Decision-making under great uncertainty: environmental management in an era of global change

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Global change issues are complex and the consequences of decisions are often highly uncertain. The large spatial and temporal scales and stakes involved make it important to take account of present and potential consequences in decision-making. Standard approaches to decision-making under uncertainty require information about the likelihood of alternative states, how states and actions combine to form outcomes and the net benefits of different outcomes. For global change issues, however, the set of potential states is often unknown, much less the probabilities, effect of actions or their net benefits. Decision theory, thresholds, scenarios and resilience thinking can expand awareness of the potential states and outcomes, as well as of the probabilities and consequences of outcomes under alternative decisions.

Decision-making in the context of global change

Humanity faces unprecedented challenges arising from the scale of human activity and its impacts [1,2]. In the 'Anthropocene' [3] (see Glossary), human actions are important drivers of global change, including changes in land use and biogeochemical cycling, emergent diseases, invasive species, biodiversity loss and climate. Global change could have a potentially large impact upon ecosystems, biodiversity, and the well-being of current and future generations. Analyzing the impacts of human actions on the trajectory of global change and human well-being requires integrated analysis of the dynamics of social–ecological systems. The rapid rate of change, the lack of a historical analog and the complexity of feedback effects in social–ecological systems shroud the future trajectory in uncertainty and attempts to compare the probable consequences of alternative decisions have large elements of guesswork.

Although difficult, trying to understand the future trajectory of global change is, in some sense, unavoidable. Sustainable development, as articulated by the World Commission on Environment and Development (the 'Brundtland Commission'), aims to meet 'the needs of the present without compromising the ability of future generations to meet their own needs' [4]. Actions taken to meet the needs of the present can have long-lasting and potentially unforeseen consequences for future generations (e.g. carbon emissions). Many innovations during the 20th century were quite successful in their intended use (e.g. CFCs for use in refrigerators and aerosols), but these 'successes' also led to unintended and damaging consequences (e.g. depletion of the ozone layer). Without reliable information about how current actions are likely to affect the trajectory of global change, and how global change is likely to alter the well-being of future generations, it is hard to provide sensible advice to decision-makers.

How then can one best guide decision-making to meet present and future human needs given pervasive uncertainty? Managing in an era of global change requires an enhanced ability to gather new information and perspectives to better anticipate future conditions. In addition, it

Glossary

Adaptive management: an iterative decision-making process under uncertainty that is designed to learn and incorporate new information and thereby improve future decision-making.
Anthropocene: the most recent geologic time period, in which humans activities have had a dominant impact on Earth systems.
Expected utility: utility is a measure of relative satisfaction or net benefit. Under uncertainty, expected utility is the average (mean) utility.
Maxi-min: an approach for comparing alternative decisions under uncertainty that looks at the worst possible outcome under each strategy and chooses the strategy with the best (least bad) minimum.
Mini-max regret: an approach for comparing alternative decisions under uncertainty that calculates the difference between the outcome for a decision and the best possible outcome (regret) under all possible realizations of uncertainty and chooses the strategy with the lowest regret.
Option value: the value of maintaining flexibility in decision-making (keeping options open) until new information relevant to the decision is obtained.
Reactive nitrogen: forms of nitrogen, such as nitrate and ammonia, that are biologically active and useable by plants and animals.
Regime shifts: large and persistent changes in the structure and function of systems, such as the shift from one stable state to another.
Resilience thinking: a type of systems thinking that explicitly considers feedbacks, nonlinearities and the sensitivity to change. Resilience thinking places high value on the dynamic processes of learning, adaptation and capacity building.
Robust optimization: an approach to optimization that seeks to avoid worst-case outcomes by seeking alternatives that are less sensitive to uncertainty or variations in model assumptions.
Threshold: a defined target level or state based on the avoidance of unacceptable outcomes or an ecologically defined shift in system status.

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requires the ability to make good decisions without full knowledge, but using fully what is known at the time. Furthermore, with iterated decision-making through time, prior decisions will help determine the conditions under which following decisions will be made. It is important then to consider not only the future impacts of current decisions, but also the potential for learning from decisions that can help inform future decisions. Here, we discuss several approaches that, in combination, address learning and application of existing knowledge in iterated decision-making under uncertainty.

We begin with a brief review of decision theory, which provides a systematic approach to decision-making under uncertainty. Decision theory is a powerful tool for providing advice on which management alternative is optimal given the available information. Decision theory, however, requires information about probabilities of various outcomes under alternative management options and the desirability of those outcomes. Such information is unlikely to be readily available in the context of global change issues. We next discuss threshold approaches that focus attention on critical values and try to limit the chance that these values will be exceeded. We then review scenario planning and resilience approaches. These approaches are well suited to scoping problems from broad perspectives and from multiple viewpoints and so can reduce the danger of unforeseen events or unintended consequences.

In our view, an approach to decision-making under uncertainty has value if it helps clarify the effect that alternative decisions have on the probable desirability of outcomes in terms of stated objectives. Although there is no perfect approach to decision-making for global change, various approaches contain potentially useful components that help address different aspects of learning and decision-making. Indeed, we argue that there can be great value in using a combination of approaches.

Approaches to decision-making under uncertainty

The future is always uncertain, but with global change it is highly uncertain. Dynamic elements of social–ecological systems under global change, such as biophysical relationships, human preferences and behavior, and feedbacks among system components, are poorly understood [5]. Additional uncertainty in global change arises with the vast spatial and temporal scales involved and the often limited data available. Guidance on approaches to decision-making under high degrees of complexity and uncertainty has arisen in disparate fields, including ecology, economics and management science, among others. As we illustrate here, promising approaches are often highly interdisciplinary, acknowledge and explore uncertainty, and use a combination of approaches [6–10].

Decision theory

Decision theory is an approach that uses available information to make optimal decisions under uncertainty [11]. In standard decision theory, uncertainty is represented by assuming a set of possible states of the system with a known probability for the occurrence of each state. The decision-maker chooses an action from a set of possible alternative actions. Outcomes are a joint product of the action and the state, generating a set of conditional probabilities of outcomes given the action. Each outcome yields a known net benefit (utility) expressed in a common metric. The standard objective in decision theory is to choose the action that maximizes expected utility, which equals the net benefit of an outcome times its probability of occurrence summed over all possible outcomes (Box 1).

Box 1. Alternative methods for decision-making under uncertainty

The standard objective in decision theory is to maximize expected utility, but other objectives that do not depend on knowing probabilities, such as maxi-min and mini-max regret (defined below), are also used. To illustrate the application of these objectives, consider a decision-maker who makes a one-time choice among three pollution control actions under uncertainty (Table I).

Probabilities of states (zero, low or high damages) will affect the decision on which control action maximizes expected utility. For example, if the probability of each state is 1/3, then it is optimal to choose moderate control as this yields expected net benefits of –6.67 (0.33*(–1 + –5 + –14), which is greater than –10 with stringent control, and –13.33 with lax control. However, stringent control will be optimal when high damage is likely, and similarly for lax control if zero damage is likely.

Determining the optimal choice under maxi-min or mini-max regret does not depend on knowing probabilities of states. The optimal action under the maxi-min objective is the one that has the least bad outcome (i.e. the maximum minimum value). In the example given in Table I, stringent control is the maxi-min action because the worst score is –11, versus –14 and –30 for moderate and lax control, respectively. The maxi-min approach has been criticized as being overly conservative because all weight for decision-making is on the worst possible outcome.

Mini-max regret is less conservative. Under mini-max regret, the loss from the best outcome in each state is computed for each action for all potential states (Table II) and the maximum loss is found for each action. The optimal action minimizes the maximum loss. In the example shown in Table II, the mini-max regret action is moderate control because its maximum regret is –3, versus –9 and -–19 for stringent and lax control, respectively.

Table I. Example showing costs as a function of control action and state[a]

	Zero damage	Low damage	High damage
Stringent control	–9	–10	–11
Moderate control	–1	–5	–14
Lax control	0	–10	–30

[a] In this example of decision-making under uncertainty, there are three possible pollution control strategies: stringent, moderate or lax controls. There is uncertainty about the impacts of pollution represented by three possible states: zero, low and high damage. Outcomes are determined by the combination of action and state. The numbers in each cell represent the sum of damages from pollution plus abatement costs under each control strategy and state combination. Net benefits of each outcome equal the sum of emissions costs and damages and, thus, are negative.

Table II. Example calculation of regret[a]

	Zero damage	Low damage	High damage
Stringent control	–9 – 0 = –9	–10 – (–5) = –5	–11 – (–11) = 0
Moderate control	–1 – 0 = –1	–5 – (–5) = 0	–14 – (–11) = –3
Lax control	0 – 0 = 0	–10 – (–5) = –5	–30 – (–11) = –19

[a] The numbers in each cell represent the regret for a control strategy for a particular state (zero, low and high damage) for the example shown in Table I. The regret for a control strategy for a particular state is found by taking the difference between the outcome for the control strategy and the control strategy with the best outcome for that state. For example, the best outcome under the high damage state is stringent control, with an outcome of –11. The regret for moderate control under high damage is equal to –3 because the outcome under moderate control is –14: –14 – (–11) = –3.

The major advantages of decision theory are that it provides a clear statement of the problem and objective for decision-making, brings to bear available quantitative scientific and economic information in a coherent framework, and provides a transparent and repeatable analysis for generating a recommended course of action. The major disadvantage of decision theory for global change problems is that it requires more information to implement than is likely to exist. In the context of global change, it is highly unlikely that a decision-maker (or analyst) will know all of the possible future states for the global system, or the probabilities of those states. Without this knowledge, it is not possible to define the conditional probability of outcomes or to calculate expected utilities. The difficulties of specifying probabilities have led to the development of alternative, non-expected utility decision rules that do not rely on probability assessments (Box 1). These approaches, however, still require information about the range of possible states, how states combine with actions to generate outcomes and the net benefits of those outcomes.

Application of decision theory can be done in an iterative manner and can be designed to incorporate learning and adaptive management. A forward-looking decision-maker should take account of how current decisions might influence future conditions, future decisions and the probable impacts of decisions on current and future well-being. The potential to obtain new information that would be useful for future decision-making gives rise to an important set of issues in iterative decision-making that are missing in one-time ('static') decision-making. Hoegh-Guldberg *et al.* [12] use a decision tree with sequential decision-making to evaluate alternative conservation strategies under rapid climate change. In the decision tree, answers to one set of questions determine the next set of questions to ask and eventually lead to a preferred option. In adaptive management, decisions are treated as experiments, often involving active participation by interested parties, that generate information that can improve future decisions [13–15]. A closely related literature in economics and finance developed the notion of 'option value,' which is the value of maintaining flexibility for future decisions and avoiding irreversible, or costly to reverse, outcomes [16]. Option value can be applied to ecosystem management. For example, there is an option value for conserving an ecosystem because current development will foreclose the option for future conservation, whereas current conservation does not foreclose the option of future development. Option value can make it desirable to conserve an ecosystem even though the expected value of development exceeds the expected value of conservation [17].

Decision theory provides a powerful set of tools for making good decisions when the existing information is fairly extensive, but it can be of limited utility when there are large gaps in current understanding. Exclusive reliance on decision theory can lead analysts and decision-makers to focus too narrowly on issues with sufficient current data and understanding to permit analysis and ignore potential futures with limited data or understanding. For this reason, using decision theory in concert with alternative methods discussed here (scenario planning and resilience) can lead to better scoping of potential future states and outcomes under global change and, hence, better decision-making.

Thresholds approach

Social–ecological systems are complex adaptive systems [18] that can exhibit nonlinear dynamics, historical dependency, have multiple basins of attraction and limited predictability [19,20]. When crossed, thresholds between multiple basins of attraction can lead to fundamental transformations in system feedbacks and dynamics [21]. Regime shifts, defined as crossing a threshold into a new basin of attraction, have been documented for a range of ecosystems and social–ecological systems [22–25].

A threshold approach can be useful in organizing thinking about complex problems by focusing attention on critical boundaries that have major consequences if crossed. Examples of the application of thresholds in global change include planetary boundaries that define important limits on key environmental variables [26] and limits on emissions to avoid dangerous climate change [27]. Thresholds can be used as a screen to rule out actions thought to have too high a risk of crossing a threshold or to rank actions based on risk. If crossing the threshold leads to worst-case outcomes, then a threshold approach will be formally similar to decision theory approaches that use maxi-min (Box 1) or to types of robust optimization [28]. In general, both decision theory and threshold will generate similar policy recommendations when crossing a threshold will cause large losses and can be avoided at reasonable cost. Threshold approaches can lead to different policy recommendations from those made based on decision theory in other circumstances (Box 2).

Box 2. Framing climate change: minimizing risk or maximizing expected utility

Policy advice on climate change spans a broad spectrum from doing nothing, to modest immediate reductions of greenhouse gas emissions that increase in stringency over time (e.g. [58,59]), to large-scale emission reductions that would cap maximum atmospheric concentrations below 550 ppm (e.g. [60]), to calls for immediately reducing atmospheric concentrations to 350 ppm (e.g. [61]). This wide spectrum of policy advice partly reflects different interpretations of the current state of scientific understanding, including uncertainty about temperature sensitivity that links atmospheric concentrations to mean global temperature increase, and differences in the probable impacts on human well-being associated with various degrees of climate change. Given the complexity of the climate system, reductions in uncertainty might not be forthcoming [62].

This wide spectrum of policy advice also reflects differences in how the climate change policy question is framed. Policy advice for modest immediate reductions tends to come from analysts using decision theory to choose an optimal path of emissions through time (e.g. [59,63]). Other analysts use a thresholds perspective and provide advice based on reducing the likelihood of crossing dangerous climate change thresholds (e.g. [27]). In this vein, Stern and Taylor [64] frame the policy debate as whether paying 1% of income to stabilize atmospheric concentrations below 550 ppm is worthwhile to avoid potentially catastrophic risks from higher atmospheric concentrations.

Under decision theory, the optimal policy is quite sensitive to the treatment of uncertainty. Differences in assumptions about the tails of probability distributions and the losses associated with tail outcomes can lead to large changes in optimal emissions reductions [65,66]. Similarly, what is considered an unacceptable risk, either in terms of probabilities of occurrence or negative consequences with occurrence, will influence policy advice using a threshold approach [29].

There is often uncertainty about the exact level of a threshold, in which case decision-making involves choices about what risks are acceptable [29]. Putting more stress on the system can increase current benefits but at a cost of having a higher probability of crossing a critical threshold. Thresholds have been criticized as giving a false impression that degradation below the threshold level is 'safe' [30] and improvements beyond a threshold are of no value. Thresholds are often used in regulatory or legal contexts to distinguish permissible from impermissible activities, but these laws and regulations are not necessarily tied to ecological or other real system thresholds.

Scenario planning

Scenario planning is a method for thinking creatively and systematically about complex futures [31]. Scenarios are sets of plausible stories, supported with data and simulations, about how the future might unfold from current conditions under alternative human choices. In the context of global change, scenarios organize complex information into coherent, memorable and richly detailed stories that help people conceptualize the future. They illustrate a range of potential futures and decision-makers can assess the robustness of alternative policy options by determining how each policy would play out in each of the different futures. In scenario planning, unlike decision theory, it is not necessary to assign probabilities or values to the alternatives.

The benefits of using scenario planning in decision-making when the future is complex and uncertain can be illustrated by examples from the business world. During the 1980 s, IBM did not use scenario planning and, as a result, greatly underestimated the market for personal computers. The company retreated from a market that became more than 100 times larger than its forecasts [32]. By contrast, Shell used scenarios to evaluate long-term decisions. Even though oil prices were low in 1970 and predicted to remain so, scenario planners from Shell considered alternate states, including some in which a consortium of oil-producing countries limited production and drove oil prices upward. Shell hedged against this case by changing its strategy for refining and shipping oil. This exercise in scenario planning allowed Shell to adapt more rapidly than its competitors to price increases during the mid-1970 s and it rose to become the second largest oil company in the world [33].

Scenarios were first used in the analysis of global change during the 1970 s [34]. The current generation of global change scenarios originated in 1995 with the Global Scenario Group (GSG) at the Stockholm Environment Institute [35]. Recent influential efforts include the Global Environmental Outlook [36], the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC) [37] and Millennium Ecosystem Assessment [38]. These studies explored widely contrasting alternative visions using quantitative models and a diverse set of quantitative indicators.

Although scenarios are useful in exploring potential states of complex global systems, their weakness lies in the difficulty of assessing the likelihood of alternative futures. Scenarios are often based on storylines that interweave complex social, economic and biophysical factors, making assessment of probabilities difficult. The SRES presented six scenarios based on different assumptions about economic growth, population change, technological change, and cultural and social factors. Scenarios predicted a doubling or tripling of $CO_{2,}$ but no attempt was made to assign probabilities to these scenarios, instead labeling all scenarios as 'equally sound' (Box 2). The omission of probabilities from the SRES was controversial. Some argued that high uncertainty prevented realistic assessments of probabilities, whereas others contended that the lack of probabilities limited the value of the scenarios to decision-makers [29]. Recent work on robust decision-making attempts to incorporate probabilistic information into scenarios [28,39,9]. Under this approach, computer simulations are used to evaluate the sensitivity of different strategies to significant uncertainties and highlight scenarios that are particularly robust to changing levels of uncertainty.

Resilience thinking

Resilience thinking focuses on critical thresholds for system performance, the capacity to adapt to changing conditions and thereby conserve certain key processes, and the capacity to transform to a completely new mode of operation if the old mode becomes untenable [19,40,41]. Building capacity to recognize and respond to emerging transformations before they occur is a key element to dealing with uncertainty in complex systems [42]. Transformations in complex systems are often preceded by weak but persistent early warning signals [20]. Successful planning to identify and respond to early warnings involves gathering information and opinion from many independent sources about highly unusual but plausible outcomes [43], training leaders to watch for these weak signals and creating mechanisms to share understanding.

Similar to scenarios, a resilience approach uses processes that uncover uncertainty by engaging multiple perspectives [44]. Complex problems can often be better addressed by a diverse team of competent individuals than by a team composed of the best individual problem-solvers [45]. Diverse teams, such as those that combine experienced-based knowledge with scientific knowledge, can be adept at developing responses to complex problems because they expand the scope of what is considered possible, the set of questions being asked and the set of options under consideration [44,46,47].

Generality and inclusiveness is both a strength and weakness of resilience thinking. Resilience thinking generates a comprehensive, inclusive view of the entire system that aims to include all relevant factors for a decision, even if they are ambiguous or not quantifiable. However, it often does not provide clear guidance on specific policy or management alternatives. Because it is comprehensive, resilience thinking can be usefully combined with decision theory, threshold approaches and scenario planning to provide guidance in management settings. Fischer *et al.* [10] present a framework for integrating resilience thinking with optimization methods for conservation planning. Resilience approaches are used to characterize spatial and temporal boundaries of the social–ecological system, highlight key social and ecological drivers of change, and identify key actors and institutions, complementing many of the same processes necessary to create robust decisions [19]. A resilience approach also considers key thresholds, regime shifts and risk targets, similar to threshold approaches. Finally, as in adaptive management, a fundamental concept of resilience is the need for iterated decision-making where assumptions are revisited and actions re-evaluated as decision-makers adapt to changing conditions and new information.

Application to global change science and policy

The future of complex social–ecological systems under global change, and how that future might be influenced by alternative decisions, is subject to considerable uncertainty. Although classical decision theory brings a powerful set of tools to bear on problems of decision-making under uncertainty, it is not directly applicable to the analysis of global change because it requires a fully specified set of future potential states and probabilities of their occurrence, an understanding of how states and actions combine to yield outcomes, and an understanding of the net benefits of each potential outcome. Implementing decision theory for global change would require extensive reliance on subjective probability assessments over which reasonable observers will probably disagree.

In situations of profound uncertainty, threshold approaches, scenario planning and resilience thinking can be useful ways to both expand the scope of what is considered, thereby reducing the risk of unintended consequences, and to organize complex materials to focus on key factors and boundaries (Box 3). Providing advice to decision-makers in complex systems with great uncertainty can be aided by bringing in diverse viewpoints and using multiple tools.

Decision-making for global change issues is an iterated process that can be thought of as involving two phases with continuous feedbacks. One phase involves scoping the problem as broadly as possible to expand the space of imaginable states and associated outcomes. Such thinking can provide impetus to explore widely for evidence beyond what is currently considered probable [48,49]. Scenario planning and resilience thinking are ways, among others, of expanding the frame of reference to anticipate unexpected outcomes for complex systems [44]. Analyses that take a broad view of the space of plausible outcomes can generate a richer understanding of complex system dynamics, a more accurate and comprehensive assessment of uncertainties, and deeper insights into potential threats to human well-being [50].

The other phase involves actually making decisions given current understanding. Guidance to decision-makers should rely on a broad set of models, data and experience to generate insights about the probable desirability of alternative decisions. Analyses should bring to bear what is known as well as what is possible although unknown. For complex systems, scientific approaches are often more successful in finding major vulnerabilities than in accurately predicting the future [51]. In this sense, analysis of complex systems might be well suited to highlighting potential thresholds and choosing robust decisions that do well under a wide variety of circumstances. Analyses are also useful for pointing out gaps in understanding that should guide future research efforts. Scoping of possible futures, analysis and decision-making are revisited in a continuous loop as conditions, information and understanding of the complex system evolves. How much broad scoping and research should be done before any given decision depends on the cost of scoping and research as well as on the benefits of improved decision-making with improved information.

Box 3. The iterative decision-making process applied to global nitrogen management

Anthropogenic sources of reactive nitrogen exceed all natural sources combined. The consequences of accelerated nitrogen cycling include biodiversity loss, greenhouse gas emissions, and air and water pollution [67–69]. Among the challenges posed by nitrogen management are the multiple forms of reactive nitrogen, high spatial and temporal variability in nitrogen pathways and numerous feedbacks that link nitrogen cycling with other ecosystem processes. Additional uncertainty arises in the complicated social–ecological interactions that drive global reactive nitrogen creation, transport and management. Furthermore, the desired outcomes of nitrogen management are subject to a range of opinion among different stakeholders.

The complexity and uncertainty surrounding reactive nitrogen precludes straightforward assignment of probabilities as needed to apply decision theory. Instead, a combination of scenarios, thresholds and decision theory can be used to assess broadly the problem while still providing guidance for decision-makers. Researchers have identified various thresholds, including nitrogen saturation sensitivity in temperate forests [70], safe drinking water standards for nitrate and a 'planetary boundary' of an upper bound for global nitrogen fixation [26]. In the case of coastal hypoxia in the Gulf of Mexico, analysts have defined a desired maximum extent of the hypoxic zone [71]. The hypoxia threshold defines acceptable bounds on nutrient exports from the Mississippi River and helps guide nutrient management and conservation planning in the Upper Mississippi River Basin [72,73]. Scenarios are used in combination with the hypoxia threshold to evaluate the consequences of land use and climate change on the likelihood of meeting hypoxia goals [73,74]. However, it is difficult to tie nutrient management to hypoxia because of the variability in weather and soil conditions and the consequent variability in nitrogen loadings to the Mississippi River, in addition to variability of conditions in the Gulf of Mexico. There are also only a few studies that have attempted to quantify the damages of hypoxia and compare these to costs of reducing nitrogen loadings. Nevertheless, initial work on defining thresholds and using scenarios and models to explore the impacts of alternative decisions in the context of the hypoxia in the Gulf is laudable and has made progress in addressing the problem. Greater integration of the approaches presented in this paper will help to avoid unintended consequences and integrate science and decision-making in the face of uncertainty.

A major challenge in global change decision-making is that it is global. Although we share one common planet, we do not all share common viewpoints or values. Multiple decision-makers whose actions affect others but whose interests are not aligned raise difficult governance issues [52,53]. In addition, groups with different agendas have incentives to misuse, obfuscate, or ignore information [54,55]. A challenge for scientific assessments of global change is to provide credible and transparent analyses presented in a clear manner to minimize the potential for manipulation in the face of uncertainty. Collaborative approaches that generate trust and common understanding improve the chance of successful joint governance.

Decision-making on global change involves combining what is known, what is possible but unknown, along with judgements about the net benefits of different potential futures. This process inevitably involves value judgments. In classic decision theory, value judgements enter when subjective probabilities are used because objective probabilities are not available and when a common metric is used to measure all benefits. Avoiding embedding value judgements in the analysis can be important when dealing with multiple groups who hold different values. As discussed in Box 1, some approaches do not require probabilities (e.g. maxi-min and mini-max regret). Furthermore, some approaches do not require measuring all benefits in a common metric. For example, Polasky *et al.* [56] derive an efficiency frontier that shows the feasible tradeoffs between biodiversity conservation and value of commodity production without attempting to value biodiversity in monetary terms. Evaluation of multiple dimensions [7] and multi-criteria analysis [57] can also be used to demonstrate how alternatives fare on different desirable attributes.

The potential of human action to cause global change with significant impacts on current and future well-being makes it important to consider potential consequences when making choices. Turning a blind eye to potentially large problems and simply hoping that things will work out is not a sensible approach. The only unsurprising thing about the future is that there will be surprises. Enhancing the ability to learn and maintaining the ability to respond are important elements of successfully dealing with surprises. Scientific assessments have a key role to play in improving decision-making regarding global change. Making good decisions, even with limited information and great uncertainty, is necessary if we hope to steer the global social–ecological system towards sustainable trajectories and away from potentially destructive trajectories.

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