Trends in Ecology & Evolution

Review

Scenarios and Models to Support Global Conservation Targets

Emily Nicholson ,[1,*] Elizabeth A. Fulton,[2,3] Thomas M. Brooks,[4,5,6] Ryan Blanchard,[7] Paul Leadley,[8] Jean Paul Metzger,[9] Karel Mokany,[10] Simone Stevenson,[1] Brendan A. Wintle,[11] Skipton N.C. Woolley,[2] Megan Barnes,[12] James E.M. Watson,[13,14] and Simon Ferrier[10]

Global biodiversity targets have far-reaching implications for nature conservation worldwide. Scenarios and models hold unfulfilled promise for ensuring such targets are well founded and implemented; here, we review how they can and should inform the Aichi Targets of the Strategic Plan for Biodiversity and their reformulation. They offer two clear benefits: providing a scientific basis for the wording and quantitative elements of targets; and identifying synergies and trade-offs by accounting for interactions between targets and the actions needed to achieve them. The capacity of scenarios and models to address complexity makes them invaluable for developing meaningful targets and policy, and improving conservation outcomes.

Highlights

The Strategic Plan for Biodiversity 2011–2020 commits countries to achieve specific conservation targets (the Aichi Targets). How such targets are designed and implemented has far-reaching implications for biodiversity worldwide.

Scenarios and models hold great promise for ensuring that conservation targets are well founded, effectively implemented, and lead to good conservation outcomes, but are not currently being used to their full potential. In particular, scenarios and models can ensure quantitative targets are based on scientific evidence.

Our review highlights information gaps, where data and models are lacking, and implementation gaps, where the theory and tools exist but have seen little use. Both gaps present opportunities for collaboration between decision-makers and researchers as the global community moves towards new sets of conservation targets beyond 2020.

The Potential of Scenarios and Models to Inform Conservation Targets

The Aichi Targets of the Strategic Plan for Biodiversity 2011–2020[i] provide an agreed set of conservation aspirations for the international community, as well as explicit targets that countries have committed to achieve [1]. Justified and compelling targets have the power to shape policy and activity within and beyond the environment sector [2]. Knock-on effects of environmental targets, such as the 2015 global target of less than 2°C warming [3], can be profound, but the ways in which they are realised are complex. Feedbacks and trade-offs between sectors and policies, in particular, are challenging to characterise, understand, and navigate [4,5]. A poor understanding of the potential consequences of conservation targets, the interactions between targets, and the actions needed to achieve them, can lead to unexpectedly poor conservation outcomes, inefficient actions, and lost opportunities for meeting commitments. For example, some of the easiest pathways towards achieving the global target to protect 17% of the terrestrial ecosystems on Earth would not adequately safeguard the **biodiversity** (see Glossary) this target is intended to conserve [6–9].

Scenarios depict plausible futures and alternative policies and management strategies that may affect the achievement of conservation goals [10,11]. **Models** represent simplified and idealised understandings of a system, and can describe or **predict** (or forecast) conservation outcomes under a range of alternative scenarios. They range from qualitative conceptual models describing relationships between elements of a system, to quantitative models, built from either a principled understanding of the mechanics of a system, or through analysis of the emergent patterns observed in data [11,12]. Here, we focus primarily on quantitative correlative and process-based models dealing with biodiversity and **ecosystem services**, such as biophysical, ecological, and socio-ecological models. Together, scenarios and models provide a powerful means of characterising, understanding, and projecting the conservation implications of targets, and the positive and negative consequences of actions aimed at achieving them [11,13]; for example, scenarios and models have underpinned climate change targets and the actions needed to meet them [3,14]. Scenarios and models can capture complex

[1]Deakin University, School of Life and Environmental Sciences, Centre for Integrative Ecology, Geelong, VIC, Australia
[2]CSIRO Oceans & Atmosphere, Hobart, TAS, Australia
[3]Centre for Marine Socioecology, University of Tasmania, Hobart, TAS, Australia
[4]IUCN, Gland, Switzerland
[5]World Agroforestry Center (ICRAF), University of the Philippines, Los Baños, Laguna, Philippines
[6]Institute for Marine & Antarctic Studies, University of Tasmania,

Hobart, TAS, Australia
[7]CSIR, Natural Resources and the Environment, Stellenbosch, South Africa
[8]Ecologie Systématique Evolution, Université Paris-Sud, CNRS, AgroParisTech, Université Paris-Saclay, Orsay, France
[9]Department of Ecology, University of São Paulo, São Paulo, Brazil
[10]CSIRO Land and Water, Canberra, ACT, Australia
[11]School of BioSciences, Australian Research Council Centre of Excellence for Environmental Decisions, University of Melbourne, VIC, Australia
[12]Department of Natural Resources and Environmental Management, University of Hawaii at Manoa, Manoa, HI, USA
[13]School of Earth and Environmental Sciences, University of Queensland, Brisbane, QLD, Australia
[14]Wildlife Conservation Society, Global Conservation Program, Bronx, NY, USA

*Correspondence:
e.nicholson@deakin.edu.au
(E. Nicholson).

feedbacks and social and ecological interactions, and harness data and expert and local knowledge in a framework that is logically consistent, repeatable, and transparent – in ways that the human mind cannot. They can also represent and quantify uncertainty about alternative futures and about the effectiveness of policy and management options [14–16].

Scenarios and models have a key role in designing and informing effective conservation targets, and evaluating the actions needed to achieve them. Importantly, they enable **projections** of the impacts of policies and management plans, including the targets themselves, on the ultimate goal of biodiversity conservation, by modelling the responses of genetic diversity, species and ecosystems, and human actors to policy scenarios. Scenarios and models can and should contribute across all four phases of the policy cycle within which conservation targets are embedded [11,17]: (i) agenda-setting: identifying the problem(s), developing a compelling case for change supported by multiple lines of evidence, and motivating the need for action and, therefore, targets; (ii) formulation: designing the overarching concept or goal of each target, its phrasing, quantification, and associated **indicators** for measuring progress; (iii) implementation: taking an international target to local action, including interpreting the **global conservation targets**, and devising and evaluating policies and on-ground actions for achieving them; and (iv) review: assessing the status and trends in indicators of progress towards targets, and evaluating the effectiveness of policies and actions aimed at achieving targets.

Here, we show how scenarios and models can and should support the Aichi Targets of the Strategic Plan for Biodiversity 2011–2020, although our argument is also relevant to global targets in many sectors, including the United Nations (UN) Sustainable Development Goals[ii]. Modelling and scenario analyses have already been used widely in setting policy agendas by motivating conservation targets, including in the Millennium Ecosystem Assessment[iii], the Global Species Assessment[iv], and Global Biodiversity Outlook[v,vi]. Following agreement on the Aichi Targets in 2010, the global community has been implementing actions aimed at achieving these targets, and reviewing their progress [1]. As 2020 approaches, the post-2020 agenda is being refined, with reformulation of existing targets and formulation of new targets [18]. With this arises an opportunity to use scenarios and models to devise better and more effective targets. While scenarios and models offer considerable potential benefits across all of these activities, there is limited evidence of use to date beyond their role in agenda-setting at global levels [11].

We illustrate how scenarios and models have contributed or could contribute to implementing, reviewing, formulating, and reformulating the Aichi Targets (Figure 1) with examples from local to global scales (see Table S1 in the supplemental information online). Their uses include: exploratory scenarios and models that investigate potential responses of biodiversity and impacts of actions; target-seeking and policy-screening scenarios to evaluate means of reaching biodiversity targets; and developing **counterfactuals** for comparison with realised changes to evaluate costs and benefits of conservation actions [9,19]. We highlight the roles that scenarios and models have had within the management of fisheries and marine ecosystems (Box 1), which offer considerable insight for informing the choice of actions towards achieving Aichi Target 6. We then focus on the potential roles of scenarios and models in relation to three targets: Aichi Target 12 on species extinctions (Box 2 and Figure 1B–E), Aichi Target 11 on protected areas (Box 3), and Aichi Target 5 on habitat loss (see 'Accounting for Interactions' section). We emphasise the benefits of using models in capturing interactions between targets, and improving coherence between the implementation, review, and formulation of targets.

Formulating, Implementing, and Reviewing Targets

Formulation and Reformulation

The formulation of a target involves defining its overarching concept or goal, phrasing of the target, setting any quantitative elements, and highlighting indicators for measuring progress. Elements of

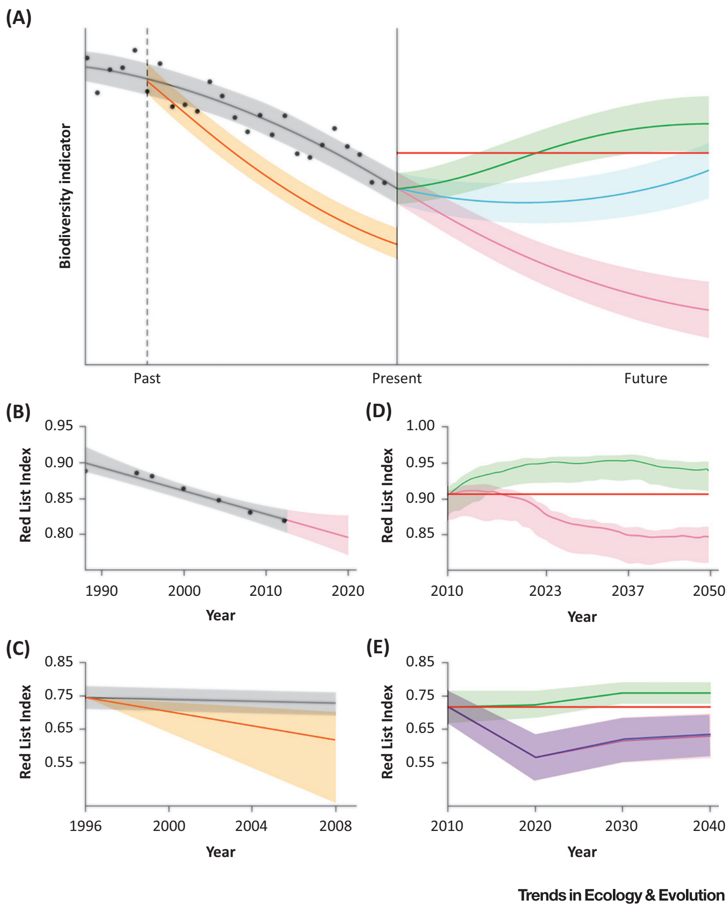

Figure 1. The Roles of Scenarios and Models in the Review, Formulation, and Implementation of Conservation Targets

For a Figure360 author presentation of Figure 1, see the figure legend at https://doi.org/10.1016/j.tree.2018.10.006

Models and scenarios have important roles across the phases of the policy cycle for conservation targets, both in theory (A), and as exemplified for Aichi Target 12 on species extinctions (B–E; see Box 2 in the main text): *review*: through analysing and interpreting trend data (black dots and grey line) and developing counterfactuals of the past (orange) to evaluate the effectiveness of policy or targets implemented in the past against realised biodiversity outcomes (black and grey); *formulation*, through testing the effectiveness and achievability of the target (red) by various scenarios (green, blue, and pink, where pink could represent business-as-usual), and indicators for measuring progress; *implementation*, through evaluation of alternative scenarios and policies (in green, blue, and pink); *agenda-setting*, when examining plausible scenarios to contribute to problem identification. Models can be used to quantify associated uncertainties in analyses of data and projections, shown by coloured band around lines. The application of models and scenarios to Aichi Target 12 (on preventing species extinctions) at various stages of the policy cycle are shown in (B–E) (see Box 2 in the main text for details); here the target can be interpreted as a stable or increasing Red List Index (red): (B) *Review and agenda-setting*: observed values (black dots) and modelled trend (grey line) in the Red List Index (1986–2012, for birds, mammals, amphibians, and corals), extrapolated from 2013–2020 under business-as-usual (pink), with 95% confidence intervals; (C) *Review* with counterfactual: observed trends in the Red List Index 1996–2008 (black) versus an expert-derived counterfactual of species extinction status in the absence of conservation action (orange), for 235 ungulate species; grey shows 95% confidence intervals, while orange shows upper and lower plausible bounds; (D) *Implementation* (exploratory scenarios) and *formulation* (assessing target achievability): projections of the Red List Index for terrestrial carnivore and ungulate species under two global socioeconomic scenarios of climate and land-use change: business-as-usual (pink), and consumption change (green), assuming no dispersal or adaptation to change, with 95% confidence intervals; (E) *Implementation (policy-screening):* projections of the Red List Index under scenarios of protected area planning and management for implementing Aichi Target 11, for 53 mammal species in subSaharan Africa: effective management to halt declines in protected areas (green), expansion with current management effectiveness (blue), which is almost indistinguishable from business-as-usual (pink), with 95% confidence intervals. Adapted from [1] (B), [45] (C), [33] (D), and [7,27] (E).

Glossary

Biodiversity: the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species, and of ecosystemsAppendix A[i] [11].

Counterfactual: the unobserved outcome had conditions, policy, or management been different, for example, had interventions not been undertaken [19].

Ecosystem service: the benefits (and occasionally disbenefits or losses) that humans obtain from ecosystems, including: provisioning services, such as food and water; regulating services, such as flood and disease control; and cultural services, such as recreation, ethical and spiritual, educational, and sense of place [11].

Forecast: when a projection is branded 'most likely', it becomes a forecast or prediction. A forecast is typically obtained using a model or set of models, outputs of which can enable some level of confidence to be attached to projectionsAppendix A[viii].

Global conservation target: targets for biodiversity conservation and sustainability that are agreed by multiple countries, typically including a mixture of qualitative and quantitative aspirations for policy and management; these include the Aichi Targets of the Strategic Plan for Biodiversity 2011–2020Appendix A[i], and the UN Sustainable Development GoalsAppendix A[ii].

Hindcast: a form of model verification to determine how well a model predicts historical events or measurements; also referred to as 'backcast' [11].

Indicator: a measure that conveys information about more than just itself. Indicators are purpose dependent: the interpretation or meaning given to the data depends on the purpose or issue of concern [27].

Model: models represent simplified and idealised understandings of a system, and can describe or predict conservation outcomes under a variety of alternative scenarios. They range from qualitative conceptual models describing relationships

Box 1. Aichi Target 6

By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.

Aichi Target 6 demonstrates how scenarios and models can influence the formulation, implementation, and review of a target. The formulation of Target 6 appears qualitative, but relies on terms that have specific meanings within fisheries science and policy, informed by model-based testing. 'Safe ecological limits' refers to keeping stocks above limit reference points, which are stock-specific quantitative thresholds defined scientifically (e.g., via quantitative models) [25]. A species considered to be 'harvested sustainably' should have stocks around a target reference point; 'overfishing' occurs when fishing pressure is at a level that would push the stock below its target; and when a stock is depleted to the point it is below the limit point it is considered 'overfished'. 'Ecosystem-based' management aims at sustainable fisheries supported by healthy ecosystems, rather than management of individual species [63], although the science to underpin ecosystems reference points is still evolving [64,65]. By tying Target 6 to the concepts of sustainability and overfishing, rather than fixed quantitative values, there is the flexibility to use ecosystem- and species-specific targets and incorporate new information.

Scenarios and models have been used extensively within marine systems in implementation, to simulate potential policy changes, to **forecast** whether the actions will deliver as expected, and to identify any potential unintended consequences or perverse outcomes [31,58,61]. Models of stocks, species, and ecosystems have been used to project impacts of fishing and management strategies, define thresholds and management triggers under given states and trajectories, and under scenarios of stressors, such as climate change and eutrophication [32,66]. Increasingly, human behaviour, social, and economic systems are included in such models [31,58]. Models have also been used in evaluation and review, to analyse trend data (e.g., [26,37,67]), including reconstructing global landings [38], and to explore ecological dynamics [68].

Scenarios and models are increasingly used to formulate, implement, and review fisheries and ecosystem-level targets through integrated approaches, such as management strategy evaluation [31,46]. For example, in the Northwest Shelf region of Australia, scientists and stakeholders developed management targets and scenarios for evaluation with models [46]. The use of multispecies fish and habitat models posed competing hypotheses around fishing effects, prompting a monitoring scheme to distinguish between the hypotheses, and laid out the management options that meet objectives robustly. The modelled management actions ultimately became the basis of ongoing management for the fisheries [46].

While these examples show how models and scenarios can help a target, achieving Target 6 remains challenging because the fisheries work has been heavily biased both geographically and taxonomically. Such work has largely focussed on developed countries and economically important species [69], and will require ongoing regular review and revision to adapt to changing systems

between elements of a system, to quantitative models, built from either a principled understanding of the mechanics of a system, or through analysis of the emergent patterns observed in data [11].
Prediction: see 'forecast'.
Projection: in general usage, a projection can be regarded as any description of the future and the pathway leading to it [11].
Scenario: scenarios depict plausible futures, and alternative policies and management strategies that may affect the achievement of conservation goals [10,11].

the Aichi Targets have been criticised for being arbitrary, ambiguous, overly complex, difficult to quantify, and unachievable [20–22]. The use of scenarios and models could help to alleviate such shortcomings. For example, Target 11 aims for 17% of terrestrial areas to be protected, a number that was negotiated and without a basis in science [2,20]. Models could be used to set more scientifically appropriate and effective targets for protection (Box 3). Scenarios and models do appear to have influenced the formulation of some targets, but it is challenging to discern or reconstruct this from their wording; any influence, either direct or indirect, often remains undocumented [2]. The use of specific terms, informed by theory and models, can result in less ambiguous and arbitrary targets; for example, the wording in Target 12 was influenced by models of extinction risk that underpin species conservation status [23,24] (Box 2). Target 6 relies on qualitative terms, such as 'sustainably harvested', that have specific meanings in fisheries science, relating to thresholds of risk; the development of these thresholds is typically supported by quantitative models of fish stocks and ecosystems [25]. The choice of terms can affect target achievability: because Target 6 addresses sustainable management of fisheries, it can be achieved one ecosystem or stock assessment at a time (Box 1); by contrast, other targets require coordinated efforts, such as for representative and connected protected areas (Target 11), making

Box 2. Aichi Target 12

> By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

The formulation of Target 12 is relatively concise and precise, linked to defined terms underpinned by theory and models. 'Extinction' is defined as when the last individual dies[vii]. 'Conservation status' refers to the extinction risk or Red List status of a species, as assessed using the categories and criteria of the IUCN Red List of Threatened Species[vii]. 'Improved and sustained' can be applied to the conservation status of individual species, or to the Red List Index, an aggregate index of change in IUCN Red List status across species [70]. Therefore, understanding of models appears to have informed the formulation of the target. The IUCN Red List criteria are in turn underpinned by theory and models [23], and tests of their capacity to predict extinction risk [24,71]. The Red List is biased taxonomically towards vertebrates, especially birds, mammals, and amphibians, with low coverage for plants, fungi, and invertebrates. Work aimed at redressing these biases includes expansion of comprehensive assessments [72] and a sampled approach for poorly known speciose groups [73]. The target of halting extinctions of known species is made more challenging by extinction debt [74], but understanding this again facilitates its implementation.

While models of species distributions and population viability have seen considerable use in guiding conservation management at local scales [75,76], models directed at the implementation of Target 12 have largely been exploratory (see Figure 1B–E in the main text), rather than directed at policies to achieve conservation targets; this remains an area of great potential. For example, projections of the extinction risk of species, in particular through population modelling [77], can explore impacts of climate change and management on extinction risk [78,79]. Some researchers model the impacts of population trajectories onto IUCN Red List status [80,81] and the Red List Index [7,27,33] under different scenarios and policies (see Figure 1 in the main text), including estimating costs of actions [82]. McCarthy *et al.* [40] projected optimal investment in the conservation of bird species in Australia, based on past management and observed changes in Red List status.

Many examples demonstrate how models can be used to review recent trends and provide counterfactuals to better understand the effectiveness of conservation actions for species persistence. Analyses of bird conservation in Australia found that increased expenditure reduced the risk of worsening Red List status, but had little impact on improving the status of species [40]. Hoffmann *et al.* [41] estimated the impact of conservation action on the aggregate extinction risk of 25 000 vertebrate species around the globe, assuming the species would have remained at their previous status in the absence of action. They concluded that the rate at which species move towards extinction would have been 20% worse in the absence of conservation action [41]. An improved counterfactual was used in a later study for 235 ungulate species, estimating that the likely trajectory in extinction risk would have been seven times worse, had conservation efforts ceased in 1996 [45] (see Figure 1C in the main text). A conservation nongovernmental organisation (NGO), Durrell Wildlife Conservation Trust, used expert opinion to develop a counterfactual to evaluate the impact of their work [83]. As well as projecting future scenarios, Visconti *et al.* [33] **hindcast** the responses of species to land-use and climate change, comparing predicted and observed trends from 1970 to 2010 in the Red List Index for 440 mammal species across the globe.

achievement more challenging. Models can also be used to test whether targets are measurable, to evaluate the efficacy of indicators used to track trends and status [26–29], and to identify and quantify undesirable side-effects of achieving targets in particular places [30].

Implementation

Global targets are typically implemented through action at national scale and below, requiring translation into targets within national legislation or policies, development of programs or strategies to achieve them, and realisation of on-the-ground actions. Scenarios and models have the potential to contribute to assessing alternative policies and actions, target achievability, and target effectiveness, as demonstrated at the local scale by the use of models and scenarios to implement fisheries targets (Box 1) [31]. Examples from the literature exemplify how scenarios and models can be used in target implementation: comparing alternative policies and strategies in their capacity to attain targets for protected areas and species conservation [7]; projecting biodiversity and ecosystem service trajectories under climate change and land-use scenarios [32–34]; identifying how conservation objectives can be met alongside other objectives for sustainable fisheries [31]; and comparing cost-effectiveness of land-use and conservation options under climate change [35], business-as-usual, or current

Box 3. Aichi Target 11

> By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

Several of the terms in the formulation of Aichi Target 11 show influences of scenarios and models. For example, focusing protected area expansion onto areas of importance for biodiversity is supported by quantitative spatial models of irreplaceability [84]. Similarly, connectivity and integration are underpinned by models of the movements of species and ecological and evolutionary processes across wider land- and sea-scapes [85,86]. By contrast, the quantitative elements of Aichi Target 11 (17% for terrestrial protected areas and 10% for marine areas) have no basis in science [2,20]. While agreed percentage targets drive countries to achieve set levels of protection, models have shown they drive a perverse incentive for the establishment of protected areas in places that are cheap to protect per unit area, at the expense of more important places for biodiversity [87]. Fixed targets do not reflect the heterogeneous and dynamic distribution of biodiversity (they are severely insufficient in some places, e.g., marine ecosystems [54] and the Cape Floristic Province [88]) or nonlinear responses of species to the amount and fragmentation of habitat [89]. Scenarios and models should influence evidence-based reformulation of the target beyond 2020, to make it less arbitrary and more likely to achieve conservation goals.

A range of models has been developed that could support the implementation of Aichi Target 11. Among the simplest are models that compare current rates of increase in protected areas with rates needed to meet targets [1,90], and gap analysis to assess how well protected area systems represent biodiversity [6,91]. Models can feed into decision-support tools, which have been used to plan protection area expansion [92–95]. Scenarios can evaluate the projected biodiversity benefits of policy emphasis across different elements of the target; Fuller *et al.* [96] showed that replacement of poorly placed protected areas with new, strategically located reserves would greatly improve biodiversity outcomes. Nicholson *et al.* [27] and Costelloe *et al.* [7] compared improving management with expanding protected areas, finding that effective management provided greater benefits to biodiversity than increased area alone. Visconti *et al.* [9,33] showed that protected area expansion driven by information on species-specific information and targets could substantially reduce species extinction risk compared with business-as-usual, but that expansion based on representation of ecoregions could be worse for threatened species than no action [9].

Modelling and scenarios can guide target review by comparing actual outcomes of protected area establishment to null models or counterfactuals; for example, comparing biodiversity benefits of current protected areas with predicted benefits had reserve placement been optimal or random [97,98]. Butchart *et al.* [99] found that species for which most important sites are protected are moving towards extinction at half the rate of poorly protected species. Comparison with equivalent unprotected areas has proven crucial in demonstrating protected area impacts on reducing deforestation [43], forest fires [100], and poverty [101].

trajectories [1]. Models for evaluating policies are increasingly able to integrate social and economic factors and human behaviour [31,36]. Yet, the application of such scenarios and models to the real-world implementation of conservation targets remains scant [11].

Review and Evaluation

Critical elements of any review of target achievement include assessing the status and trend of indicators measuring progress towards each target, and evaluating the effectiveness of policies that have been implemented. Models can be used to: interpret, interpolate, and analyse data [37–39]; evaluate the effectiveness of conservation action [40,41], such as protected area impacts on reducing deforestation [42,43]; and project implications of those data, such as abundance trends to infer population trajectories [7]. Scenarios and models can also contribute significantly to evaluating policy effectiveness through the construction of counterfactuals, that is, pathways expected had policies not been implemented or had management actions not been undertaken [9,19,44] (Figure 1). For example, the likely trajectory in extinction risk of 235 ungulate species would have been seven times worse without conservation efforts over the past two decades, based on expert assessments [45]. Models provide a structure for integrating new knowledge and updated understanding through time; for example, developing alternative models of a system can improve understanding of what is driving observed patterns [26,46] (Box 1).

CellPress REVIEWS

Accounting for Interactions between Targets

Scenarios and models provide a powerful means of explicitly accounting for the interactions between targets. Interactions include both synergies and trade-offs in the targets, and in the actions governments undertake to meet each target [8,21,36,47,48]. As an example of how scenarios and models could help to integrate across multiple targets, we consider cross-target links involving Aichi Target 5: 'By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced'.

Target 5 is clearly linked with other targets, both in terms of how actions implemented under other targets will contribute to the achievement of Target 5, and vice versa, where efforts to achieve Target 5 will affect other targets [48]. For example, protection of areas vulnerable to habitat loss under Target 11 might contribute positively to the achievement of Target 5, while reduction of habitat loss under Target 5 will, in turn, contribute positively to reducing the risk of species extinctions under Target 12 [6,8], and to enhancing the provision of some ecosystems services under Target 14 (Figure 2). Expansion of protected areas (Target 11) may also contribute directly to achieving Target 12 by removing threats other than habitat loss [8,9].

Conflicts may exist between and within targets, for example between different ecosystems services (Target 14), and between biodiversity and ecosystem services [47,49]. Accounting for synergies and trade-offs in choosing the best actions to simultaneously reduce habitat loss, improve species protection, and increase ecosystem services, such as carbon stocks (Target 15), may result in a very different answer to that obtained if these targets are dealt with in isolation from one another [6,8]. Scenarios and models can provide a powerful means of enabling this more integrated perspective.

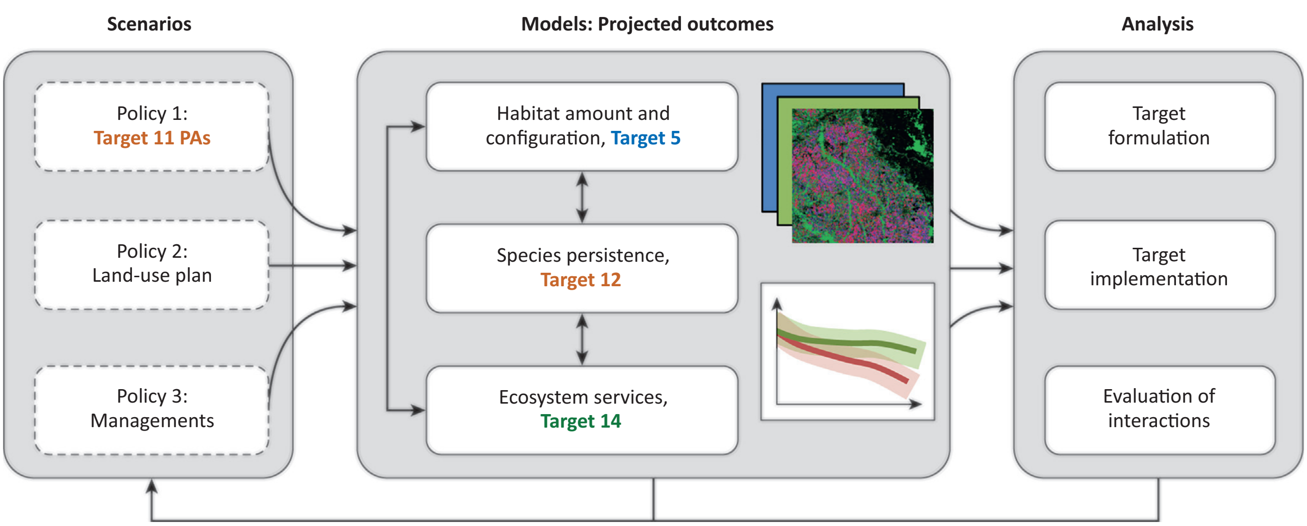

Figure 2. Accounting for Interactions between Targets with Scenarios and Models. The ways in which governments act to improve the coverage of their protected area networks to meet Aichi Target 11, will, in conjunction with other policies such as land-use planning and management, influence the amount and configuration of ongoing habitat loss (Aichi Target 5). These will combine to influence other targets, such as the persistence of threatened species (Aichi Target 12) and ecosystem services (Aichi Target 14). Ecosystem or habitat extent and function may in turn be affected by species persistence and extraction of ecosystem services. Analyses of these interactions should inform target formulation, implementation, and evaluation and/or review, forming an iterative rather than linear process. Abbreviation: PA, protected area.

In target formulation and reformulation, scenarios and models enable a structured perspective on how key aspects of natural systems are linked, including links between human activities (policy-making, planning, and management) and their outcomes (biodiversity persistence, extinctions, habitat loss, and ecosystem services). Models can aid the formulation of targets that account for these linkages, by improving understanding about the nature of these interactions. In implementation, scenarios and models can help governments identify how different potential suites of actions could combine to influence the achievement of multiple targets [8,14,50] (Figure 2). This could not only help governments to identify actions to achieve those targets simultaneously, but can also be combined with structured decision making to highlight the cost-effectiveness of different suites of approaches [6]. In addition, the structure and knowledge provided by scenarios and models could help governments to manage potential trade-offs in how actions influence progress towards different targets, where an action focussed on meeting one target could hamper progress towards other targets [47]; for example, quantitative analyses correlating indicators of the UN's Sustainable Development Goals identified potential trade-offs, including where human welfare can conflict with environmental sustainability [51]. Similarly, in the review phase, scenarios and models can improve understanding of the contributions of policies towards multiple targets (e.g., reducing habitat loss and species extinction rates) and between targets (e.g., impacts of protected areas on deforestation rates [43,50]).

Concluding Remarks

The mission of the Strategic Plan for Biodiversity 2011–2020 is to 'take effective and urgent action to halt the loss of biodiversity'[i]. Scenarios and models offer a powerful means of evaluating the actions needed to halt biodiversity loss, and quantifying their impacts on species, ecosystems, ecosystem services, and human well-being, thus explicitly relating the individual Aichi Targets back to the mission of the plan. They enable a structured perspective on how natural systems and human activities are linked [5], relating anthropogenic pressures (e.g., land conversation for agriculture) and responses (e.g., establishment of protected areas) to their likely outcomes for biodiversity [11,13]. Although the science underpinning such modelling is always developing [19,52,53] (see Outstanding Questions), available scenarios and models can already be used to better motivate, formulate, implement, and review conservation targets.

Quantitative targets allow clear performance measures and, thus, force signatories to achieve specific outcomes [22]; for example, Aichi Target 11 aims for at least 17% of terrestrial and inland water and 10% of coastal and marine areas to be protected (Box 3). However, when quantitative targets are arbitrary, they can become meaningless and contribute little to overall goals [54,55], or can result in unintended or even perverse outcomes [6–8]. Few of the Aichi targets have quantifiable elements [22] (highlighted in Table S1 in the supplemental information online) and, somewhat surprisingly, some of the quantifiable elements have little scientific evidence to support them. Yet, these targets may be more likely to be achieved due to their unequivocal measurability; this is a paradox of the current quantitative targets, which could be addressed directly through the application of scenarios and models to develop the required evidence base.

While scenarios and models can have an important role in relation to individual targets, their greatest strength comes in their capacity to explicitly address interactions between targets. They can bring coherence to the phases of agenda-setting, target formulation, implementation, and review, by integrating consideration of multiple targets and how they can be achieved and measured (Figure 2 and Box 1). Management strategy evaluation, used successfully within fisheries to link phases of target-setting and achievement [31,46], has the potential to be more widely applied within conservation science [56]. In particular, scenarios and models provide a

Outstanding Questions

How can scenarios and models mitigate the paradox of quantitative targets, which are measurable and often achievable, yet typically political, arbitrary, and with little scientific evidence to support them, to support the development of more effective, evidence-based targets?

How can other quantitative and qualitative models not addressed in this review, in particular those relating to uptake of knowledge or human behavioural responses, better inform biodiversity targets?

What processes, conte xt, and interactions can enable and support improved collaboration between policy makers and scientists in target formulation and implementation? In particular, how can we close information gaps, where knowledge and methods to solve problems are lacking, and implementation gaps, where the theory and tools exist to support target achievement, review, and formulation, but have seen little use?

How can uncertainty, including large uncertainties associated with modelling complex systems and future projections, be better quantified, understood, accounted for in decision-making, and communicated?

means for integration across targets, by explicitly considering how different types of action can contribute to multiple targets [8], and where the achievement of targets may be in conflict and, therefore, requires consideration of trade-offs [21]. Quantitative models are able to evaluate interaction effects and may reveal unanticipated consequences of feedbacks; the semiquantitative use of qualitative approaches (e.g., [5,57]) is also informative. Uncertainty is an inevitable aspect of life, particularly when projecting alternative futures; modelling can make the magnitude and sources more transparent. Thoughtful model-based analyses can reveal key sources of uncertainty, data gaps, and pathways for filling knowledge gaps, and support the identification of actions and policies that are robust to uncertainties in parameterisation, model choice, scenarios, or pathways [56,57], including how people in the system might respond to any decisions made [44,58].

While we have focused here primarily on quantitative models of biodiversity and ecosystem services, many other types of model (quantitative and qualitative) can inform biodiversity targets, such as psychological, game theoretic, and governance models [5,58,59]. Such models can contribute to understanding how processes such as the uptake of knowledge or human behavioural responses can influence both the form of a target and the success of its implementation, but remain largely unexplored.

Despite the considerable potential for scenarios and models to inform the formulation and implementation of targets, they have been little used in this capacity to date. Common reasons for not using these approaches include data and knowledge constraints [52,53], technical capacity, lack of trust in models and modellers, and unwillingness to engage from both decision-makers and scientists [11,60]. Our analyses highlight information gaps, which policy-makers and researchers should strive to fill by working together to develop new knowledge and methods, and implementation gaps, where the theory and tools exist to support target achievement, review, and formulation, but have seen little use. Addressing both gaps represents a great opportunity for collaboration between decision-makers and researchers.

Where scenarios and models have had important roles in policy design and implementation, success has derived largely from: strong partnerships and trust between decision-makers, stakeholders, and scientists; commitment of all parties to the decision process and the use of decision support tools; the timeliness of the modelling work; and a structured approach to problem solving [46,60,61]. If scenarios and models are to be successfully deployed in support of target development and implementation, the willingness of both researchers and decision-makers to engage with one another, and respond to each other's needs, will be critical. In particular, a greater understanding of the information and tools required by decision-makers can allow modellers to devise tailored solutions, at the appropriate temporal and spatial scales, that can integrate multiple knowledge types [11,62].

As the global community moves towards new sets of conservation targets beyond 2020, there are many ways in which scenarios and models can continue to contribute, by motivating the need for new targets and helping to improve existing ones [11]. For example, Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assessments that are underway, in particular the global assessment, provide an outstanding opportunity to contribute to setting future international biodiversity targets and highlighting their broader interactions with the UN Sustainable Development Goals [11]. The application of scenarios and models, and the science that underpins them, can greatly reduce the prevalence of ambiguous terms, superfluous or unmeasurable elements, and unreliable indicators. In target formulation and implementation, models and scenarios can evaluate not only whether targets are achievable, but also how they can be achieved and with what level of certainty. This will require scientists, stakeholders, and decision-makers to come together with an open mind and the will to learn and work together, to help halt the loss of biodiversity and maintain the benefits it provides for human wellbeing.

Author Contributions

E.N. led the writing and analysis; E.A.F., R.B., and S.S. contributed to the writing and analysis; all other authors contributed to the writing.

Acknowledgments

E.N. acknowledges the support of a Veski Inspiring Women Fellowship (IWF001) from the Victorian Government, and the Australia Research Council (ARC, DP170100609); B.A.W. and the workshop were supported by ARC Future Fellowship (FT100100819), by the ARC Centre of Excellence for Environmental Decisions (CE110001014) and a Belmont Forum Network grant. R.B. was funded by a CSIR YREF grant. We thank Stuart Butchart, Michael Hoffmann, and two anonymous reviewers for their comments.

Resources

[i] www.cbd.int/sp/
[ii] https://sustainabledevelopment.un.org/sdgs
[iii] www.millenniumassessment.org/en/index.html
[iv] www.iucnredlist.org/
[v] www.cbd.int/gbo/
[vi] www.cbd.int/gbo4/
[vii] www.iucnredlist.org/
[viii] www.ipcc-data.org/guidelines/pages/definitions.html

Supplemental Information

Supplemental information associated with this article can be found, in the online version, at https://doi.org/10.1016/j.tree.2018.10.006.

References

1. Tittensor, D.P. *et al.* (2014) A mid-term analysis of progress toward international biodiversity targets. *Science* 346, 241–244
2. Campbell, L.M. *et al.* (2014) Producing targets for conservation: science and politics at the Tenth Conference of the Parties to the Convention on Biological Diversity. *Global Environ. Politics* 14, 41–63
3. Meinshausen, M. *et al.* (2009) Greenhouse-gas emission targets for limiting global warming to 2 degrees C. *Nature* 458, 1158–1162
4. Perrings, C. *et al.* (2011) The biodiversity and ecosystem services science-policy interface. *Science* 331, 1139–1140
5. Hill, R. *et al.* (2015) A social–ecological systems analysis of impediments to delivery of the Aichi 2020 Targets and potentially more effective pathways to the conservation of biodiversity. *Global Environ. Change* 34, 22–34
6. Venter, O. *et al.* (2014) Targeting global protected area expansion for imperiled biodiversity. *PLoS Biol.* 12, e1001891
7. Costelloe, B.T. *et al.* (2016) Global biodiversity indicators reflect the modelled impacts of protected area policy change. *Conserv. Lett.* 9, 14–20
8. Di Marco, M. *et al.* (2016) Synergies and trade-offs in achieving global biodiversity targets. *Conserv. Biol.* 30, 189–195
9. Visconti, P. *et al.* (2015) Socio-economic and ecological impacts of global protected area expansion plans. *Philos. Trans. R. Soc. B Biol. Sci.* 370, 20140284
10. Kok, M.T.J. *et al.* (2016) Biodiversity and ecosystem services require IPBES to take novel approach to scenarios. *Sustain. Sci.* 12, 177–181
11. Ferrier, S. *et al.*, eds (2016) *The Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services*, IPBES
12. Connolly, S.R. *et al.* (2017) Process, mechanism, and modeling in macroecology. *Trends Ecol. Evol.* 32, 835–844
13. Pereira, H.M. *et al.* (2010) Scenarios for global biodiversity in the 21st century. *Science* 330, 1496–1501
14. Riahi, K. *et al.* (2017) The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. *Global Environ. Change* 42, 153–168
15. Peterson, G.D. *et al.* (2003) Scenario planning: a tool for conservation in an uncertain world. *Conserv. Biol.* 17, 358–366
16. Moss, R.H. *et al.* (2010) The next generation of scenarios for climate change research and assessment. *Nature* 463, 747–756
17. Acosta, L.A. *et al.* (2016) Using scenarios and models to inform decision making in policy design and implementation. In *The Methodological Assessment Report on Scenarios and Models of Biodiversity and Ecosystem Services* (Ferrier, S., ed.), pp. 35–80, IPBES
18. Mace, G.M. *et al.* (2018) Aiming higher to bend the curve of biodiversity loss. *Nat. Sustain.* 1, 448–451
19. Law, E.A. *et al.* (2017) Projecting the performance of conservation interventions. *Biol. Conserv.* 215, 142–151
20. Maxwell, S.L. *et al.* (2015) Being smart about SMART environmental targets. *Science* 347, 1075–1076
21. Perrings, C. *et al.* (2010) Ecosystem services for 2020. *Science* 330, 323–324

22. Butchart, S.H.M. *et al.* (2016) Formulating smart commitments on biodiversity: lessons from the Aichi Targets. *Conserv. Lett.* 9, 457–468
23. Mace, G.M. and Lande, R. (1991) Assessing extinction threats: toward a reevaluation of IUCN Threatened Species categories. *Conserv. Biol.* 5, 148–157
24. Keith, D.A. *et al.* (2004) Protocols for listing threatened species can forecast extinction. *Ecol. Lett.* 7, 1101–1108
25. Caddy, J.F. and Mahon, R. (1998) *Reference Points for Fisheries Management,* FAO
26. Branch, T.A. *et al.* (2010) The trophic fingerprint of marine fisheries. *Nature* 468, 431–435
27. Nicholson, E. *et al.* (2012) Making robust policy decisions using global biodiversity indicators. *PLoS One* 7, e41128
28. Fulton, E.A. *et al.* (2005) Which ecological indicators can robustly detect effects of fishing? *ICES J. Mar. Sci.* 62, 540–551
29. Santini, L. *et al.* (2017) Assessing the suitability of diversity metrics to detect biodiversity change. *Biol. Conserv.* 213, 341–350
30. Bode, M. *et al.* (2015) A conservation planning approach to mitigate the impacts of leakage from protected area networks. *Conserv. Biol.* 29, 765–774
31. Fulton, E.A. *et al.* (2014) An integrated approach is needed for ecosystem based fisheries management: insights from ecosystem-level management strategy evaluation. *PLoS One* 9, e84242
32. Cheung, W.W.L. *et al.* (2009) Projecting global marine biodiversity impacts under climate change scenarios. *Fish Fish.* 10, 235–251
33. Visconti, P. *et al.* (2016) Projecting global biodiversity indicators under future development scenarios. *Conserv. Lett.* 9, 5–13
34. Nel, J.L. *et al.* (2014) Natural hazards in a changing world: a case for ecosystem-based management. *PLoS One* 9, e95942
35. Wintle, B.A. *et al.* (2011) Ecological-economic optimization of biodiversity conservation under climate change. *Nat. Clim. Change* 1, 355–359
36. Gao, L. and Bryan, B.A. (2017) Finding pathways to national-scale land-sector sustainability. *Nature* 544, 217–222
37. Link, J.S. *et al.* (2010) Relating marine ecosystem indicators to fishing and environmental drivers: an elucidation of contrasting responses. *ICES J. Mar. Sci.* 67, 787–795
38. Pauly, D. and Zeller, D. (2016) Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nat. Commun.* 7, 10244
39. Ferrier, S. (2011) Extracting more value from biodiversity change observations through integrated modeling. *Bioscience* 61, 96–97
40. McCarthy, M.A. *et al.* (2008) Optimal investment in conservation of species. *J. Appl. Ecol.* 45, 1428–1435
41. Hoffmann, M. *et al.* (2010) The impact of conservation on the status of the world's vertebrates. *Science* 330, 1503–1509
42. Joppa, L. and Pfaff, A. (2010) Reassessing the forest impacts of protection. *Ann. N. Y. Acad. Sci.* 1185, 135–149
43. Andam, K.S. *et al.* (2008) Measuring the effectiveness of protected area networks in reducing deforestation. *Proc. Natl. Acad. Sci.* 105, 16089–16094
44. Fulton, E.A. *et al.* (2015) Modelling marine protected areas: insights and hurdles. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 370, 20140278
45. Hoffmann, M. *et al.* (2015) The difference conservation makes to extinction risk of the world's ungulates. *Conserv. Biol.* 29, 1303–1313
46. Sainsbury, K.J. *et al.* (1997) Experimental management of an Australian multispecies fishery: examining the possibility of trawl-induced habitat modification. In *Global Trends: Fisheries Management* (Pikitch, E.K., ed.), pp. 107–112, American Fisheries Society
47. Perrings, C. *et al.* (2011) Ecosystem services, targets, and indicators for the conservation and sustainable use of biodiversity. *Front. Ecol. Environ.* 9, 512–520
48. Marques, A. *et al.* (2014) A framework to identify enabling and urgent actions for the 2020 Aichi Targets. *Basic Appl. Ecol.* 15, 633–638
49. Bullock, J.M. *et al.* (2011) Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends Ecol. Evol.* 26, 541–549
50. Soares-Filho, B. *et al.* (2010) Role of Brazilian Amazon protected areas in climate change mitigation. *Proc. Natl. Acad. Sci.* 107, 10821–10826
51. Pradhan, P. *et al.* (2017) A systematic study of sustainable development goal (SDG) interactions. *Earth's Future* 5, 1169–1179
52. Urban, M.C. *et al.* (2016) Improving the forecast for biodiversity under climate change. *Science* 353, aad8466
53. Titeux, N. *et al.* (2016) Biodiversity scenarios neglect future land-use changes. *Global Change Biol.* 22, 2505–2515
54. O'Leary, B.C. *et al.* (2016) Effective coverage targets for ocean protection. *Conserv. Lett.* 9, 398–404
55. Doherty, T.S. *et al.* (2018) Expanding the role of targets in conservation policy. *Trends Ecol. Evol.* 33, 809–812
56. Bunnefeld, N. *et al.* (2011) Management strategy evaluation: a powerful tool for conservation? *Trends Ecol. Evol.* 26, 441–447
57. Dambacher, J.M. *et al.* (2009) Qualitative modelling and indicators of exploited ecosystems. *Fish Fish.* 10, 305–322
58. Fulton, E.A. *et al.* (2011) Human behaviour: the key source of uncertainty in fisheries management. *Fish Fish.* 12, 2–17
59. Boschetti, F. *et al.* (2016) Modelling and attitudes towards the future. *Ecol. Model.* 322, 71–81
60. Addison, P.F.E. *et al.* (2013) Practical solutions for making models indispensable in conservation decision-making. *Divers. Distrib.* 19, 490–502
61. Dichmont, C.M. and Fulton, E.A. *et al.* (2016) Fisheries science and participatory management strategy evaluation: eliciting objectives, visions and system models. In *Conservation Decisions in a Complex World: From Models to Implementation* (Bunnefeld, N., ed.), pp. 19–45, Cambridge University Press
62. Bryant, B.P. and Lempert, R.J. (2010) Thinking inside the box: a participatory, computer-assisted approach to scenario discovery. *Technol. Forecasting Soc. Change* 77, 34–49
63. Pikitch, E.K. *et al.* (2004) Ecosystem-based fishery management. *Science* 305, 346–347
64. Rätz, H.-J. *et al.* (2015) An alternative reference point in the context of ecosystem-based fisheries management: maximum sustainable dead biomass. *ICES J. Mar. Sci.* 72, 2257–2268
65. Moffitt, E.A. *et al.* (2016) Moving towards ecosystem-based fisheries management: options for parameterizing multi-species biological reference points. *Deep Sea Res. II Top. Stud. Oceanogr.* 134, 350–359
66. Fulton, E.A. and Gorton, R. (2014) *Adaptive Futures for SE Australian Fisheries & Aquaculture: Climate Adaptation Simulations,* CSIRO
67. Cheung, W.W.L. *et al.* (2013) Signature of ocean warming in global fisheries catch. *Nature* 497, 365–368
68. Christensen, V. and Walters, C.J. (2004) Ecopath with Ecosim: methods, capabilities and limitations. *Ecol. Model.* 172, 109–139
69. Costello, C. *et al.* (2012) Status and solutions for the world's unassessed fisheries. *Science* 338, 517–520
70. Butchart, S.H.M. *et al.* (2007) Improvements to the Red List Index. *PLoS One* 2, e140
71. Keith, D.A. *et al.* (2014) Detecting extinction risk from climate change by IUCN Red List Criteria. *Conserv. Biol.* 28, 810–819
72. Stuart, S.N. *et al.* (2010) The barometer of life. *Science* 328, 177
73. Butchart, S.H.M. *et al.* (2005) Using Red List Indices to measure progress towards the 2010 target and beyond. *Philos. Trans. R. Soc. B Biol. Sci.* 360, 255–268
74. Kuussaari, M. *et al.* (2009) Extinction debt: a challenge for biodiversity conservation. *Trends Ecol. Evol.* 24, 564–571

75. Morris, W.F. *et al.* (2002) Population viability analysis in endangered species recovery plans: past use and future improvements. *Ecol. Appl.* 12, 708–712
76. Gregory, R. *et al.* (2013) Structuring decisions for managing threatened and endangered species in a changing climate. *Conserv. Biol.* 27, 1212–1221
77. Beissinger, S.R. and McCullough, D.R., eds (2002) *Population Viability Analysis*, The University of Chicago Press
78. Keith, D.A. *et al.* (2008) Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models. *Biol. Lett.* 4, 560–563
79. Bakker, V.J. and Doak, D.F. (2009) Population viability management: ecological standards to guide adaptive management for rare species. *Front. Ecol. Environ.* 7, 158–165
80. Connors, B.M. *et al.* (2014) The false classification of extinction risk in noisy environments. *Proc. R. Soc. B Biol. Sci.* 281, 20132935
81. de L. Brooke, M. *et al.* (2008) Rates of movement of threatened bird species between IUCN Red List categories and toward extinction. *Conserv. Biol.* 22, 417–427
82. McCarthy, D.P. *et al.* (2012) Financial costs of meeting global biodiversity conservation targets: current spending and unmet needs. *Science* 338, 946–949
83. Young, R.P. *et al.* (2014) Accounting for conservation: using the IUCN Red List Index to evaluate the impact of a conservation organization. *Biol. Conserv.* 180, 84–96
84. Di Marco, M. *et al.* (2016) Quantifying the relative irreplaceability of important bird and biodiversity areas. *Conserv. Biol.* 30, 392–402
85. Kininmonth, S. *et al.* (2011) Dispersal connectivity and reserve selection for marine conservation. *Ecol. Model.* 222, 1272–1282
86. Gerber, L.R. *et al.* (2003) Population models for marine reserve design: a retrospective and prospective synthesis. *Ecol. Appl.* 13, S47–S64
87. Pressey, R.L. (1994) Ad hoc reservations – forward or backward steps in developing representative reserve systems. *Conserv. Biol.* 8, 662–668
88. Rodrigues, A.S.L. *et al.* (2004) Effectiveness of the global protected area network in representing species diversity. *Nature* 428, 640–643
89. Banks-Leite, C. *et al.* (2014) Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. *Science* 345, 1041–1045
90. Boonzaier, L. and Pauly, D. (2016) Marine protection targets: an updated assessment of global progress. *Oryx* 50, 27–35
91. Butchart, S.H.M. *et al.* (2015) Shortfalls and solutions for meeting national and global conservation area targets. *Conserv. Lett.* 8, 329–337
92. Bottrill, M.C. and Pressey, R.L. (2012) The effectiveness and evaluation of conservation planning. *Conserv. Lett.* 5, 407–420
93. Knight, A.T. *et al.* (2006) Designing systematic conservation assessments that promote effective implementation: best practice from South Africa. *Conserv. Biol.* 20, 739–750
94. Xu, W. *et al.* (2017) Strengthening protected areas for biodiversity and ecosystem services in China. *Proc. Natl. Acad. Sci.* 114, 1601–1606
95. Ouyang, Z. *et al.* (2016) Improvements in ecosystem services from investments in natural capital. *Science* 352, 1455–1459
96. Fuller, R.A. *et al.* (2010) Replacing underperforming protected areas achieves better conservation outcomes. *Nature* 466, 365–367
97. Rodrigues, A.S.L. *et al.* (2004) Global gap analysis: priority regions for expanding the global protected-area network. *Bioscience* 54, 1092–1100
98. Watson, J.E.M. *et al.* (2011) The capacity of Australia's protected-area system to represent threatened species. *Conserv. Biol.* 25, 324–332
99. Butchart, S.H.M. *et al.* (2012) Protecting important sites for biodiversity contributes to meeting global conservation targets. *PLoS One* 7, e32529
100. Nelson, A. and Chomitz, K.M. (2011) Effectiveness of strict vs. multiple use protected areas in reducing tropical forest fires: a global analysis using matching methods. *PLoS One* 6, e22722
101. Andam, K.S. *et al.* (2010) Protected areas reduced poverty in Costa Rica and Thailand. *Proc. Natl. Acad. Sci.* 107, 9996–10001