J. McIntosh, unpublished interview data). This map shows only the zones within the GBR Marine Park; it does not show the coral reefs or any other components of the GBR ecosystem (for details of the zones, see http://www.gbrmpa.gov.au). Note: Map Projection: Unprojected Geographic Horizontal Datum: Geocentric Datum of Australia 1994. SDC 101006b, January 2016. Map courtesy of the Spatial Data Centre, Great Barrier Reef Marine Park Authority, reformatted for publication with permission. © Commonwealth of Australia (GBRMPA) 2017.
in planning exercises but will also continue to operate in uncertainty about the most effective approaches.

This review focuses on evidence for the outcomes of SCP, rather than the underlying principles and technical approaches commonly employed when developing plans, which have been extensively covered in this journal (11) and elsewhere (17–19). We describe the background and ontology of SCP before reviewing trends in the evaluation of conservation planning interventions. We then provide an exploration of how conservation impact can be defined and measured, as well as a review of new initiatives in this area for SCP. Finally, we reflect on the framing of SCP as a “challenging” intervention and recommend alternative approaches for impact evaluation and information sharing across the discipline.

2. THE ONTOLOGY OF SYSTEMATIC CONSERVATION PLANNING

Conservation planning is “the process of making informed conservation decisions” (20, p. 1). Approaches to allocating conservation resources vary widely, from ad hoc to highly structured decision support such as SCP. SCP refers to a structured, consultative process for choosing between, locating, configuring, and implementing conservation actions such that (a) the benefits of conservation actions (objectives) are specified as either threshold amounts of natural features to be represented or continuous functions with increasing amounts of features, and (b) the outputs are at least one optimal or near optimal set of spatially bounded conservation actions (21).

The first published instance of a reserve selection algorithm, the precursor to SCP, was a simple iterative algorithm calculated by hand to assess conservation options for plants in Tasmania (22, 23). In subsequent years, the approach has spread across the globe. Between 1980 and 2011, 1,834 articles were published that made reference to SCP or related themes (based on a keyword search conducted in Web of Science); 18, and a popular SCP software package, Marxan (24), was downloaded by more than 6,708 users from 184 countries between August 2011 and July 2016 (http://marxan.net/globe). As an example, one of the most recently implemented conservation areas designed using SCP is Tun Mustapha Park, an almost 1 million ha marine reserve in Malaysia, gazetted in May 2016 (25, 26).

In contrast to the explicit scoring or ranking approaches to identifying conservation priorities widely promoted in the 1970s (27), the goal of SCP has always been to identify emergent properties of sets of areas. Initially, this was expressed through complementarity between areas (3, 28) but, increasingly, the focus is also on connectivity (29). The core ecological principles underpinning SCP are representation and persistence, with the latter often approached through connectivity of multiple species and habitats across landscapes and seascapes (see 11, 18, 19 for further details and related terms).

Early on, SCP was envisaged as a six-stage process intended to guide conservation area selection (3). Following this model (Figure 2a), the first stage is data collection. A strength of the SCP process is the variety of data types that can be incorporated; biological elements, such as species distribution data, spatial surrogates for biodiversity, and metapopulation dynamics (11), can be considered alongside social, financial or political constraints and opportunities, such as the willingness of a local population to conserve an area (30, 31). For the second stage, specific quantitative objectives must be set, indicating how much of each biodiversity feature should be represented, often combined with quantitative or qualitative objectives for aspects such as connectivity, and the shape or size of conservation areas. Stage three consists of reviewing the extent to which the objectives are met by existing conservation area networks.

Available data are then analyzed (stage four) using an algorithmic approach in decision support software, to produce sets of priority areas for the expansion of the conservation area network. The
The primary stages of systematic conservation planning (SCP). SCP is an iterative, rather than a linear process, with feedbacks in light of new data or logistical considerations and with stakeholder engagement throughout. (a) Early six-stage view of the SCP process (3). (b) The dominant framework available for SCP, modified from Reference 12, with greater emphasis on implementation considerations. Light blue boxes indicate equivalent stages in a and b; dark blue indicates novel stages in b. The stages in orange refer to the spatial conservation prioritization stages, typically involving special-purpose software.

Most widely used purpose-built software packages are Marxan (32), C-Plan (33), and Zonation (34). This stage can also be done by hand or manually using geographic information system (GIS) software, but doing so is only feasible for small areas or less complex plans. Stages 3 and 4 together are often referred to as conducting a spatial conservation prioritization (or just prioritization) or conservation assessment (the former is used in this article) (35). Two fundamentally distinct applications are typically encountered when conducting prioritizations: the “minimum set covering” problem (36) in which the whole set of target features (e.g., species) is represented while minimizing some other factor (e.g., cost), and the “maximal covering” problem in which the selected set of target features is some maximized subset of the whole, subject to a ceiling on conservation resources (37).

Following this, in stage 5, appropriate management activities must then be identified and implemented, often comprising expanding an existing conservation area network. Finally, the network must be actively managed to maintain the contributions of conservation areas to the predetermined objectives (stage 6).

Since the 2000 envisioning of SCP as consisting of six stages (3), numerous other operational models have been proposed that include iterative elements and increasing numbers of stages (11, 12, 38, 39). One recent articulation includes eleven primary stages (Figure 2b). The focus on implementation has been expanded to include greater consideration of stakeholder engagement, reviewing the local context, and incorporating socio-economic data from the outset (stages 1–5 in Figure 2b), better reflecting SCP as a social process.

The iterative aspects were included because SCP was increasingly seen as part of an adaptive process, responding to changing scenarios, novel data, and reviews of the success of activities, all based on the assumption that planning recommendations emerging from adaptive decisions are more likely to be effective (40). Overall, the addition of implementation-oriented stages in the eleven-stage model reflect an increased recognition that “effective conservation planning is fundamentally a practice, rather than a science” (41, p. 371). 

**Figure 2**

The primary stages of systematic conservation planning (SCP). SCP is an iterative, rather than a linear process, with feedbacks in light of new data or logistical considerations and with stakeholder engagement throughout. (a) Early six-stage view of the SCP process (3). (b) The dominant framework available for SCP, modified from Reference 12, with greater emphasis on implementation considerations. Light blue boxes indicate equivalent stages in a and b; dark blue indicates novel stages in b. The stages in orange refer to the spatial conservation prioritization stages, typically involving special-purpose software.
The scope of problems addressed has also expanded beyond the initial conceptualization of SCP as reserve selection. In addition to the design of new conservation areas, SCP is increasingly applied to diverse off-reserve mechanisms, including fire management and control of invasive species (42). Other applications focus on restoration (35) and the allocation of management actions within established protected areas. Prioritizations can also be used in nonspatial cases, such as the prioritization of threatened species (43); however, we focus on spatial applications for the purposes of comparability between projects.

The expansion of SCP has given rise to multiple terms with overlapping definitions and unclear distinctions. There are different schools of thought for terms including goals and objectives; here we follow Pressey & Bottrill (12), but confusingly the term targets has been used in the wider literature to refer to both conservation features of interest and the objectives for those features. As we explain throughout this article, there is also confusion between systematic conservation planning and spatial conservation prioritization.

Spatial conservation prioritizations can be conducted as stand-alone exercises to investigate the influence of types of data, not necessarily intended for implementation or application in a broader SCP process. However, their similar terminology, three-letter acronyms, and map-based outputs often lead to prioritizations and the whole SCP process being confused. This confusion complicates the challenge of conducting impact evaluations for SCP, when a variety of decision support exercises are referred to with the same name. To ensure a comparison of like with like, clear definitions must be used and individual projects carefully characterized prior to any evaluation. In this article, we use SCP exclusively to refer to the broader, consultative planning process focused on implementation (distinct from other forms of conservation planning due to the inclusion of a prioritization exercise) (Figure 2b), as compared with prioritization exercises themselves, which may or may not be intended for direct implementation.

3. PRINCIPLES OF IMPACT EVALUATION

Impact evaluation is primarily focused around identifying the intended and unintended consequences of an intervention (44). Working toward conservation impact requires a clear understanding of what is to be achieved and how to determine when conservation goals are reached; in other words, it requires a clear definition of what impact is meant to indicate. This knowledge alone, however, is insufficient; it is also necessary to hypothesize how proposed actions will lead to the desired impacts. This section expands on these considerations and suggests reasons for the deficiency of impact evaluation studies of SCP.

3.1. Defining Impact

Consider a hypothetical SCP project to prevent the extirpation of a native species by habitat loss, by providing advice on where to establish a new protected area. We begin by defining the SCP project as an intervention. We refer to the change in the amount of habitat protected as a measurable product of the intervention—an output. The assumed or measured degree to which the native species responds to the output is the outcome of the intervention. But nothing up to this point actually measures the effectiveness of the intervention, which can only be judged on the difference between outcomes across a counterfactual comparison. We define this counterfactual difference as the impact of the intervention; here, we follow Pressey et al. (45).

Conservation plans must do several things to maximize conservation gains: achieve explicit objectives, involve stakeholders and minimize harm to people, promote transition to implementation, deliver cost-effective outcomes, and make a difference to biodiversity and/or people (have
conservation impact). Evaluations should extend beyond the measurement of whether objectives have been met in areas identified as priorities (15). They should also consider the cost and efficiency of reaching these objectives and the effects of using cost-effectiveness analysis and threat reduction assessment (alongside sociocultural and ecological considerations) (46). In the context of SCP, conducting evaluations in the form of the representativeness of a proposed conservation area can give misleading results for conservation impact. Representativeness in theoretical, or even implemented, conservation areas can be a weak measure of impact because it does not necessarily reflect consequences for biodiversity protection (45), e.g., species persistence on the ground.

Impact evaluation addresses a critical question: What would have happened without the intervention? Impact evaluation, rather than measuring outcomes, is the only way to attribute apparent changes in the condition of biodiversity to a planning exercise (47) because it allows distinguishing the effects of the planning process from other external factors. For example, the outcome of increased native species in a protected area could be due to influences such as weather or climatic events, not necessarily the reduction in habitat loss. Consequently, an outcome associated with a conservation plan should merely be reported as such—an outcome, possibly reflecting factors other than the planning process, rather than a verified impact.

An evidence hierarchy exists in the evaluation literature, with double-blind randomized control trials commonly regarded as the gold standard for establishing attribution, particularly in the medical and health sciences literature (48). Such experimental approaches are often less practical or desirable for conservation interventions, for which quasi-experimental and qualitative analyses can also yield valuable information (47). Ultimately, the most important considerations are the design of the evaluation, a strong conceptual understanding of chains of causal inference (and an attempt to verify these with data), good knowledge of the local context, and elimination of alternative explanations for observed outcomes (47).

3.2. Theories of Change for Systematic Conservation Planning

Understanding how and why an intervention led to conservation impacts is almost as important as understanding the impacts themselves, particularly if there is an interest in using the findings to inform interventions in other contexts. Theories of change (also known as results chains and logic models) are explicit statements about the expected effects of an intervention, usually presented in the form of diagrams showing causal links (49–51). They are rarely published in SCP, the documentation of which is often littered with unjustified assumptions, even simply that the outputs can and will receive vital stakeholder and political support (52).

Conservation planners [and conservation scientists generally (53)] must improve efforts to account for the likelihood of intended actions being applied (54, 55) and the influence on biodiversity of pressures that can be only partially mitigated, or perhaps not mitigated at all, by managing the spatial arrangement of conservation areas. Beyond this kind of analysis, theories of change are also needed to justify assumptions about how decisions at each stage of the planning process can influence the impacts of projects (20). For example, high-level political lobbying could increase funds available for an intervention, perhaps to increase the area of land added to a conservation area network, which could result in greater conservation impacts (45). This lobbying would be a nonspatial intervention outside the scientific dimensions of the planning process but one that could have major implications on impacts for biodiversity. Theories of change form the basis of any impact evaluation: Did what was expected to happen occur, and did it occur because of actions associated with the project or external factors, either anticipated or unanticipated (49, 51)?

The different frameworks outlined in Figure 3 highlight an important challenge for impact evaluation of SCP—that a single, standardized theory of change would not meet all the potential
**a**

- Goals, objectives
  - Actions
    - Inputs
    - Outputs
    - Outcomes
      - Impact (avoided threats)
      - Impact (avoided loss of biodiversity)
      - Actual outcome (with protection)
        - e.g., Avoided poaching or unplanned fires
      - Counterfactual outcome (without protection)
      - Actual outcome (with protection)
        - e.g., Avoided reduction in abundance of vulnerable species
      - Counterfactual outcome (without protection)

**b**

- Implementation
  - Policy
    - Implementation (of policy)
      - Question identification
      - Design of research
      - Consultation with decision-makers and other stakeholders
    - Results
      - Communication and promotion of results
      - Education
        - Improved understanding
        - Capacity building
      - Uptake
      - Application in conservation practice
        - Improved responses
        - Reduced threats
        - Conservation impact

**c**

- Inputs
  - Stakeholders (experts and nonexperts)
  - High-level goals
    - Datasets (socio-economic, biodiversity, etc.)
  - Specific objectives
- Outcomes
  - e.g., No-take marine reserve created (institutional capital)
    - Form of enactment
      - Planning process
    - Levels of threats to biodiversity
      - State of biodiversity
  - e.g., Increased persistence of vulnerable species (natural capital)
  - e.g., Reduction in threat from land conversion (natural capital)
    - Improved understanding
uses of such a model, nor capture all the complexities of planning. This is a major barrier to the widespread development of impact evaluations of SCP. It has been advised that transdisciplinary teams work collaboratively to ensure appropriate design of theories of change for each application and to thoroughly explore the feasibility of conservation actions in a given context (56).

3.3. The Evaluation Knowledge Gap

It is surprising that there is currently no definitive record of how many SCP projects have been developed, implemented, or evaluated or where they have been applied, and by whom. This is partly due to the relative youth of the discipline (22), lack of resources and obligations to report outcomes, and the time-lag associated with observing changes in the condition of natural assets (i.e., outcomes). However, the lack of impact evaluations of SCP may have more to do with the absence of an agreed system and standardized culture of recording such information. In the academic literature to date, the subdiscipline concerned with implementing and evaluating SCP projects (5, 57) has been the poor cousin of the subdiscipline concerned with developing novel methods to improve the datasets, algorithms, and computational tools that underpin prioritizations (41). The latter research is essential and has led to great advances in the past few decades, but there is a need to consolidate information on developing planning processes that result in positive (or zero, or negative) conservation impacts and how best to translate evidence-informed SCP recommendations into on-ground action. There is also the potential for evaluation and methods to inform each other, given that not every analytical approach or dataset will necessarily add value to outcomes on the ground, and some technical advances (e.g., computationally intensive approaches or very large datasets) could conceivably hinder implementation.

Very few impact evaluations of SCP projects have been published in academic journals (16, 21) and, of these evaluations, most have focused on a particular time period or geographic region (15, 16, 58), or exclusively on analyses of the academic literature rather than the gray literature. Despite success being perceived differently by different stakeholders (16, 59), most reported evaluations have focused on the views of academics or anecdotal reports from the conservation planners.

Figure 3

Theory of change frameworks (or logic models) can be developed at different scales or specificities, as demonstrated by these three examples. Blue arrows indicate directions of influence, dashed blue arrows indicate incidental components, and green arrows indicate feedbacks. (a) Framework of protected-area planning directed at achieving impact, focusing on the examples of avoided threats and avoided loss of biodiversity [adapted from Reference 45 (CC BY license)]. In this model, outputs and outcomes of sampling are incidental. (b) Framework for research and conservation planning (adapted with permission from Reference 91, appendix S1). Inputs from other types of conservation activities are shown in hexagons, and the star indicates the “key outcome” in relation to reducing threats and the improving responses of conservation targets. (c) Theory of change developed to guide the design of, and data extraction requirements for, a meta-analysis of evaluations of systematic conservation planning (SCP) (reproduced with permission from 21). Hence, the focus is on identifying inputs and outcomes of SCP, rather than on identifying impacts (counterfactuals and impacts are excluded) or identifying the specific pathways between inputs and outcomes. The first framework (a) is most suitable for physical interventions (protected areas, constructing fencing, etc.) and employs clear counterfactuals due to the focus on impacts. The theories of change in the second (b) and third (c) frameworks represent more of the stakeholder ecosystem—less on using counterfactuals to identify impact—and demonstrate more (b) and less (c) specified causal pathways during the planning process. These different frameworks demonstrate the range of scales at which planning (and evaluation) can operate and highlight that a single pluripotent theory of change for SCP is impossible to conceive. This is a major barrier to widespread impact evaluations of SCP.
involved in developing the SCP in question, rather than the perceptions of other people involved or affected by the planning process (10, 15, 25).

It is tempting to attribute the knowledge gap on impact evaluations of SCP to barriers preventing practitioners publishing, lack of knowledge about evaluation, or scarce resources for evaluation. Although these are real limitations, it is important to recognize that the knowledge gap does not necessarily reflect an unwillingness to conduct impact evaluations. Other important factors are misunderstandings of real measures of impact (45), the logistical challenges associated with the complexity of conservation planning, fear of failure (60), and infeasible expectations around applying only the most rigorous impact evaluation methodologies. Furthermore, there is currently no standardized protocol for undertaking impact evaluations of SCP projects (16; see also Figure 3). Evidence shows that practitioners generally know what is required to develop robust evaluation designs but that limited time or continuity of funding constrains the application of such programs (61). The five most common barriers to implementing high-quality impact evaluation methods, as reported by practitioners in the conservation policy field, were lack of funding, poor availability of baseline data, time constraints, lack of forward planning, and absence of a suitable control group (61).

There is a growing body of evidence on the impact of protected areas for biodiversity conservation (62, 63) as well as on their social impacts (64) and management effectiveness (65, 66), all of which hold lessons for the evaluation of conservation planning processes. However, although impact evaluation of specific interventions, such as one or more protected areas, is slowly gaining momentum, assessing the effectiveness of a planning or decision support process, involving multiple potential interventions, is more difficult. It is plausible to want to measure outcomes at various stages of the planning process (e.g., during a consultation process or upon a conservation area being written into legislation) or at different time periods following the completion of an SCP project. (The recovery of a threatened plant community could take several decades to observe.)

When interpreting the results of an evaluation of a planning process, there are likely to be many confounding factors, such as climatic changes, other human impacts (e.g., noncompliance with no-take marine reserves) (67), invasive species, differential stakeholder buy-in (31), and political resistance, all of which make it difficult to determine the difference made by the planning process specifically. Finally, logistical considerations are also important. Planning is often a one-off activity: Organizations and people frequently move on after project completion, when the organizational focus and associated resources disappear, so those best positioned to document or evaluate planning processes may not be able or may have moved into completely different roles (5).

4. STATE OF KNOWLEDGE ABOUT THE IMPACTS OF SYSTEMATIC CONSERVATION PLANNING

4.1. Existing Perspectives on Evaluating Systematic Conservation Planning

Questions about the impacts of SCP sparked debates in the 2000s, primarily about the suitability of some of the academic outputs for on-ground implementation (6, 54, 68) and the dangers of neglecting genuine engagement with land owners and local communities throughout the process (14, 69, 41).

In one of the first studies to attempt to determine the impact of the SCP discipline, the proportion of spatial conservation prioritizations designed for direct implementation was assessed (15). A literature search was conducted within academic journals published between 1998 and 2002 (this study did not include gray literature), and questionnaires were sent to the first authors of each publication. Knight et al. (15) found that two-thirds of the prioritizations they assessed did not deliver conservation action, primarily because researchers did not plan for implementation.
A later review of similar publications published between 2010 and 2012 also found that implementation of conservation was less of a focus of publications than improving the theory and methods of conservation prioritization (58). A limitation of the 2008 study was that it focused on prioritization exercises, rather than examples of the broader SCP processes. Some academics have defended baseline research and prioritizations as distinct from applied studies, and much of the progress in applications of SCP has built on necessary basic research into spatial prioritizations. However, academic publications about prioritizations continue to outnumber those about SCP implementation and evaluation.

An alternative approach is to measure the characteristics of the spatial prioritizations with regard to implementation. By focusing on the type and sources of research most often translated into the implementation of conservation projects, Smith et al. (57) argued that the more relevant analyses for on-ground conservation were fine-scale prioritizations that included cost data and biodiversity data for more than one taxon. A simple scoring system was used to investigate the likelihood of publications on spatial conservation prioritizations having relevance for implementation. On the basis of the authors’ scoring criteria, almost half of all academic articles failed to score any points for relevance, whereas those that had at least one author affiliated with a government conservation agency had the highest summed scores (57).

As previously discussed, whether implementation occurred can be informative, but it is not a holistic measure of success. Implementation indicates that a planning exercise has had some consequences, but not necessarily whether it led to impacts for species, habitats, or local communities. SCP is also notable in having diverse outcomes that are not conditional on implementation. For example by familiarizing stakeholders with planning processes, raising expectations about objectives and results, and influencing policy and legislation (16), an SCP exercise might provoke positive change, and even potentially have impact, even if the proposed actions were not in fact implemented.

This diversity of potential benefits from SCP was highlighted in another, case-study approach. Bottrill et al. (70) used qualitative methods to examine the benefits reported by those employing SCP approaches at The Nature Conservancy, an international NGO with extensive expertise in developing and applying SCP (see sidebar Evaluating Social, Financial, and Institutional Benefits of Systematic Conservation Planning at The Nature Conservancy).

### Evaluating Social, Financial, and Institutional Benefits of Systematic Conservation Planning at The Nature Conservancy

In a review of five SCP projects undertaken by The Nature Conservancy, Bottrill et al. (70) undertook document analysis and 17 semistructured interviews with senior planning staff to explore the interviewees’ perceptions of (a) the purpose and intent of each planning process; (b) the benefits according to aspects of natural, financial, social, institutional, and human capital; and (c) the enabling and constraining factors that influenced the realization of these benefits (broken into process, inputs, and context). Natural capital benefits such as the reduction in threats to biodiversity were not reported as having been fully achieved in any project. Improvements in human and institutional systems such as social interactions, attitudes, and institutional knowledge were the most frequently reported. This study provided in-depth insights into the factors that constrained the realization of benefits (primarily social and political aspects of the region) and enabled the delivery of benefits (most importantly design of the process, leadership, funding, and timing). Overall, Bottrill et al. (70) demonstrated the value of, and need to measure, proximal benefits when evaluating SCP projects, particularly because intended conservation outcomes for natural capital are difficult to monitor in the short term.
The majority of these and other published impact evaluations of individual SCP projects involve the views of staff and academics involved in the planning process (e.g., 10, 25). Although useful as a starting point to share information on procedures and observed short-term outcomes, these studies are very vulnerable to bias and, by our definition, are not designed to demonstrate impact.

A major advantage of SCP is that it involves setting specific objectives at the start of the planning process, and counting the number of objectives met can be informative when assessing project outcomes (e.g., 4). This is particularly useful for comparisons with historical patterns (71), sites selected at random (72), or expert-derived scenarios on what could have happened in the absence of the SCP exercise (73). Given the relative ease of conducting such evaluations, these approaches provide considerable opportunities to integrate counterfactual thinking when assessing outcomes, if not conservation impact.

4.2. Guidance on Designing Systematic Conservation Planning Projects

Even in the absence of a reference library of rigorous impact evaluations of SCP, it is worth noting trends in commonly reported outcomes or traits affiliated with supposedly effective and ineffective planning exercises. A range of literature exists on what makes a good planning process (6, 20, 38, 41, 69, 74–76), although much of this is based on experience-based predictions, not on demonstrated impact. These can still provide useful indications of factors influencing planning processes and aid in the identification of potential causal pathways and important external variables. The Open Standards for the Practice of Conservation developed by the Conservation Measures Partnership is also a valuable resource when designing projects (see sidebar Open Standards for the Practice of Conservation).

Outcomes commonly associated with reportedly successful planning projects include multi-stakeholder collaborations, integration of local and scientific knowledge, capacity building, the use of multiple-use zoning, and participation in learning and governance networks (6, 20, 25). In addition to these traits, priority setting requires explicit and defensible objectives to be developed at the start of a planning process, not only for representation and configuration, but also for outcomes and impacts. Spatial prioritizations should also incorporate economic, political, and social constraints on actions and a consideration of complementarity. The principles supporting collaborative and transdisciplinary approaches to conservation planning include accountability,
adaptability, social learning, and pragmatism, added to genuine engagement with multiple types of knowledge (local, scientific, and traditional) (41).

The importance of several key contextual factors, such as the presence of local champions (54), has been identified, and the need to embrace opportunism in the selection of conservation areas or actions debated (77, 78). However, the relative importance of social and governance factors is still unclear and probably varies across contexts (30). Universally applicable solutions are elusive and the technical challenges of planning are less severe than the operational challenges (41, 56).

### 4.3. Emerging Studies

The above-mentioned knowledge gaps and challenges for the evaluation of conservation planning have led to several ongoing projects designed to collate and review existing information about the applications and effectiveness of SCP worldwide. J.G. Álvarez-Romero et al. (manuscript in preparation) have compiled a centralized collection of SCP projects and spatial prioritzations. This database currently includes all marine planning exercises documented in the primary literature, although it does not distinguish between spatial prioritzations and full SCP processes. The authors designed the database to allow future inclusion of all terrestrial and freshwater prioritzations, as well as to connect this to other databases such as the World Database on Protected Areas ([http://www.protectedplanet.net](http://www.protectedplanet.net)). This will be a significant resource given that there is currently no accurate estimate of how many prioritzations exist and only approximate information on where they are being developed and by whom (15, 18). The database will provide a means to extract statistics and trends, generate maps, and encourage the standardization of reporting. Álvarez-Romero et al. extracted data on an extensive suite of criteria from 155 marine prioritzation studies published over the past 15 years. They were able to demonstrate that five countries (Australia, United States, Canada, United Kingdom, and South Africa) accounted for 80% of all published prioritzations, suggesting a strong geographical bias in terms of activity and expertise (J.G. Álvarez-Romero et al., manuscript in preparation). This geographical bias is consistent with the finding that 40% of studies published in three top conservation journals between 2011 and 2015 were carried out in only three developed countries (United States, Australia, and the United Kingdom) (79).

McIntosh et al. (21) are developing a systematic map (80) to identify the extent and distribution of evidence on the conservation outcomes of SCP (with projects that are prioritzations alone excluded from this study). This involves replicable searches of publication databases (e.g., Web of Science), search engines (e.g., Google Scholar), and online repositories (e.g., conference proceedings), as well as targeted searches of relevant organizational websites. The gray literature has never before been thoroughly searched, despite the large number of conservation organizations that are unlikely to publish all (or even much) of their output in academic journals. Standardized data about the objectives and characteristics of each SCP project, the impact evaluation study design, reported outcomes (according to natural, social, human, financial, and institutional capitals), and context of the evaluation are being compiled in a database, creating the most thorough international repository of impact evaluations of SCP available. It is intended that this will be cross-compatible with the database being developed by J.G. Álvarez-Romero et al. (manuscript in preparation), which does not yet extend to include information on implementation and impact evaluation.

S.P. Lloyd et al. (manuscript in preparation) are conducting a global survey of conservation plans with the aim of understanding who is creating them, how, where, and why. Representing one of the first explorations of SCP projects published in academic journals and the gray literature, this study aims to understand the relationship between approaches to conducting SCP, challenges faced, and, ultimately, whether or not the projects led to implementation. A literature review has been used to populate a comprehensive list of SCP projects mentioned in academic journals, the
authors of which have then been invited to participate in the survey. Due to the absence of an available database, a snowballing approach has also been used to reach a broad spectrum of SCP developers from the gray literature.

Another relevant study is a recently completed survey into the use of decision support tools in marine spatial planning (MSP) practice, which was conducted as part of the BALTSPACE project (http://www.baltspace.eu/). BALTSPACE was set up to explore integration challenges (for example across disciplines, between stakeholders, across political boundaries) in marine planning in the Baltic Sea region. Similar to the work by Álvarez-Romero et al. and the survey developed by Lloyd et al., the aim of this project was to assess the degree to which decision support tools are used in MSP globally and the reasons surrounding whether practitioners choose to use them.

When it comes to shared learnings, coordination between these and similar projects is key, as is the accessibility of the findings. The resources required to screen potentially relevant studies, conduct surveys, and extract relevant information are not insignificant, and the opportunities for comparing complementary approaches and pooling their findings are substantial. There remain significant barriers, however, in the form of inconsistent terminology and definitions (in particular the now-ubiquitous conflation of SCP and spatial conservation prioritization), which will need to be overcome before rigorous inference about impact can eventually be made from these resources.

5. ANALYZING CHALLENGING INTERVENTIONS

Conservation planning problems are “inherently wicked” (81), as there is no definitive formulation of the problem, there is no clear end point or distinct solution, there are no obviously right and wrong decisions. Every implemented solution has consequences, and every conservation planning scenario is largely idiosyncratic. The early conceptions of SCP (3) as a series of stages did not sufficiently capture this complexity. Although not intended to present the process as being strictly linear, it is interesting to note that these stages were analogous to the “problem definition, information gathering, and analysis and synthesis and solution” approach, which Rittel & Webber (81) particularly highlight as being unsuitable for addressing wicked problems.

We are not the first to suggest that this framing is probably no longer ideal for conservation planning (82). However, it may be necessary to take the advice that “[conservation] problems are never solved. At best they are only resolved—over and over again” (81, p. 160). This is not to say that evidence-based policy should be rejected as a goal of conservation planners, rather that it is necessary to recognize that “evidence is not based on a simple mechanistic view of the relationship between interventions and outcomes” (83, p. 225).

Instead, it is necessary to develop a more nuanced conceptual understanding of SCP as a type of intervention, to guide the impact evaluation process. Drawing from program theory (59), it is apparent that SCP does not fit a simple logic model (e.g., following inputs, processes, outputs, outcomes, and impacts). SCP is complicated, in that it often concerns multiple components (e.g., multiple concurrent causal pathways in different contexts, and may involve multiple governance agencies), but overall, it is complex; exhibiting feedback effects throughout a planning process, and outcomes can emerge during the process of design rather than only at a discrete end-point (5, 19, 70, 84). Unfortunately, the most difficult interventions to evaluate are those that contain both complicated and complex elements (59), which may explain why so few impact evaluations of SCP have been conducted to date. Identifying the complicated and complex elements of SCP is one way of developing a theory of change to use when designing an impact evaluation for a specific project. These considerations are relevant for all types of conservation planning, and lessons can be learned from a wider range of examples than other SCP processes alone.
6. ALTERNATIVE APPROACHES TO IMPACT EVALUATION FOR SYSTEMATIC CONSERVATION PLANNING

SCP is a process, rather than simply one or more implemented conservation areas or actions. In SCP, as in many real-world conservation scenarios, true counterfactuals might be possible to observe only in rare, opportunistic circumstances. An example would be two similar, adjacent administrative regions both designing new protected areas but with only one adopting SCP approaches to do so. Such opportunities to measure impacts should be seized when they arise but experimentally creating such circumstances is unlikely to be possible. However, site counterfactuals may be easier to find, and, as hypothesized by Bottrill & Pressey (16), it has proven to be possible to assess where stakeholders locate conservation activities before and after SCP has been conducted, to determine the influence of the planning recommendations over subsequent conservation actions (85, 86).

Existing methods for evaluating individual components of planning processes could also be explored, such as for stakeholder consultation activities, or the degree of collaboration between partner organizations. In fact, in related disciplines such as urban planning, it is common to employ several concurrent evaluation questions and approaches (83).

Rather than aspiring to some notion of best practice impact evaluation for SCP, it might be best to promote an acceptable minimum standard for impact evaluations (61) and to direct efforts to the recognition and management of patterns and trends (82). As a bare minimum, write-ups of how SCP projects were developed, as well as observations from practitioners of outcomes (both positive and negative) (87), are promoted in publicly accessible reports and academic publications. Given SCP involves emergent outcomes, which can arise at various points throughout the process, it might be helpful to integrate an evaluator within the design team in what is called developmental evaluation (88). Ultimately, for complex interventions such as SCP, multiple complementary methods, including “softer” qualitative methods such as semistructured interviews, will be necessary to capture an overall picture and key dimensions of the local context (83).

In addition to promoting a culture of reporting the outcomes, standardized approaches to reporting impact evaluation results will be necessary to compare studies. These should include study design, inputs, outputs, outcomes, and context (Table 1). This will help facilitate the development of a communal database of SCP projects and impact evaluations as proposed by Álvarez-Romero et al. (manuscript in preparation) and McIntosh et al. (21).

7. DISCUSSION

SCP is an influential discipline in shaping conservation investment and research, and, as such, it is essential SCP be developed and implemented so as to maximize impacts for biodiversity conservation. Efforts are underway to develop substantive databases of SCP projects and their outcomes (21), and we hope that these developments will be extended to include understandings of the causal chains that lead to those impacts. But these are only really the first stages of assessing true conservation impact, as opposed to the outcomes observed for some planning processes. Evaluating impact will require more reporting and monitoring, but also maximizing opportunities for counterfactual evaluations. Evaluation could be aided by conservation planners articulating their theories of change, to enable follow-up assessments of whether expected outcomes were realized, or whether unintended outcomes arose. There is also a need for more qualitative approaches to impact evaluation, such as measures of perceived utility of planning processes (70), particularly where counterfactual approaches are deemed infeasible, because the former can be highly informative when appropriately conducted.
Table 1  Ideal standardized reporting categories for impact evaluations of systematic conservation plans, modified from an existing data extraction template (21)

| Metadata category | Specific details |
|-------------------|------------------|
| Bibliographic information | Standard bibliographic details (author, date, etc.), including publication type |
| Basic information about the conservation plan | Location of study (including GPS coordinates) |
| | Name of resultant conservation area or similar |
| | Type of organization leading the planning process |
| | Size of area considered for the planning process (ha) |
| | Type of biome(s) |
| | Broad goals of the planning process |
| | Specific objectives set for the planning process |
| | Nature of stakeholder participation (including who participated) |
| | Type of actions considered in planning |
| | Cost of SCP development |
| Impact evaluation study design | Methods (a measure of study quality and rigor), e.g., experimental, quasi-experimental, or nonexperimental |
| Outputs, outcomes, and impacts | Reported outputs |
| | Reported outcomes of planning process |
| | Direction of change of outcome (positive or negative) |
| | Proportion of project objectives met |
| | Reported impacts (if the evaluation design is robust enough to allow for counterfactuals and attribution) |
| Context of the study | Location of lead author’s organization and type of organization |
| | Purpose/rationale for the study (stated reasons for undertaking an impact evaluation) |
| Outcome pathways | Theory of change or logic model (if included) |

To further improve the quality and availability of rigorous impact evaluations of SCP processes, clear and consistent definitions are required, including consistent definitions of spatial conservation prioritizations as distinct from broader SCP processes. Standardized reporting of SCP attributes, including objectives and outcomes, would also aid comparisons between different planning contexts. In addition, those evaluating planning processes should be clear when referring to impact evaluation methods used so the reader can determine the study quality and correctly interpret claims of an SCP project having been successful or having achieved impact. Finally, centralized repositories of geo-located projects and associated evaluation records will be essential to track the continued expansion and influence of the discipline in shaping biodiversity conservation efforts globally.

**SUMMARY POINTS**

1. Systematic conservation planning (SCP) is one of the most rigorous approaches for choosing between, locating, and implementing biodiversity conservation actions.

2. Despite the widespread influence and application of SCP, very few impact evaluations have been conducted, and there is much still to understand about how decision support aspects of SCP lead to conservation impact.

3. There are many challenges to evaluating a planning process. However, it is clear that the processes can be as important as any end-products, and outcomes can range widely, from social, human, institutional, and financial, through to those for natural capital.
4. Emerging perspectives and studies on the implementation of SCP are opening up a shared understanding of when, where, and why it can influence conservation actions.

FUTURE ISSUES
1. Improved use of theories of change and counterfactual analyses are required to further our existing understanding of how SCP can lead to conservation impact.
2. Clarity is required in the use of key terms, such as outcome versus impact and systematic conservation plan versus spatial conservation prioritization.
3. The creation and maintenance of centralized repositories of geo-located SCP projects and associated evaluation records will be necessary to track the continued expansion and influence of the discipline.

DISCLOSURE STATEMENT
The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS
Thanks to J.G. Álvarez-Romero and C. Göke for sharing information on their ongoing projects and to A.T. Knight for his comments on an earlier draft of this article. E.J.M. is supported by the General Sir John Monash Foundation.

LITERATURE CITED
1. Bottrill MC, Joseph LN, Carwardine J, Bode M, Cook C, et al. 2008. Is conservation triage just smart decision making? Trends Ecol. Evol. 23(12):649–54
2. Soulé M. 1985. What is conservation biology? Bioscience 35(11):727–34
3. Margules CR, Pressey RL. 2000. Systematic conservation planning. Nature 405(6783):243–53
4. Fernandes L, Day J, Lewis A, Slegers S, Kerrigan B, et al. 2005. Establishing representative no-take areas in the Great Barrier Reef: large-scale implementation of theory on marine protected areas. Conserv. Biol. 19(6):1733–44
5. Pressey RL, Mills M, Weeks R, Day JC. 2013. The plan of the day: managing the dynamic transition from regional conservation designs to local conservation actions. Biol. Conserv. 166:155–69
6. Knight AT, Driver A, Cowling RM, Maze K, Desmet PG, et al. 2006. Designing systematic conservation assessments that promote effective implementation: best practice from South Africa. Conserv. Biol. 20(3):739–50
7. Morrison J, Loucks C, Long B, Wikramanayake E. 2009. Landscape-scale spatial planning at WWF: a variety of approaches. Oryx 43(4):499–507
8. Kareiva P, Groves C, Marvier M. 2014. The evolving linkage between conservation science and practice at The Nature Conservancy. J. Appl. Ecol. 51(5):1137–47
9. Driver A, Sink KJ, Nel JN, Holness S, van Niekerk L, et al. 2012. National Biodiversity Assessment 2011: an assessment of South Africa’s biodiversity and ecosystems. Synth. Rep., S. Afr. Natl. Biodiversity Inst., Dep. Environ. Aff., Pretoria, S. Afr.
10. Osmond M, Airame S, Caldwell M, Day J. 2010. Lessons for marine conservation planning: a comparison of three marine protected area planning processes. Ocean Coast. Manag. 53(2):41–51
11. Sarkar S, Pressey RL, Faith DP, Margules CR, Fuller T, et al. 2006. Biodiversity conservation planning tools: present status and challenges for the future. Annu. Rev. Environ. Resour. 31(1):123–59
12. Pressey RL, Bottrill MC. 2009. Approaches to landscape- and seascape-scale conservation planning: convergence, contrasts and challenges. Oryx 43(4):464–75
13. Watson JEM, Grantham HS, Wilson KA, Possingham HP. 2011. Systematic conservation planning: past, present and future. In Conservation Biogeography, ed. RJ Ladle, RJ Whittaker, pp. 136–60. Chichester, UK: Blackwell Publ.
14. Knight AT, Sarkar S, Smith RJ, Strange N, Wilson KA. 2011. Engage the hodgepodge: Management factors are essential when prioritizing areas for restoration and conservation action. Divers. Distrib. 17(6):1234–38
15. 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. Conserv. Biol. 22(3):610–17
16. Bottrill MC, Pressey RL. 2012. The effectiveness and evaluation of conservation planning. Conserv. Lett. 5(6):407–20
17. Moilanen A, Wilson KA, Possingham HP, eds. 2009. Spatial Conservation Prioritisation: Quantitative Methods and Computational Tools. Oxford, UK: Oxford Univ. Press
18. Weeks R, Aliño PM, Atkinson S, Beldia P, Binson A, et al. 2014. Developing marine protected area networks in the Coral Triangle: good practices for expanding the Coral Triangle Marine Protected Area System. Coast. Manag. 42(2):183–205
19. Magris RA, Pressey RL, Ban NC. 2014. Integrating connectivity and climate change into marine conservation planning. Biol. Conserv. 170:207–21
20. Ban NC, Mills M, Tam J, Hicks CC, Klain S, et al. 2013. A social-ecological approach to conservation planning: embedding social considerations. Front. Ecol. Environ. 11(4):194–202
21. McIntosh EJ, Mckinnon MC, Pressey RL, Grenyer R. 2016. What is the extent and distribution of evidence on conservation outcomes of systematic conservation planning around the globe? A systematic map protocol. Environ. Evid. 5(15):1–13
22. Pressey RL. 2002. The first reserve selection algorithm—a retrospective on Jamie Kirkpatrick’s 1983 paper. Prog. Phys. Geogr. 6(3):334–41
23. Jumin R, Binson A, McGowan J, Magupin S, Beger M, et al. 2017. From Marxan to management: ocean zoning with stakeholders for Tun Mustapha Park in Sabah, Malaysia. Oryx. https://doi.org/10.1017/S0030605316001514
24. Ball I, Possingham HP. 2000. Marxan (v1.8.2): Marine Reserve Design Using Spatially Explicit Annealing. A Manual Prepared for the Great Barrier Reef Marine Park Authority. Brisbane, Aust.: Univ. Qld.
33. Pressey RL, Watts ME, Barrett TW, Ridges MJ. 2009. The C-plan conservation planning system: origins, applications and possible futures. See Ref. 17, pp. 211–34
34. Lehtomäki J, Moilanen A. 2013. Methods and workflow for spatial conservation prioritization using zonation. *Environ. Model. Softw.* 47:128–37
35. Wilson KA, Cabeza M, Klein CJ. 2009. Fundamental concepts of spatial conservation prioritization. See Ref. 17, pp. 16–27
36. Camm JD, Polasky S, Solow A,Csuti B. 1996. A note on optimal algorithms for reserve site selection. *Biol. Conserv.* 78(3):353–55
37. Williams JC, ReVelle CS, Levin SA. 2005. Spatial attributes and reserve design models: a review. *Environ. Model. Assess.* 10(3):163–81
38. Knight AT, Cowling RM, Campbell BM. 2006. An operational model for implementing conservation action. *Conserv. Biol.* 20(2):408–19
39. Sarkar S, Illoldi-Range P. 2010. Systematic conservation planning: an updated protocol. *Nat. Conserv.* 8(1):19–26
40. Conservation Measures Partnership (CMP). 2013. *Open Standards for the Practice of Conservation: Version 3.0.* http://cmp-openstandards.org/wp-content/uploads/2014/03/CMP-OS-V3-0-Final.pdf
41. Knight AT, Rodrigues ASL, Strange N, Tew T, Wilson KA. 2013. Designing effective solutions to conservation planning problems. In *Key Topics in Conservation Biology* 2, ed. DW Macdonald, KJ Willis, pp. 362–83. Oxford: Wiley
42. Wilson KA, Underwood EC, Morrison SA, Klausmeyer KR, Murdoch WW, et al. 2007. Conserving biodiversity efficiently: what to do, where, and when. *PLOS Biol.* 5(9):e223
43. Joseph LN, Maloney RF, Possingham HP. 2009. Optimal allocation of resources among threatened species: a project prioritization protocol. *Conserv. Biol.* 23(2):328–38
44. Leeuw F, Vaessen J. 2009. *Impact Evaluations and Development. NONIE Guidance on Impact Evaluation.* Washington, DC: Netw. Netw. Impact Eval. (NONIE)
45. Pressey RL, Visconti P, Ferraro PJ. 2015. Making parks make a difference: poor alignment of policy, planning and management with protected-area impact, and ways forward. *Philos. Trans. R. Soc. B* 370:20140280
46. Laycock HF, Moran D, Raffaelli DG, White PCL. 2013. Biological and operational determinants of the effectiveness and efficiency of biodiversity conservation programs. *Wildl. Res.* 40(2):142–52
47. Ferraro PJ, Hanauer MM. 2014. Advances in measuring the environmental and social impacts of environmental programs. *Annu. Rev. Environ. Resour.* 39:495–517
48. Deaton A, Cartwright N. 2016. *Understanding and misunderstanding randomized controlled trials.* NBER Work. Pap. 22595. http://www.nber.org/papers/w22595
49. White H. 2009. *Theory-Based Impact Evaluation: Principles and Practice.* New Delhi, India: Intl. Init. Impact Eval. (3ie)
50. Margoluis R, Stern C, Swaminathan V, Brown M, Johnson A, et al. 2013. Results chains: a tool for conservation action design, management, and evaluation. *Ecol. Soc.* 18(3):22
51. Patton MQ. 2008. Conceptualizing the intervention: alternatives for evaluating theories of change. In *Utilization-Focused Evaluation*, pp. 333–80. Saint Paul, MN: Sage Publ. Inc. 4th ed.
52. World Wildlife Fund (WWF) European Alpine Programme. 2005. *Ecoregion Conservation Plan for the Alps.* Bellinzona, Switz.: World Wildlife Fund (WWF). http://www.wwf.at/de/view/files/download/showDownload/?tool = 12&field = download&sprach_connect = 2657
53. Fisher B, Balmford A, Ferraro PJ, Glew L, Mascia M, et al. 2014. Moving Rio forward and avoiding 10 more years with little evidence for effective conservation policy. *Conserv. Biol.* 28(3):880–82
54. Knight AT, Cowling RM, Difford M, Campbell BM. 2010. Mapping human and social dimensions of conservation opportunity for the scheduling of conservation action on private land. *Conserv. Biol.* 24(5):1348–58
55. Knight AT, Cowling RM, Boshoff AF, Wilson SL, Pierce SM. 2011. Walking in STEP: lessons for linking spatial prioritisations to implementation strategies. *Biol. Conserv.* 144(1):202–11
56. Raymond CM, Knight AT. 2013. Applying social research techniques to improve the effectiveness of conservation planning. *Bioscience* 63(5):320–21
57. Smith RJ, Verissimo D, Leader-Williams N, Cowling RM, Knight AT. 2009. Let the locals lead. *Nature* 462(7271):280–81
58. Kullberg P, Moilanen A. 2014. How do recent spatial biodiversity analyses support the convention on biological diversity in the expansion of the global conservation area network? *Nat. A Conserv.* 12(1):3–10
59. Rogers PJ. 2008. Using programme theory to evaluate complicated and complex aspects of interventions. *Evaluation* 14(1):29–48
60. Knight AT. 2009. Is conservation biology ready to fail? *Conserv. Biol.* 23(3):517
61. Curzon HF, Kontoleon A. 2016. From ignorance to evidence? The use of programme evaluation in conservation: evidence from a Delphi survey of conservation experts. *J. Environ. Manag.* 180:466–75
62. Geldmann J, Barnes M, Coad L, Craigie I, Hockings M, Burgess N. 2013. *Effectiveness of terrestrial protected areas in reducing biodiversity and habitat loss*. Review 10-007, Collab. Environ. Evid. [http://www.environmentalevidence.org/completed-reviews/effectiveness-of-terrestrial-protected-areas-in-reducing-biodiversity-and-habitat-loss](http://www.environmentalevidence.org/completed-reviews/effectiveness-of-terrestrial-protected-areas-in-reducing-biodiversity-and-habitat-loss)
63. Oldekop JA, Holmes G, Harris WE, Evans KL. 2015. A global assessment of the social and conservation outcomes of protected areas. *Conserv. Biol.* 30(1):133–41
64. Schreackenberg K, Camargo I, Withall K, Corrigan C, Franks P, et al. 2010. *Social Assessment of Conservation Initiatives: A Review of Rapid Methodologies, Natural Resource Issues No. 22*. London: Intl. Inst. Environ. Dev.
65. Cockings M, Stolton S, Dudley N, Leverington F, Courrau J. 2006. *Evaluating Effectiveness: A Framework for Assessing Management of Protected Areas*. Gland, Switz./Cambridge, UK: IUCN 2nd ed.
66. Coad L, Leverington F, Knights K, Geldmann J, Eassom A, et al. 2015. Measuring impact of protected area management interventions: current and future use of the global database of protected area management effectiveness. *Philos. Trans. R. Soc. B.* 370(Nov.):20140281
67. Bergseth BJ, Russ GR, Cinner JE. 2015. Measuring and monitoring compliance in no-take marine reserves. *Fish Fish.* 16(2):240–58
68. Cowling RM, Pressey RL, Sims-Castley R, Le Roux A, Baard E, et al. 2003. The expert or the algorithm? Comparison of priority conservation areas in the Cape Floristic Region identified by park managers and reserve selection software. *Biol. Conserv.* 112(1–2):147–67
69. Biggs D, Abel N, Knight AT, Leitch A, Langston A, Ban NC. 2011. The implementation crisis in conservation planning: Could “mental models” help? *Conserv. Lett.* 4(3):169–83
70. Bottrill MC, Mills M, Pressey RL, Game ET, Groves C. 2012. Evaluating perceived benefits of ecoregional assessments. *Conserv. Biol.* 26(5):851–61
71. Venter O, Fuller RA, Segan DB, Carwardine J, Brooks T, et al. 2014. Targeting global protected area expansion for imperiled biodiversity. *PLOS Biol.* 12(6):e1001891
72. Kuempel CD, Chauvenet ALM, Possingham HP. 2016. Equitable representation of ecoregions is slowly improving despite strategic planning shortfalls. *Conserv. Lett.* 9:422–28
73. Visconti P, Bakkenes M, Smith RJ, Joppa L, Sykes RE. 2015. Socio-economic and ecological impacts of global protected area expansion plans. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 370(1681):20140284
74. Cowling R, Pressey R. 2003. Introduction to systematic conservation planning in the Cape Floristic Region. *Biol. Conserv.* 112(1–2):1–13
75. Knight AT, Cowling RM, Possingham HP, Wilson KA. 2009. From theory to practice: designing and situating spatial prioritization approaches to better implement conservation action. See Ref. 17, pp. 249–59
76. Driver A, Cowling RM, Maze K. 2003. *Planning for Living Landscapes: Perspectives and Lessons from South Africa*. Cape Town, S. Afr.: Botanical Soc. S. Afr.
77. Knight AT, Cowling RM. 2007. Embracing opportunism in the selection of priority conservation areas. *Conserv. Biol.* 21(4):1124–26
78. Pressey RL, Bottrill MC. 2008. Opportunism, threats, and the evolution of systematic conservation planning. *Conserv. Biol.* 22(5):1340–48
79. Di Marco M, Chapman S, Althor G, Kearney S, Besancon C, et al. 2017. Changing trends and persisting biases in three decades of conservation science. *Glob. Ecol. Conserv.* 10:32–42
80. James KL, Randall NP, Haddaway NR. 2016. A methodology for systematic mapping in environmental sciences. *Environ. Evid.* 5(1):7
81. Rittel HWJ, Webber MM. 1973. Dilemmas in a general theory of planning. *Policy Sci.* 4:155–69
82. Game ET, Meijaard E, Sheil D, McDonald-Madden E. 2014. Conservation in a wicked complex world: challenges and solutions. *Conserv. Lett.* 7(3):271–77
83. Harrison T. 2000. Urban policy: addressing wicked problems. In *What Works? Evidence-Based Policy and Practice in Public Services*, ed. HTO Davies, SM Nutley, PC Smith, pp. 207–28. Bristol, UK: Policy Press
84. Wendt HK, Weeks R, Comley J, Auldersberg W. 2016. Systematic conservation planning within a Fijian customary governance context. *Pac. Conserv. Biol.* 22(2):173–81
85. Carter SK, Keuler NS, Pidgeon AM, Radeloff VC. 2014. Evaluating the influence of conservation plans on land protection actions in Wisconsin, USA. *Biol. Conserv.* 178:37–49
86. Fisher JRB, Dills B. 2012. Do private conservation activities match science-based conservation priorities? *PLOS ONE* 7(9): e46429
87. Knight AT. 2006. Failing but learning: writing the wrongs after Redford and Taber. *Conserv. Biol.* 20(4):1312–14
88. Patton MQ. 1994. Developmental evaluation. *Am. J. Eval.* 15(3):311–19
89. Redford KH, Schwartz MW, Hulvey K. 2014. *Summative Evaluation Of Conservation Measures Partnership And Conservation Coaches Network To Strengthen Results-Based Management In Conservation*. Conserv. Coach. Net. [http://www.ccnetglobal.com/resource/summative-evaluation-of-conservation-measures-partnership-and-conservation-coaches-network-to-strengthen-results-based-management-in-conservation/](http://www.ccnetglobal.com/resource/summative-evaluation-of-conservation-measures-partnership-and-conservation-coaches-network-to-strengthen-results-based-management-in-conservation/)
90. Day J. 2016. The Great Barrier Reef Marine Park: the grandfather of modern MPAs. In *Big Bold Blue: Lessons from Australia’s Marine Protected Areas*, ed. J Fitzsimons, G Wescott, pp. 65–97. Clayton, Aust.: CSIRO Publ.
91. Kapos V, Balmford A, Aveling R, Bubb P, Carey P, et al. 2008. Calibrating conservation: new tools for measuring success. *Conserv. Lett.* 1(4):155–64
Contents

I. Integrative Themes and Emerging Concerns

Plastic as a Persistent Marine Pollutant
   Boris Worm, Heike K. Lotze, Isabelle Jubienville, Chris Wilcox, and Jenna Jambeck ........................................... 1

African Environmental Change from the Pleistocene to the Anthropocene
   Colin Hoag and Jens-Christian Svenning ................................................................................................................. 27

The Intergovernmental Panel on Climate Change: Challenges and Opportunities
   Mark Vardy, Michael Oppenheimer, Navroz K. Dubash, Jessica O'Reilly, and Dale Jamieson ........................................... 55

The Concept of the Anthropocene
   Yadvinder Malhi .................................................................................................................................................. 77

Marked for Life: Epigenetic Effects of Endocrine Disrupting Chemicals
   Miriam N. Jacobs, Emma L. Marczylo, Carlos Guerrero-Bosagna, and Joelle Ruegg .................................................. 105

II. Earth's Life Support Systems

Degradation and Recovery in Changing Forest Landscapes: A Multiscale Conceptual Framework
   Jaboury Ghazoul and Robin Chazdon .................................................................................................................. 161

III. Human Use of the Environment and Resources

Drivers of Human Stress on the Environment in the Twenty-First Century
   Thomas Dietz .................................................................................................................................................. 189

Linking Urbanization and the Environment: Conceptual and Empirical Advances
   Xuemei Bai, Timon McPhearson, Helen Cleugh, Harini Nagendra, Xin Tong, Tong Zhu, and Yong-Guan Zhu .................................................. 215
Debating Unconventional Energy: Social, Political, and Economic Implications
Kate J. Neville, Jennifer Baka, Shanti Gamper-Rabindran, Karen Bakker, Stefan Andreasson, Avner Vengosh, Alvin Lin, Jewellord Nem Singh, and Erika Weinthal

Emerging Technologies for Higher Fuel Economy
Automobile Standards
Timothy E. Lipman

The Future of Low-Carbon Electricity
Jeffery B. Greenblatt, Nicholas R. Brown, Rachel Slaybaugh, Theresa Wilks, Emma Stewart, and Sean T. McCoy

Organic and Conventional Agriculture: A Useful Framing?
Carol Shennan, Timothy J. Krupnik, Graeme Baird, Hamutahl Cohen, Kelsey Forbush, Robin J. Lovell, and Elissa M. Olimpi

Smallholder Agriculture and Climate Change
Avery S. Cohn, Peter Newton, Juliana D.B. Gil, Laura Kubl, Leab Samberg, Vincent Ricciardi, Jessica R. Manly, and Sarah Northrup

The Future Promise of Vehicle-to-Grid (V2G) Integration:
A Sociotechnical Review and Research Agenda
Benjamin K. Sovacool, Jonn Axsen, and Willett Kempton

Technology and Engineering of the Water-Energy Nexus
Prakash Rao, Robert Kostecki, Larry Dale, and Ashok Gadgil

IV. Management and Governance of Resources and Environment

Landscape Approaches: A State-of-the-Art Review
Bas Arts, Marleen Buizer, Lamina Horlings, Verina Ingram, Cora van Oosten, and Paul Opdam

Foreign Direct Investment and the Environment
Matthew A. Cole, Robert J.R. Elliott, and Liyun Zhang

Land Tenure Transitions in the Global South: Trends, Drivers, and Policy Implications
Thomas K. Rudel and Monica Hernandez

Ecosystem Services from Transborder Migratory Species: Implications for Conservation Governance
Laura López-Hoffman, Charles C. Chester, Darius J. Semmens, Wayne E. Thogmartin, M. Sofia Rodriguez-McGoffin, Robert Merideth, and Jay E. Diffendorfer
V. Methods and Indicators

Legacies of Historical Human Activities in Arctic Woody Plant Dynamics
Signe Normand, Toke T. Høye, Bruce C. Forbes, Joseph J. Bowden, Althea L. Davies, Bent V. Odgaard, Felix Riede, Jens-Christian Svenning, Urs A. Treier, Rane Willerslev, and Juliane Wischnewski ........................................... 541

Toward the Next Generation of Assessment
Katharine J. Mach and Christopher B. Field ........................................... 569

Sustainability Transitions Research: Transforming Science and Practice for Societal Change
Derk Loorbach, Niki Frantzeskaki, and Flor Avelino ..................................... 599

Attribution of Weather and Climate Events
Friederike E.L. Otto .................................................................................. 627

Material Flow Accounting: Measuring Global Material Use for Sustainable Development
Fridolin Krausmann, Heinz Schandl, Nina Eisenmenger, Stefan Giljum, and Tim Jackson .................................................................................. 647

The Impact of Systematic Conservation Planning
Emma J. McIntosh, Robert L. Pressey, Samuel Lloyd, Robert J. Smith, and Richard Grenyer ................................................................. 677

Indexes

Cumulative Index of Contributing Authors, Volumes 33–42 ......................... 699
Cumulative Index of Article Titles, Volumes 33–42 ...................................... 705

Errata

An online log of corrections to Annual Review of Environment and Resources articles may be found at http://www.annualreviews.org/errata/environ