1 Overview and vision

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1.1 Introduction

This initial chapter introduces the background, purpose and scope of the IPBES Methodological Assessment of Scenario Analysis and Modelling of Biodiversity and Ecosystem Services. It also provides a general introduction to the role of scenarios and models in assessment and decision support, describes the structure of the remaining chapters of the report, and highlights key high-level messages for IPBES emerging from this assessment. The chapter is purposely written for a broader, less technical audience than the other seven chapters of the report, each of which examines in greater depth a subset of issues and challenges associated with scenario analysis and modelling of biodiversity and ecosystem services.

For the purposes of this assessment, we define “models” as qualitative or quantitative representations of key components of a system and of relationships between these components. Throughout this assessment, and in most IPBES activities, the term "models" usually, but not exclusively, refers to quantitative descriptions of relationships: i) between indirect drivers and direct drivers; ii) between direct drivers and nature (biodiversity and ecosystems); and iii) between nature and nature's benefits to people, including ecosystem services. Each of these relationships is discussed in more detail later in this chapter.

We here define "scenarios" as plausible representations of possible futures for one or more components of a system, and/or as alternative policy or management options intended to alter the future state of these components. Throughout this assessment the term “scenarios” usually refers to plausible futures for, and/or interventions targeting, indirect or direct drivers. The consequences of these scenarios for nature and nature’s benefits to people are then typically evaluated using models as defined above.

Scenarios and models of biodiversity and ecosystem services play important roles in assessments, policy support and decision making because they can provide many benefits, including to "better understand and synthesize a broad range of observations; alert decision makers to undesirable future impacts of global changes such as land use change, invasive alien species, overexploitation, climate change and pollution; provide decision support for developing adaptive management strategies; and explore the implications of alternative social-ecological development pathways and policy options. One of the key objectives in using scenarios and models is to move away from the current reactive mode of decision-making in which society responds to the degradation of biodiversity and ecosystem services in an uncoordinated, piecemeal fashion to a proactive mode in which society anticipates change and thereby minimizes adverse impacts and capitalizes on important opportunities through thoughtful adaptation and mitigation strategies" (IPBES/2/16/Add4[1])

The most fundamental message emerging from this assessment is that scenario analysis and modelling can, and should, contribute significantly to achieving the overarching goal of IPBES "to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development". To this end, this assessment provides a conceptual framework and guidelines for using scenarios and models in a wide range of policy and decision-making contexts, as well as detailed documentation of the variety of available scenarios and models. This is backed up by numerous examples throughout this and subsequent chapters of the wide variety of applications of scenarios and models to assessments, policy design and policy implementation.

1.1.1 Purpose and scope of this assessment

The methodological assessment on scenarios and models was initiated in order to provide expert advice on "the use of such methodologies in all work under the Platform to ensure the policy relevance of its deliverables" (IPBES/2/17 Annex IV). It is one of the first assessment activities of IPBES because it lays the foundations for the use of scenarios and models in the regional, global and thematic assessments, outlines a plan of action for IPBES task forces and expert groups in terms of supporting and mobilizing scenarios and modelling expertise and identifies key gaps that need to be addressed in collaboration with the scientific community. There are a large number of reviews providing typologies of scenarios and models and summarizing their strengths and weaknesses (Coreau et al. 2009; Henrichs et al. 2010; Kelly et al. 2001; Bellard et al. 2012; Harfoot et al. 2014a), but all of these have a much narrower scope than this assessment and do not provide recommendations that are specifically adapted to the IPBES mandate.

The primary audiences for this methodological assessment are the participants in the expert groups and task forces associated with other deliverables of the IPBES Work Programme (see section 1.4 for further details). For these experts, this methodological assessment provides an overview of scenarios and models, a critical analysis of the types and uses of scenarios and models currently available and perspectives on the development of new methods in the near future. It also provides a set of specific recommendations for experts involved in all the activities of the IPBES work programme, particularly in terms of good practice and support for use of scenarios and models.

This assessment also addresses several audiences in addition to experts involved in IPBES activities. The Summary for Policy Makers and this chapter have been written with non-experts in mind so that it is accessible for a broad audience including members of the IPBES plenary, stakeholders and policy makers. The critical analysis and perspectives in Chapters 2-8 of this assessment are more technical in nature and address the broader scientific community in addition to the expert groups and task

[1] For official IPBES documents cited in this assessment, see the IPBES web site at www.ibpes.net under the tab "Plenary Sessions". The first number in the IPBES document reference indicates the number of the plenary session.

forces of IPBES. They are written for a scientific audience working on issues related to biodiversity and ecosystem services. Highly technical descriptions and jargon have been kept to a minimum, because this audience has widely varying degrees of familiarity with the full spectrum of scenarios and models.

The scope of the assessment covers a broad range of scenarios and models. The objective is to provide guidance for "evaluating alternative policy options using scenarios and models; including multiple drivers in assessments of future impacts; identifying criteria by which the quality of scenarios and models can be evaluated; ensuring comparability of regional and global policies; including input from stakeholders at various levels; implementing capacity-building mechanisms to promote the development, use and interpretation of scenarios and models by a wide range of policymakers and stakeholders; and communicating outcomes of scenario and model analyses to policymakers and other stakeholders" (IPBES/2/16/Add.4).

Follow-up work by an expert group will start following the completion of this assessment in 2015 and will continue through 2017 and possibly beyond. One of the tasks of this expert group will be to establish an "evolving guide" on scenarios and models. The exact nature of this evolving guide remains to be defined, but since methods are changing very rapidly, it is important that the guidance provided in this assessment is updated on a regular basis. The task force will also interact with other IPBES deliverables and the broader scientific community to stimulate work on scenarios and models that are specifically targeted at IPBES objectives. It is envisaged that this will be similar to the interactions between the IPCC and the scientific community that have been created in order to develop scenarios and models for climate change assessment.

1.1.2 Background and context

Scenarios and models of biodiversity and ecosystems have been a key component of most global, regional and national environmental assessments carried out over the last decade. The IPCC, which is the institutional equivalent of IPBES for climate change issues, has amply demonstrated the power of scenarios and models as a cornerstone of the science-policy dialog surrounding climate change and in popularizing climate change issues. Despite the use of scenarios and models of biodiversity and ecosystem services in several major global and sub-global assessments their recognition in influencing decision making and popularizing biodiversity and ecosystem services issues is less clear cut, although there is evidence of uptake in national and international policy (Wilson et al. 2014). A variety of factors hamper more widespread use, including the relatively recent development of scenarios and models for biodiversity and ecosystem services and insufficient dialog between scientists and decision makers concerning their applications (see Chapter 2 for details). Scenarios and models in assessments of biodiversity and ecosystem services have done a good job of alerting the scientific community, natural resource managers and politicians to the possible future risks for biodiversity and ecosystem services. Examples include the Millennium Ecosystem Assessment which called attention to the possibility of greatly increased species extinction risk by 2050 driven by land use and climate change (MA 2005, Alkemade et al. 2009), and the most recent Global Biodiversity Outlook which showed that progress on reducing pressures on biodiversity and ecosystems is currently insufficient to attain many of the Convention on Biological Diversity's Aichi Targets by 2020 (SCBD GBO4 2014, Leadley et al. 2014).

Scenarios and models of biodiversity and ecosystems are used in decision contexts outside of global, regional and national environmental assessments. In particular, a wide range of policy support methodologies have been developed to allow more direct use of scenarios and models in policy design, implementation and evaluation (see Chapter 2). The bulk of this work has been done at local scales, but some methodologies are also pertinent at national to global scales. Experience shows that successful application of models and scenarios to policy design, implementation and evaluation requires sustained interactions between stakeholders, key decision makers and modellers. Many examples illustrating these applications are provided in this and subsequent chapters, particularly in boxes describing case studies.

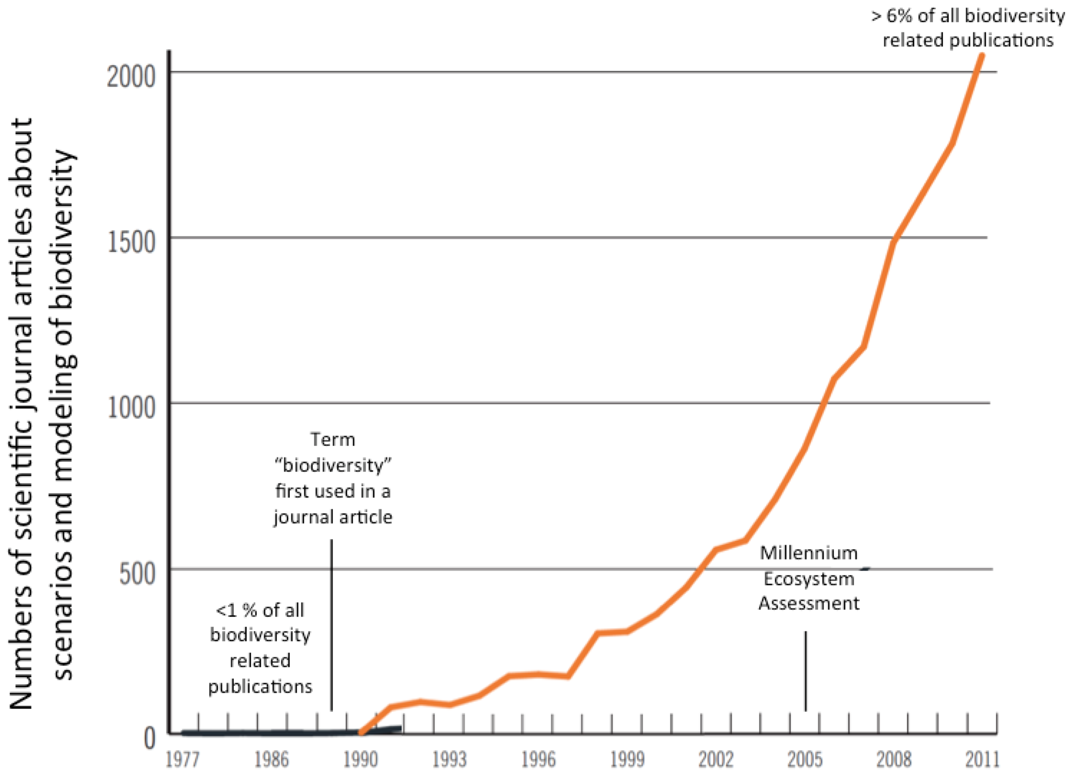


Figure 1.1.: Change over time in the number of articles published in scientific journals related to scenarios and models of biodiversity (FRB 2013)[2]. These were compared to the total number of publications on biodiversity over the same period to calculate the percentage of articles related to scenarios and models.

[2]The literature analysis was carried out by the Foundation for Biodiversity Research (FRB 2013) using the Web of Science and the following search command: TOPIC = ((projection* or prediction* or forecast* or scenario*) AND ((ecosystem and service*) or (ecological and service*) or “species loss” or biodiversity or (biological diversity) or (species richness) or (species diversity) or (functional diversity) or (biological conservation) or (species conservation) or (habitat conservation) or (genetic resource*) or (genetic diversity) or (plant diversity) or (microbial diversity) or (bacterial diversity) or (fung* diversity) or (weed diversity) or (animal diversity) or (mammal diversity) or (insect* diversity) or (functional trait*) or (virus diversity) or (bird diversity) or (invasive species) or (biological invasion*) or (landscape diversity) or (habitat diversity) or “cultural diversity” or “local knowledge” or “traditional knowledge” or “traditional local knowledge” or “environmental knowledge”))TIMESPAN = From 1975 to 2011.

The use of scenarios and models of biodiversity and ecosystem services in assessments is recent. The first global assessment with a substantial component of biodiversity scenarios was the Millennium Ecosystem Assessment released in 2005 (MA 2005). Assessments with significant use of scenarios and models to evaluate ecosystem services are even more recent (e.g., UK NEA 2011). Very rapid progress in the development and use of scenarios and modelling of biodiversity and ecosystem services over the last decade (Figure 1.1) means that IPBES is now well positioned to make substantial use of these methodologies in all of its activities.

A variety of approaches have been used for developing and presenting scenarios and models in environmental assessments. In some cases, assessment bodies have opted to support the development of a common set of scenarios of direct and indirect drivers, as well as accompanying models of impacts on biodiversity and ecosystems. Examples include the global assessments such as the Millennium Ecosystem Assessment (MA 2005), early Global Biodiversity Outlooks (SCBD GBO2 2006), and Global Environmental Outlooks (e.g. UNEP GEO4 2007), as well as some national and regional assessments (Southern Africa, van Jaarsveld et al. 2005; Japan SSA 2010; UK NEA 2011, Wilson et al. 2014). At the opposite end of the spectrum some assessments have focused on synthesizing a broad range of published analyses of scenarios and modelling studies available in the literature (e.g., CBD GBO3 2010, Leadley et al. 2010; UNEP GEO5 2012). Still others fall in between these extremes, for example the IPCC relies on a common set of scenarios of direct and indirect drivers developed specifically for the assessment, while assessment of projected impacts on biodiversity and ecosystems is primarily based on analyses of peer-reviewed literature (e.g., GBO4 2014; IPCC 2014a, b). The advantage of using a common set of scenarios and models is that they provide a clear and homogenous analysis that may be easier for non-specialists to understand: the disadvantages are that these typically are useful for a very limited range of spatial and temporal scales and decision contexts. The advantage of analyses based on a broad spectrum of published work is that they provide much greater insight into assumptions underlying scenarios and models and their associated uncertainties and can cover a wide variety of scales and decision contexts, but very diverse assumptions and indicators used in published work make synthesis difficult (Pereira et al. 2010).

Several biases need to be addressed to improve the usefulness of scenarios and models for decision makers (FRB 2013). Published studies of scenarios and models show a strong bias towards terrestrial ecosystems with climate change as a driver: stronger near term drivers such as habitat loss, invasive species and overexploitation have received insufficient attention. Marine ecosystems are reasonably well represented, with many focusing on fisheries management or climate change impacts on marine biodiversity and ecosystems (e.g., Dunstan et al. 2011; Sumaila et al. 2011). Freshwater ecosystems are under-represented in scenarios and modelling analyses compared to terrestrial ecosystems. Biodiversity studies involved scenarios and models are heavily biased towards the species level followed by community level studies, with relatively few studies of genetic level. Animals and plants are roughly equally represented, but micro-organisms are infrequently addressed. There is also a strong bias towards scenarios towards mid- and end-21st century outcomes (FRB 2013), whereas many decision makers are more focused on nearer terms goals (e.g., Aichi Targets for 2020, CBD GBO4 2014). Spatial scale ranges in assessments typically cover the range of national to global. Few assessments account for the vast amount of information in sub-national scale scenarios and models, which may be a more pertinent spatial scale for some decision makers. Socio-economic factors the most commonly accounted for are management strategies, sectorial politics, socio-cultural and socio-economic contexts and economic scenarios. Finally, most assessments have not relied on scenarios and modelling of ecosystem services outside of food production and carbon storage, even though other types of ecosystem services are key elements in decision-making (but see PBL 2012). One of the objectives of this document is to provide guidelines for addressing these biases.

1.2 The role of scenarios and models in assessment and decision support

1.2.1 Overview

The IPBES Conceptual Framework (Figure 1.2, Diaz et al. 2015) provides a logical starting point for introducing, and explaining, the respective roles of scenarios and models within the context of IPBES. This framework emerged from an extensive process of consultation and negotiation, leading to formal adoption by the second IPBES Plenary (Decision IPBES/2/4, http://www.ipbes.net/), and therefore represents a key foundation for all IPBES activities. It is a simplified representation of the complex interactions between the natural world and human societies. IPBES recognizes and considers different knowledge systems, including indigenous and local knowledge systems, which can be complementary to science-based models. The Conceptual Framework is therefore intended to serve as a tool for achieving a shared working understanding across different disciplines, knowledge systems and stakeholders that are expected to be active participants in IPBES.

As explained by Diaz et al. (2015), this framework provides a conceptual foundation for the science-policy interface through which knowledge from science, and other knowledge systems, flows through to policy and decision-making via the four main functions of IPBES – i.e. knowledge-generation, assessment, policy-support, and capacity-building.

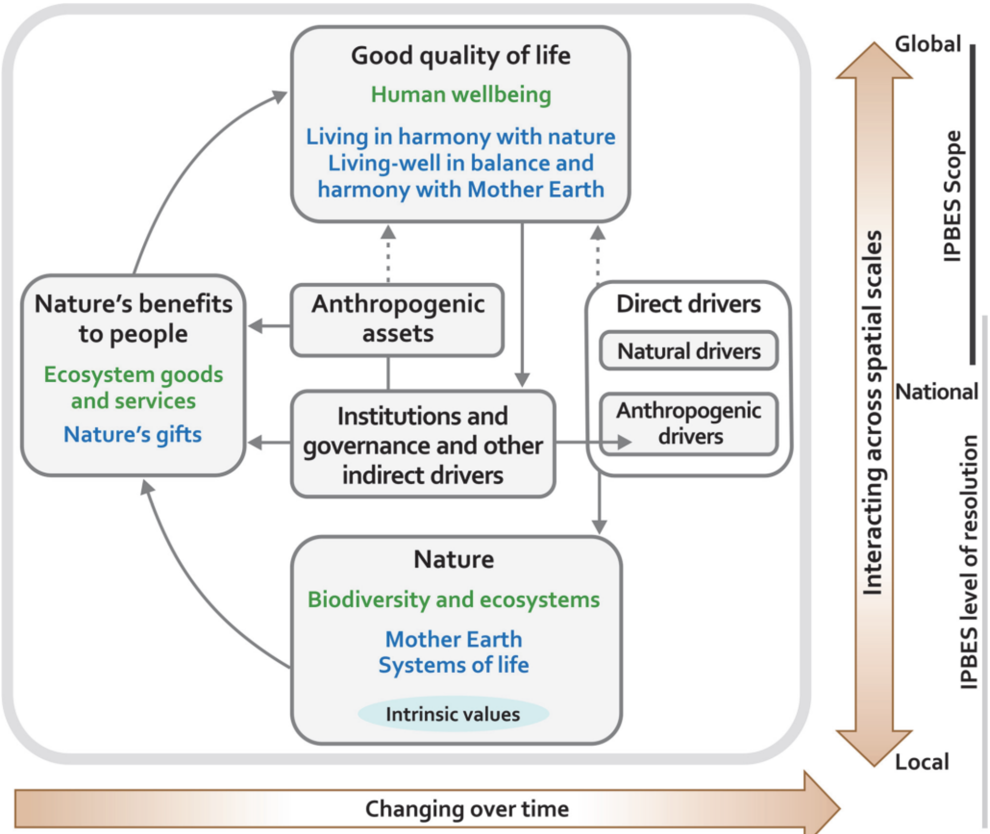


Figure 1.2.: The IPBES analytical conceptual framework, from Diaz *et al.* (2015). This depicts the main elements and relationships for the conservation and sustainable use of biodiversity and ecosystem services, human well-being and sustainable development. Similar conceptualizations in other knowledge systems include "living in harmony with nature" and "Mother Earth", among others. In the main panel, delimited in grey, "nature", "nature's benefits to people" and "good quality of life" (indicated as black headlines) are inclusive of all these world views; text in green denotes the concepts of science; and text in blue denotes those of other knowledge systems. Solid arrows in the main panel denote influence between elements; the dotted arrows denote links that are acknowledged as important, but are not the main focus of the Platform. The thick coloured arrows below and to the right of the central panel indicate different scales of time and space, respectively.

The high-level roles that scenarios and models play in enabling this flow of knowledge to policy and decision-making are depicted in Figure 1.3. Modelling offers a means of explicitly describing, and quantifying, interactions between major elements of the IPBES Conceptual Framework, based on best-available knowledge. In the original framework (Figure 1.2) arrows are used simply to indicate the existence of relationships between elements but convey very little about the precise nature of these relationships. Replacing these conceptual links with models allows observed, or projected, changes in the state of one element to be used to estimate, or project, resulting changes in other elements. The methodological assessment presented in this report focuses on models addressing three main links within the IPBES Conceptual Framework:

- the effects of changes in indirect drivers (e.g. socio-political, economic, technological and cultural factors) on direct drivers of change in, and therefore pressures on, biodiversity and ecosystems (e.g. habitat conversion, exploitation, climate change, pollution, species introductions);

- the impacts of changes in direct drivers – both negative, and positive (e.g. through policy or management intervention) – on nature, including various dimensions and levels of biodiversity, and ecosystem properties and processes; and
- the consequences of changes in biodiversity and ecosystems for the benefits that people derive from nature, and that therefore contribute to good quality of life (human well-being) – including, but not limited to, ecosystem goods and services.

As indicated in Figures 1.2 and 1.3, good quality of life can also be affected directly by changes in anthropogenic assets (built, human, social, and financial) that are not mediated by changes in biodiversity or ecosystems. Comprehensive assessment of human wellbeing is likely to involve modelling of impacts of indirect socio-economic drivers both on nature's benefits to people, and on anthropogenic assets. While models of the latter fall largely outside the scope of this document, the report does illustrate how indicators of good quality of life (e.g., people not suffering from hunger, access to electricity, etc) can be associated with scenarios and models of nature and nature's benefits. These are critical for understanding the tradeoffs and synergies between conserving biodiversity and ecosystems and attaining a broad range of sustainable development goals.

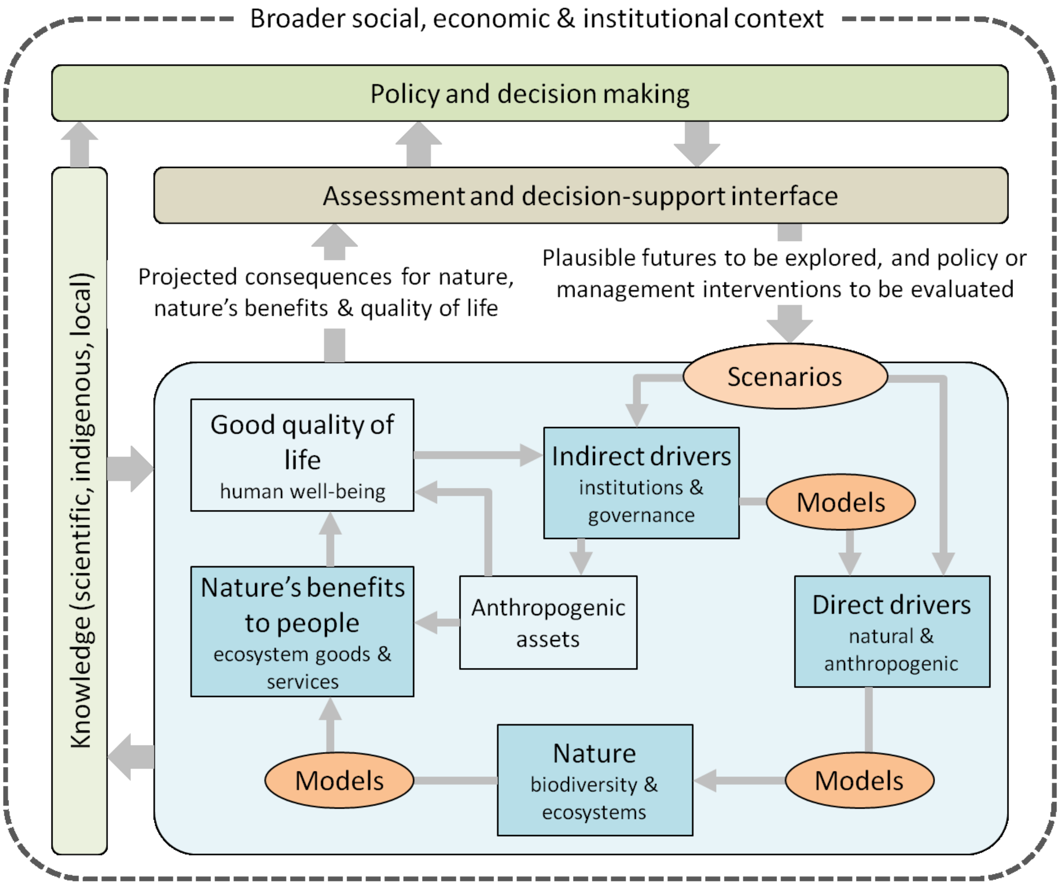


Figure 1.3.: High-level roles of scenarios and models in assessment and decision support. The rectangular boxes in the lower blue-shaded portion of the diagram represent key elements from the IPBES Conceptual Framework (see Figure 1.2).

All three types of modelling outlined above require, as input, information on the state of one element of the framework, which a model then uses to predict, or project, the state of another element. In the simplest case, models can be applied to observations (data) for the first of these two elements of interest. For example, spatially-explicit data on forest habitat loss obtained from remote sensing (satellite imagery) might be used to model the expected loss of species within this forest. Such application of models to observations can play an important role in assessing the present status of nature, or nature's benefits to people, and in assessing changes, or trends, in this status past-to-present (explored further in section 1.2.2 below).

However, policy and decision-making processes often also require looking beyond the present to the future. Questions raised in these processes might include: What is the risk of future loss of nature, or nature's benefits to people? How would alternative policy or management interventions alter this outcome? Using models to address questions relating to possible changes in the future, rather than to actual changes in the present or recent past, poses special challenges. In this situation observations of change (e.g. in drivers) are not available to use as inputs to models, because these changes are yet to occur. Furthermore there is often considerable uncertainty associated with the future trajectory of any given input variable, because this trajectory will be affected by events and decisions that have also not yet occurred, and are often unpredictable. Scenarios provide a useful means of dealing with the reality that not just one, but many, futures are possible. In policy and decision-making around nature, and nature's benefits, scenarios are most commonly used to address possible futures for indirect and/or direct drivers (Pereira *et al.* 2010; Cook *et al.* 2014).

Within this broad context scenarios can play two main roles, either separately or in combination. In the first of these roles, "explorative (or non-intervention) scenarios" (van Notten *et al.* 2003, van Vuuren *et al.* 2012; also sometimes referred to elsewhere as "descriptive scenarios") are used to explore a range of plausible futures reflecting different socio-economic assumptions, and/or uncertainties associated with key drivers, thereby informing agenda setting and high-level strategy development. In the second role, "policy (or intervention) scenarios" (*ibid*) for a driver of interest are aligned directly with possible policy or management interventions, and therefore represent choices that can be made within a given policy or decision-making process. This general class of scenarios encompasses two of the sub-classes discussed in Chapter 3 – i.e. "goal-seeking (or normative) scenarios" and forecasting scenarios underpinning "ex-ante assessments". Explorative scenarios may also be integrated with intervention scenarios in a decision-support context, as a means of addressing uncertainties associated with drivers that might affect the outcome of a given policy or decision-making process but are external to, and therefore not amenable to control or influence by, that process (Peterson *et al.* 2003). For example, in assessing intervention scenarios involving establishment of new protected-areas, modelling of outcomes for biodiversity expected from alternative reserve configurations should consider the effects of a plausible range of explorative climate scenarios, to address uncertainties in future climate impacts on biodiversity.

Scenarios and models play different, but highly complementary, roles in informing and supporting policy and decision-making (Figure 1.3). Scenarios are used to describe possible futures for drivers of change (indirect and/or direct), and options for altering the course of drivers through policy and management interventions. Models then enable scenarios of change in drivers to be translated into expected impacts on nature (biodiversity and ecosystems) and consequences for nature's benefits to people (including ecosystem services). As depicted in Figure 1.3, the interaction of policy and decision-making processes with scenarios and models will nearly always be mediated by some form of assessment or decision-support system or process, here referred to generically as an "interface". This interface manages the translation of high-level policy and decision-making needs into explicit scenarios for analysis by appropriate models and, in turn, interprets and communicates outputs from this modelling back to the world of policy and decision-making.

The effectiveness with which scenario analysis and modelling can inform policy and decision-making is very dependent on the relevance, quality, quantity and availability of data and knowledge (scientific, indigenous, and local) underpinning any scenarios and models employed. Modelling does not in any way remove, or diminish, the need for good data and knowledge. Modelling provides a means of extracting maximum value from best-available data and knowledge, but the quality of modelled outputs and the decisions they inform will always be constrained by the quality and quantity of underpinning information. The importance of linking any future application of scenario analysis and modelling by IPBES to ongoing efforts and initiatives around data collection and knowledge acquisition is addressed in depth by Chapters 7 and 8 of this report. The importance placed by IPBES on this issue is also reflected by the establishment of two key activities under the IPBES Work Programme: the Task Force on Knowledge and Data Generation; and the Task Force on Indigenous and Local Knowledge.

As depicted in Figure 1.3 any use of scenarios and models to inform policy and decision making will typically take place within a much broader, and often highly complex, social, economic and institutional context. Policy design and implementation will rarely, if ever, be driven by scenario analysis and modelling alone. It is therefore important to recognise from the outset of this assessment that guidance provided by scenarios and models will nearly always constitute just one of a number of inputs and considerations shaping policy and management decisions. In addition, the relationships between scenarios, modelling and decision-making are often more complex than Figure 1.3 depicts, and can involve highly dynamic interactions and feedbacks between scenario and model development, knowledge and data generation, and engagement with decision makers (see Chapter 8 for a more detailed discussion).

The following four subsections describe major components of the linked system depicted in Figure 1.3 in more detail, laying out the scope and main attributes of, and options for, each of these components, and highlighting important dependencies between them – starting with "policy and decision-making context", and then moving on to "assessment and decision-support interface", "scenarios", and "models".

1.2.2 Policy and decision-making context

What exactly is meant by "policy and decision-making"? The adoption of this term in Figure 1.3 follows its use in various other IPBES documents including, for example, documentation of the Conceptual Framework (Decision IPBES-2/4, http://www.ipbes.net/). However, policy and decision-making can encompass a very broad range of processes and activities conducted in a wide variety of contexts across multiple scales. A reasonable understanding of this diversity is required to better appreciate key differences in the needs of different policy and decision-making activities, and implications of these differences for the appropriateness of different approaches to assessment and decision-support, scenarios, and models, discussed in the following three subsections (Figure 1.4).

1.2.2.1 Roles of scenarios and models across phases of the policy cycle

Numerous frameworks have been proposed over recent decades for conceptualising phases or elements of the policy cycle, and similar frameworks have also been developed for describing adaptive planning or management cycles. There is considerable commonality between most of these frameworks, and this is reflected in the synthesised framework adopted recently by the IPBES Expert Group Developing a Catalogue of Policy Tools and Methodologies (Deliverable 4c; *cite document when available*), which contains three broad phases or elements: 1) agenda setting and review (evaluation); 2) policy design and decision-making; and 3) policy implementation (which is also referred to as “planning and management” in parts of this report, e.g. in Chapter 2). Scenario analysis and modelling can inform and support activities across all three of these elements.

Agenda setting and review

A sizeable proportion of previous efforts in scenario analysis and modelling of biodiversity and ecosystem services have been targeted at agenda setting – i.e. identifying and promoting the need for action to address detrimental changes in nature and nature’s benefits to people.
While this assessment is focused primarily on the integrated use of scenarios and models (in combination), and therefore on modelling change into the future, it is worth noting that modelling can, and does, play an important role in agenda setting even in the absence of scenarios. As indicated in section 1.2.1, models can be applied to observations (data) for input variables, rather than to future scenarios for these variables, thereby shedding valuable light on the present status of nature and its benefits, and on changes, or trends, in this status past-to-present (Leadley *et al.* 2014). Several elements of the IPBES conceptual framework align well with major categories of indicators within the widely adopted DPSIR (drivers-pressures-states-impacts/benefits-responses) approach to status-and-trend assessment (Feld *et al.* 2010; Sparks *et al.* 2011). Modelling can add considerable value to such assessments in two important ways.

Firstly, modelling can be used to help fill gaps in data needed to underpin key indicators. While ongoing data acquisition is clearly of vital importance (as reflected by the establishment of an IPBES Taskforce on Knowledge and Data) data are much easier and/or less costly to obtain for some elements of the IPBES conceptual framework than for others. For example, advances in remote sensing have now made it possible to track temporal changes in a number of direct drivers (pressures), including habitat conversion and climate change, at relatively fine spatial resolutions across extensive regions. On the other hand, most components of biodiversity, particularly at the species and genetic levels, are not detectable through remote sensing, and changes in their state can be observed only through direct field survey. Such data therefore tend to be sparsely and unevenly distributed across both space and time. Modelling offers a cost-effective means of filling gaps in this coverage by using remotely sensed, and therefore geographically complete, information on drivers to estimate changes in the state of biodiversity (past to present) expected across unsurveyed areas (Ferrier 2011). Using modelling to fill gaps in information can play an equally valuable role in assessing status and trends in nature's benefits to people – e.g. by estimating changes in the supply of ecosystem services from remotely-sensed land cover classes and structural or functional ecosystem attributes (biomass, net primary production, etc.) (Tallis *et al.* 2012; Andrew *et al.* 2014).

Secondly, modelling can provide a process-based alternative to the use of composite indicators in integrating multiple pressure-state-response indicators. Applications of the DPSIR framework typically generate large numbers of indicators (Butchart *et al.* 2010; Sparks *et al.* 2011), distinguished not only by their focus on different high-level components of this framework (e.g. pressure indicators versus state indicators versus response indicators) but also by differences in the focus of indicators within each component – e.g. indicators of habitat-conversion pressures versus species-introduction pressures; or indicators of habitat-protection (reservation) responses versus introduced-species-control responses. To provide a better sense of the overall status of, and trends in, the condition or "health" of the system as a whole these individual indicators are sometimes aggregated to produce one, or a small number of, composite indicators or indices (e.g. Halpern *et al.* 2012). While aggregation will often be most readily achieved through simple summation or multiplication (Butchart *et al.* 2010), this may fail to adequately address the often complex, non-linear nature of interactions between multiple pressure, state and response elements in real-world systems. Modelling offers an alternative means of integrating data, and indicators, describing past-to-present changes across multiple system elements, and thereby better accounting for complexities and dynamics in these interactions (Vackar *et al.* 2012; Pereira *et al.* 2013; Tett *et al.* 2013).

As just described, applications of modelling to actual observations can play an important role in agenda setting by providing information on the present status of nature, and nature's benefits to people, and on trends in this status past-to-present. Linking models to scenarios builds on this role by extending the focus of assessment from changes that are known to have already occurred past-to-present, to changes that might occur into the future. Using explorative scenarios (introduced in section 1.2.1) to project possible changes beyond the present provides a powerful means of assessing future risks to nature and its benefits, and therefore the need for action (Pereira *et al.* 2010; Cook *et al.* 2014). If the range of explorative scenarios considered in a given process is sufficiently broad, and scenarios are formulated with sufficient care, then the role played in agenda setting may extend beyond simply identifying the need for action, to also shedding light on the potential effectiveness and feasibility of broad options for policy intervention. By additionally incorporating outcomes from previous policy design and implementation decisions (see next subsection), this same general form of scenario analysis can be used to inform the review of implemented policies (i.e. "ex-post assessment", as discussed in Chapter 3).

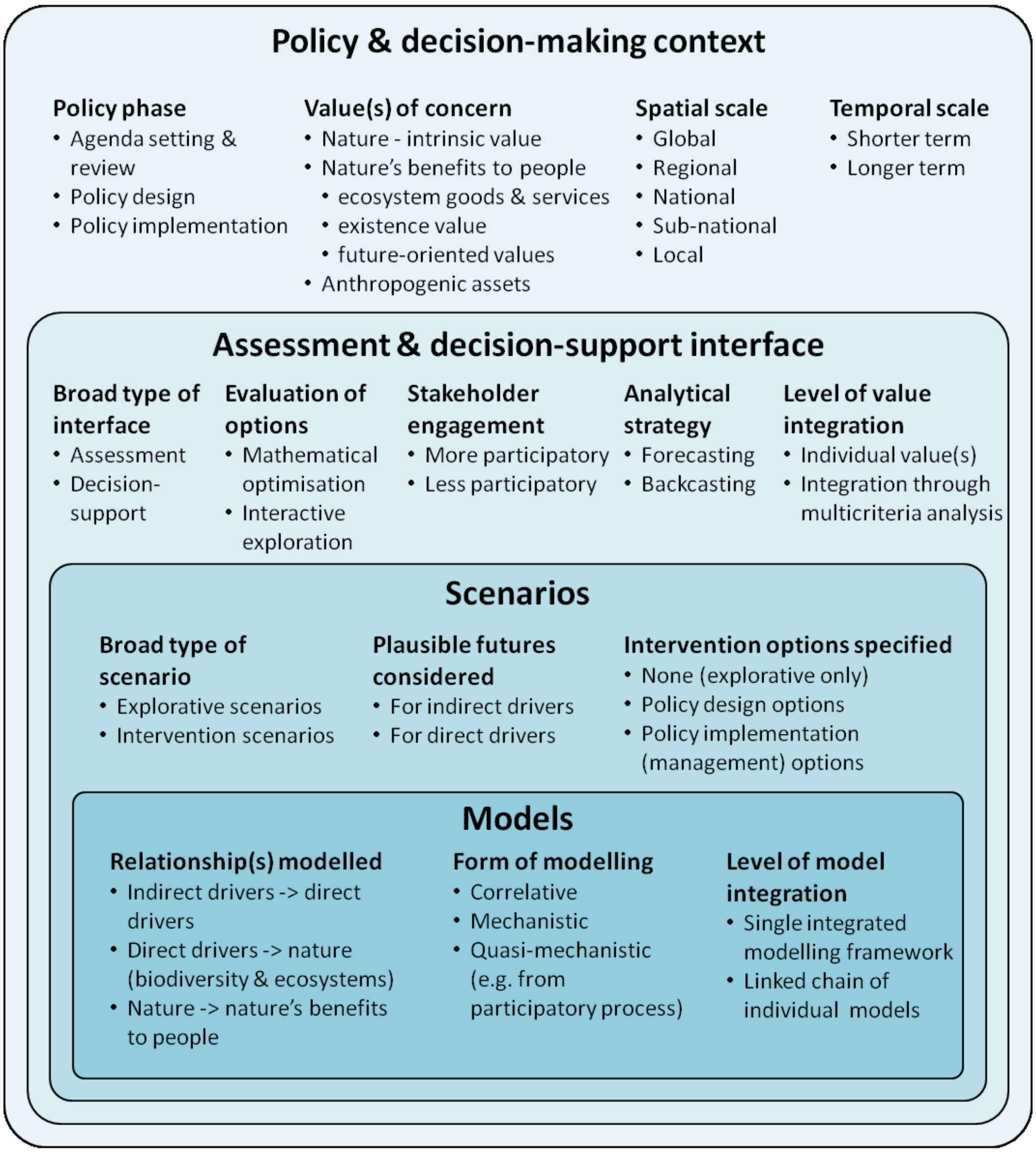


Figure 1.4.: Key attributes of, and options for, four major components of the linked system depicted in Figure 1.3 – policy & decision-making context, assessment & decision-support interface, scenarios, and models.

Policy design and implementation

Moving from assessing the need for action in agenda setting, to actual decision-making around specific actions in policy design and implementation, shifts the focus of scenario analysis and modelling from explorative scenarios to intervention scenarios (introduced in section 1.2.1; see case studies in Boxes 1.2 and 1.3). Intervention scenarios can play a role in both policy design and policy implementation, and these are therefore considered together here. While the boundary between policy design and implementation is often rather fuzzy, the requirements for intervention scenarios at either ends of this spectrum can be quite different, especially in terms of the level of specificity, and spatial explicitness, with which potential actions are defined. This is particularly the case for policies allowing choice in the location of actions implemented under these policies – e.g. establishment of new protected areas to meet a high-level percentage-reservation target, or allocation of funding under various economic instruments (e.g. an environmental stewardship scheme). In such situations, lower-level decisions made during the implementation of a high-level policy can have significant implications for the effectiveness of the outcome actually achieved by that policy – not just in biophysical terms, but also in terms of implementation costs, and socio-economic consequences for people affected by these decisions. For example, in relation to the above cases, decision-making around the precise location of new protected areas, or funded stewardship actions, may require spatially-explicit intervention scenarios at a much finer spatial resolution than those needed to inform the initial design of these high-level policies.

1.2.2.2 Diversity in scope of policy and decision-making processes: values and spatial/temporal scales

Activities relating to all three policy-cycle elements discussed in the previous subsection can occur at a wide range of spatial scales – global, regional, national, sub-national and local. The spatial extent and resolution of scenarios and models employed in any given policy or decision-making process must therefore be aligned carefully with the scale of interest for that process. Policy and decision-making processes can also address quite different temporal scales of concern – ranging from processes focused on short-term outcomes (changes made over a few years) through to those focused on achieving longer-term change (e.g. over several decades) – which again has clear implications for the temporal scale of any scenarios and models employed.

The focus placed on different values associated with nature, or nature's benefits to people, can also vary markedly across policy and decision-making processes – e.g. intrinsic values associated with different levels or dimensions of biodiversity and ecosystem properties and processes, or utilitarian values associated with different types of ecosystem goods and services (see IPBES Conceptual Framework; Diaz *et al.* 2015). Many of these processes – particularly those based in domains or sectors not focused primarily, or exclusively, on biodiversity and ecosystem services – will also involve consideration of a broader range of environmental, social and economic values (including anthropogenic assets, as depicted in Figures 1.2 and 1.3).

1.2.3 Assessment and decision-support interface

The application of scenario analysis and modelling to policy and decision-making is usually mediated by an interface of some form – i.e. a process, or system, that manages the translation of policy and decision-making needs into explicit scenarios for analysis by models and, in turn, interprets and communicates outputs from this modelling back to policy and decision-making (Figure 1.3). This interface should also ideally be set up to communicate, and help users to interpret the implications of, levels of uncertainty associated with projections from scenarios and models. The form and complexity of the interface needed for any given application depends very much on the precise nature of the policy or decision-making process being served, and particularly on the phase of the policy cycle being addressed (from section 1.2.2 above). For processes focused on agenda setting, this interface needs simply to take care of selecting and formulating any explorative scenarios to be assessed, analysing these scenarios using an appropriate set of models, and reporting results from these analyses in terms of projected outcomes for nature, or nature's benefits to people. The interface employed in such situations will often take the form of an "assessment", typically communicating results in technical reports and/or published papers. The Regional (and subsequent

Global) Assessments of Biodiversity and Ecosystem Services being planned by IPBES are likely to take this form.

A rather different type of interface may be needed to manage the application of intervention scenarios to actual policy design and implementation (as opposed to agenda setting), requiring a shift from relatively static assessment to more dynamic, and interactive, “decision support” (see Chapter 2). This is because the number of potential options for intervention can be very large, particularly within the policy-implementation phase – e.g. picking up on the examples from section 1.2.2.1, a large number of possible configurations of protected areas, or of funded stewardship actions. If all possible options of interest are known at the outset of a decision-making process then various forms of mathematical (computer-based) optimisation might be used to automate the search for a ‘best-solution’ intervention, or set of interventions, based on modelling of the consequences of these for nature, or nature’s benefits to people (Williams & Johnson 2013).

However, many policy design and implementation processes – especially at lower (more local) levels of decision-making – require consideration of intervention options that are not necessarily known in advance, but instead arise dynamically from interactions and negotiations within the process itself. This means that intervention scenarios must be formulated, and analysed, progressively throughout the decision-making process. Searching for, and reaching agreement on, effective policy or management interventions in such situations becomes more a process of interactive trial-and-error, involving adaptive evaluation and modification of intervention scenarios informed by feedback on the modelled consequences of these options. Growing recognition of this need for more interactive, and inclusive, involvement of decision-makers and stakeholders in the formulation and evaluation of intervention scenarios is reflected in the recent proliferation of planning approaches, both qualitative and quantitative, based around “participatory scenarios” (Walz *et al.* 2007; Sandker *et al.* 2010; Priess & Hauck 2014).

The basic idea of using models to evaluate consequences of intervention scenarios, as a foundation for decision-making, is already well established within several existing methodological paradigms or frameworks including, for example: “structured decision making” (Addison *et al.* 2013), “management strategy evaluation” (Fulton *et al.* 2014), “scenario planning” (Peterson *et al.* 2003), and “strategic foresight” (Cook *et al.* 2014) (see Chapter 2 for a comprehensive review of such approaches). Tools associated with these, and related, paradigms are often called upon to fulfil the role of decision-support interface depicted in Figure 1.3.

An important issue when considering alternative approaches to formulating and evaluating intervention scenarios for decision-support is the distinction between forecasting and backcasting strategies (Dreborg 1996; van Vuuren *et al.* 2012). In a forecasting strategy, scenarios are formulated and modelled for each of the intervention options being considered, and these are then evaluated and compared in terms of the relative change achieved for some aspect of nature or its benefits (referred to as “ex-ante assessment” in Chapter 3). A backcasting strategy instead first defines an end-point or goal that must be achieved – e.g. a desired level of change in nature or its benefits – and then searches for one or more intervention scenarios that fulfil this goal (referred to as “goal seeking (or normative) scenarios" in Chapter 3; see case study in Box 1.1). Both strategies can be applied either using some form of mathematical optimisation, or through more interactive, participatory engagement. This distinction between forecasting and backcasting has strong parallels with the well-established use of "maximum coverage" versus "minimum set" strategies in systematic conservation planning (Kukkala & Moilanen 2013) – where a maximum-coverage strategy searches for protected-area configurations that maximise the level of biodiversity conservation achieved given a fixed budget, while a minimum-set strategy searches for configurations that achieve a fixed conservation goal, or set of goals (end-points), at minimal cost.

A final important characteristic of some methodologies operating within the "assessment and decision-support interface" (Figure 1.3) is the ability to aggregate, and thereby synthesise, results from modelling of different values, through various forms of multi-criteria analysis (Arhonditsis *et al.* 2002). Both explorative scenarios employed in agenda setting, and intervention scenarios employed in policy design and implementation, are often evaluated using multiple models dealing with different values associated with nature (e.g. multiple biodiversity or ecosystem attributes), or nature's benefits to people (e.g. multiple ecosystem services). As mentioned in section 1.2.1, these same scenarios may also be evaluated using models focused on anthropogenic assets (built, human, social, and financial) that are not mediated by changes in biodiversity or ecosystems. Multi-criteria analysis can play a crucial role in aggregating modelled outcomes across different values into composite indices of quality of life (human wellbeing) (Ding & Nunes 2014), particularly if this analysis is well integrated with other rigorous assessment and decision-support methodologies such as those described above.

1.2.4 Scenarios

The IPBES emphasizes the importance of scenario analyses for decision making and notes that *"…Scenarios of future socioeconomic development and models of the impacts of these development pathways are key elements of nearly all environmental assessments…. scenarios and projections of future trends are crucial for anticipating future changes in biodiversity and ecosystem services and for developing proactive strategies to minimize future degradation of, or restore, biodiversity and ecosystem service"* (IPBES 2/3,p.10,12). Scenarios provide a means of depicting or visualizing plausible futures under alternative contexts, assumptions, risks and opportunities, and policy interventions/management options. Scenarios aim to foresee various pathways of changes in indirect and direct drivers so that impacts on nature and nature's benefits can be evaluated. Comparisons of alternative scenarios can then be used to guide and formulate policies such as increasing protected areas, reducing fossil fuel use or pollution, establishing hunting or fishing restrictions, regulating the use of natural resources, etc. Scenarios, in the sense that is used throughout this document, include changes in indirect drivers such as human population, per capita use of energy and development of infrastructure, and changes in direct drivers such as climate change, land use change, pollution or fishing pressure.

Scenarios are often used to capture complexity, understand uncertainties, to assess interactions of drivers of change, or to test alternative development trajectories (Priess and Hauck, 2014). There are varying definitions of 'scenarios' but on one point there is consensus – scenarios are not predictions of the future (van der Heijden et al, 2002). The EEA (2009) defines a scenario as a consistent and plausible picture of a possible future reality that informs the main issues of a policy debate. The IPCC describes scenarios as "a coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future can unfold" (IPCC 2014). Scenario development emerged following World War II in US military strategic planning with the RAND Corporation. Scenarios achieved prominence in the 1970s in speculation about the future of society, the economy and the environment (van Notten, 2005). Today scenarios are used in a wide range of contexts by small, medium and large enterprises; in regional, national foresight studies; and in environmental assessments for public policy for example the UNEP's Global Environmental Outlook, CBD's Global Biodiversity Outlooks , OECD's Environmental Outlook to 2050, UK's National Ecosystem Assessment (van Notten, 2005; Bateman et al, 2014).

As introduced in Section 1.2.1, it is useful to distinguish between two broad classes of scenarios (van Vuuren *et al.* 2012) – "explorative scenarios" and "intervention scenarios". Each of these can be implemented using a variety of methodologies, effectively yielding a larger number of sub-classes of scenario types. For explorative scenarios, the most widely used approach has been to develop "plausible futures" involving the building of narratives or storylines of socio-economic and environmental pathways including assumptions regarding, for example, technological development (Pereira et al, 2010). Thus these storylines are the backbones of the scenarios (Spangenberg et al, 2012). They are the qualitative component, defining philosophies, policies and instruments, which is then complemented by a quantitative component (Spangenberg et al, 2012). Examples of this general approach are the SRES and RCP scenarios of IPCC, the Millennium Ecosystem Assessment scenarios and the scenarios developed in GEO. Sparrow (2000) argues that planners advising decision makers should interpret such scenarios as more exploratory so that a scenario is less a strategy and more a coherently structured speculation (cited in van Notten, 2005). Recently scenarios that are highly quantitative, including those based on econometric analyses, have gained prominence (Pereira et al, 2010).

In recent years, the plausible-futures approach has been increasingly complemented by alternative approaches to the development of explorative scenarios, for example: "statistical extrapolation" into the future of past observed trends in the state of biodiversity and ecosystems (e.g. Tittensor et al 2014); and "probabilistic scenarios", employing similar process-based models to those employed in modelling plausible futures, but using inputs drawn from probability distributions for each parameter based on best-available empirical data or expert knowledge, in place of discrete "plausible" combinations of parameter values, thereby allowing probabilities to be attached to resulting projections (e.g. Abt Associates 2012).

As discussed in Section 1.2.3, intervention scenarios can be developed and applied in either a "forecasting" or a "backcasting" mode (van Vuuren *et al.* 2012). An example of the back-casting approach is the analysis developed for the Rio+20 conference, described in Box 1.1 (PBL, 2012). Examples of forecasting are the analyses of policy options presented in Boxes 1.2 and 1.3.

Scenarios can be developed in either a top-down or bottom-up manner – where, once scenarios are developed at a higher scale, these are then used as a guide to develop the scenarios at lower scales (say, from global to regional and national scales) or vice versa where after developing scenarios at lower scales these are aggregated to higher scales. An example of scaling down is the application of UNEP's GEO scenarios developed at the global scale to regional GEOs published for Latin America and the Caribbean, Africa and West Asia (van Vuuren et al, 2012). The challenge of scaling down is that drivers or factors that may be relevant at, say, a global scale may not be that important at lower scales and vice versa. Another approach is the inclusive approach where participatory methods and scenarios are developed in consultation with stakeholders and users/decision makers. No approach can be considered as superior to the other, so the choice of which approach to adopt for scenario development depends on the objectives of the scenario analysis and the needs and preferences of the users or decision makers.

The scenario development process involves a number of stages, which include: consulting stakeholders, users and decision makers; exploiting and improving the knowledge base for developing scenarios; and evaluating their credibility and validity through peer reviews. Scenario development should reflect the beliefs and understanding that different groups in society hold with regard to, for example: a) trends in biodiversity; b) likely changes in drivers and pressures impacting biodiversity; and c) likely implications of changes in biodiversity for the provision of ecosystem services in specific places. Most importantly, if scenario building is performed by those people who actually make or influence decisions benefiting biodiversity, the likelihood that these benefits will be realised through decision-making is much higher. Similarly, the accuracy of models is likely to be enhanced if different groups of stakeholders build scenarios together, thereby facilitating cross-sectorial discussion and learning. Once the contours of the scenarios are set and mapped, drivers are selected and interactions between drivers are analyzed. The consequences of these social, economic, and cultural developments, along with relevant data and other additional information, can be analyzed by using models to project and estimate the values of the variables under study. Scenario analysis and models can enable governments and societies to anticipate future events (e.g. global warming, loss of biodiversity/species) and the driving forces behind them (e.g. fossil fuel use, habitat loss, land use changes or pollution) and take remedial measures or proactive policies (e.g. reducing fossil fuel use, increasing protected area coverage, conservation programs for species under threat of extinction) in anticipation of these environmental challenges.

1.2.5 Models

This section first provides a general overview of the elements of scientific models, then broadly outlines the different types of models that are most commonly used for assessing the impacts of direct and indirect drivers on nature and nature's benefits and finishes with comments on the importance of the use of multiple types of models in IPBES activities.

1.2.5.1 What is a model?

There are various broad definitions of scientific models, such as:

- "an approximation or simulation of a real system that omits all but the most essential variables of the system" (http://www.yourdictionary.com/scientific-model) ; or

- "a schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics: a model of generative grammar; a model of an atom; an economic model" (http://www.thefreedictionary.com/model).

These definitions indicate that a scientific model is codified (for example, translated into mathematical equations) and that it contains 1) *variables* that can take on a range of values or states and 2) *relationships* between the variables (from Ritchey, 2012). This implies that a model provides a simplified description of a real system by establishing relationships between the most essential variables of that system. Models play an important role in all fields of science because they cumulate and summarize knowledge, and improve the consistency and repeatability of analyses. A scientific model aims to address specific questions about the when (temporal), where (spatial), what (pattern) or processes of real world phenomena (Borner et al., 2012). It is essential to relate these key questions and model outputs to policy and decision-making processes of IPBES.

Models of a specific system differ in the choice of essential variables and relationships, properties of the variables they describe, and the way relationships are described. Relevant properties for models are the type of variables used, the types of relationships described, and how these relationships are described.

Variable types can include variables with or without specified value ranges. Value ranges may include continuous variables (e.g., biomass of plants), discrete ordered variables (e.g., numbers of individuals) or categorical values (e.g. grassland, forest, urban). The types of relationships include quantitative (e.g., y = ax + b; describing a straight-line relationship) vs. qualitative (e.g., when x increases, so does y); dynamic (i.e., accounts for dynamics over time) vs. static; and spatial vs. non-spatial relationships. The way the relationships are established include 1) mathematical or functional relationships based on established scientific understanding and mathematical formulation of relevant underlying processes (e.g. meta-population modelling; Gordon et al., 2012), or mechanistic models of ecosystem function (e.g. Harfoot *et al.* 2014b); 2) correlative (statistical) or probabilistic models based on analyses of available empirical data (e.g. species distribution modelling, Elith and Leathwick, 2009; and 3) 'quasi' causal methods, using expert knowledge to capture and represent stakeholder knowledge , e.g. using participatory techniques (Priess and Hauck, 2014; Walz *et al.* 2007) and Bayesian Belief Networks (Haines Young, 2011). As described in detail in Chapters 3-5, the choice of modelling approach has a large influence on model construction, testing and use. For example, models of biodiversity in the scientific literature are dominated by quantitative approaches, but these may have difficulty in incorporating expert or indigenous and local knowledge compared to qualitative approaches (Chapters 3 & 7).

1.2.5.2 Types of models that may be used in IPBES activities

The models that can be used by IPBES fall into three broad categories (see Figure 1.3.):

- Models projecting changes in direct drivers of biodiversity and ecosystems (e.g., land use change, fishing pressure, climate change, invasive alien species, nitrogen deposition) as a function of changes in indirect drivers. In some cases, these changes in direct drivers are provided by existing scenarios rather than being modelled, see chapter 3;

- Models assessing the impacts of drivers on biodiversity and ecosystems (e.g., species extinctions, changes in species abundance and shifts in ranges of species, species groups or biomes), see chapter 4; and
- Models assessing the impacts of drivers, and changes in biodiversity and ecosystems, on ecosystem services and their associated values (e.g., flood control, ecosystem carbon storage, cultural values) see chapter 5.

Figure 1.5. shows examples of the variables and relationships between them that are accounted for in models that may be used by IPBES in its various activities. This figure illustrates a number of key points about the current state of models. Chapters 3-5 provide more detailed and comprehensive typologies of these categories of models, as well as recommendations for addressing key gaps.

A tremendous variety of variables are simulated by models of nature and nature's benefits. In some studies only a single variable is simulated. For example, empirical species distribution models are often used to predict the spatially-explicit response of just one variable, i.e. species presence or absence, to environmental change. In many other cases, models predict several variables, but typically only a small subset of the variables listed in Figure 1.5. For example, biodiversity models simulate dynamics of genes, or species, or functional groups, or communities; but many focus on only one of these levels and none simulate biodiversity dynamics at and between all these levels.

In practice, relationships between variables linking the three main components of nature and nature's benefits differ greatly in the frequency and detail with which they are treated in the scientific literature and assessments (Figure 1.5.). For example, models of ecosystem function, especially at large spatial scales, typically represent biodiversity using a small number of groups of species that have similar characteristics (i.e., functional groups). A few models of ecosystem function use species level variables, but very few incorporate variables related to genetic adaptation (but see Kramer et al. 2010). Models of nature's benefits typically rely on empirical relationships between habitat type and ecosystem services (arrow directly from habitat), or use inputs from variables simulated by models of ecosystem function, but few account for the contribution of species diversity to ecosystem function (Cardinale et al. 2012, but note that some models do account for a small set of key species interactions).

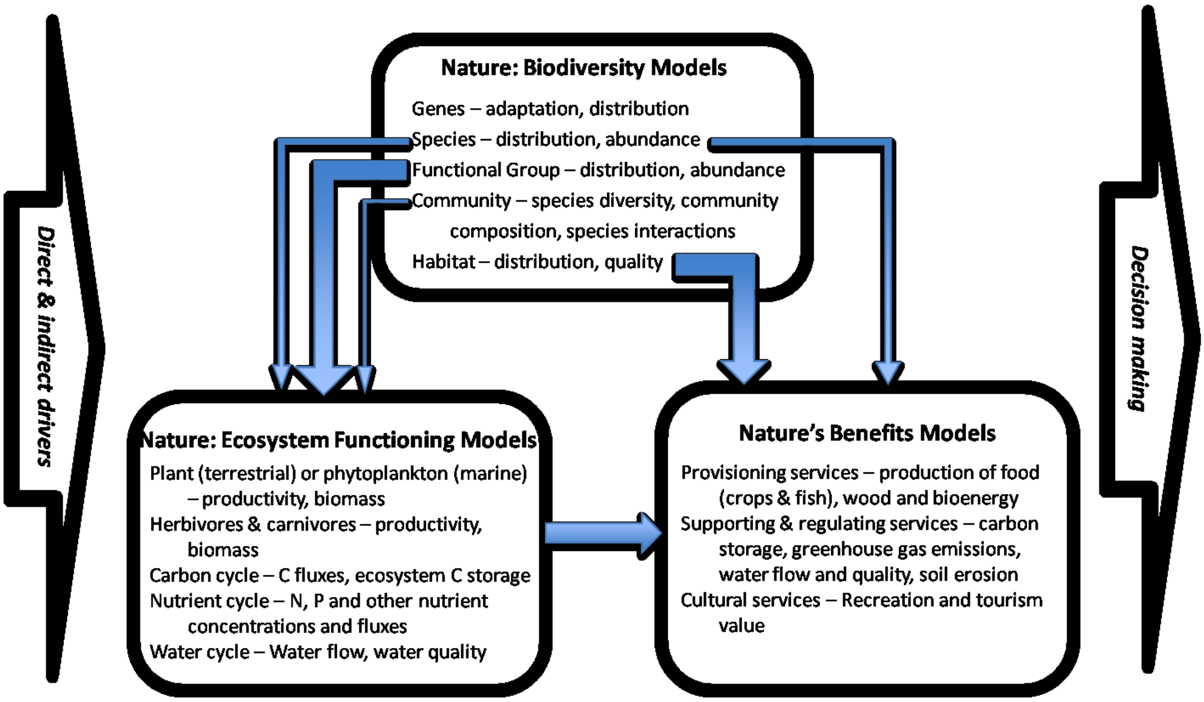


Figure 1.5.: Variables commonly simulated by models of impacts of drivers on the three main components of Nature and Nature's benefits (boxes). Relationships between variables that are found in models are indicated by blue arrows. The thickness of the arrows indicates the frequency with which variables are connected in the most commonly used modelling approaches.

Two important types of models not illustrated in this figure are: models that are used in developing scenarios of indirect drivers; and models that address the relationships between indirect drivers and direct drivers. Both of these model types are often developed for a wide range of purposes that are not expressly intended for use in modelling nature or nature's benefits. Examples of models used for developing scenarios of indirect drivers include human demographic models, governance models, economic models and agent-based models describing behaviour of social systems. Examples of models relating indirect to direct drivers include models that project changes in climate, ocean environment, land use changes and hydrology based on indirect drivers such as economics, demographics and management. Chapter 3 provides an overview of these types of models and the implications of model choice.

Policy and decision-making can be supported by models in the various parts of the policy cycle: agenda setting, exploring policy options (ex-ante assessment), evaluating the effectiveness of policies (ex-post assessment), and in policy implementation, for example in spatial planning. These applications sometimes involve the full range of modelling steps from indirect driver - direct drivers – impacts on biodiversity and ecosystem services and their implications for human well being. Linking models together is one means of increasing the number of system components and relationships that can be considered simultaneously. The modelling steps may be integrated in a single modelling framework (e.g., Integrated Assessment Models; Stehfest et al. 2014) or realized in a chain of linked models where the input for one model is derived from the output of another model (e.g., Bateman et al. 2013, Nelson et al. 2009). Great care needs to be taken when linking models to take into account for propagation of error, consistency of variables, differences in spatial and temporal resolution, and costs and benefits of increasing complexity (see Chapter 6). Integrated Assessment Models (IAMs) are widely used in global and regional assessment activities. While these models usually account for at least some ecosystem functions and services, they often exclude key ecosystem functions and omit cultural services, and generally lack representation of biodiversity below the functional group or habitat type level (Harfoot et al. 2014a, but see Alkemade et al. 2009 for examples of including species diversity in global ecosystem models). Bio-economic models also integrate several of the modelling steps, but are substantially less complex than IAMs (Swallow & Swallow 2015)

1.2.5.3 Selecting types of models for a given purpose

The questions posed in a policy or decision-making process are a key factor in determining the types of modelling approaches that are the most appropriate. Other key factors include the availability of data (see chapter 8) and the capacity to develop and use models (see chapter 7). If a model is to be used mainly for agenda setting, then explaining the main relationships in a conceptual manner using qualitative, expert-based, models may be sufficient. If models are to be used to explore effects of human behaviour on potential policies it might be sufficient to employ semi-quantitative causal models. However if models are used for ex-ante or ex-post evaluation of policies, then quantitative, spatial explicit models may be needed. Models that are used for specific policy implementations where large economic interests are involved may need to be particularly precise and quantitative.

For a given question, a variety of modelling approaches may be available. The position taken throughout this methodological assessment is that there is usually no *a priori* single best modelling approach for a given question. In particular, debates about the use of models working with correlative vs. mechanistic vs. 'quasi'-casual relationships are frequently polluted by misconceptions about the usefulness of these various types of models. Many modelling exercises have clearly illustrated the benefits of examining multiple model types in terms of understanding of underlying processes, improving the ability to simulate biodiversity and ecosystem functions, providing complementary sets of variables and estimating uncertainty (Cheaib et al. 2010, Gritti et al. 2013, van Oijen et al. 2013). The use of multiple models does not necessarily require quantitative comparisons among models. However, in some cases IPBES may want to stimulate work on quantitative multi-model comparisons since, as the IPCC has amply demonstrated for climate models and some models of impacts on ecosystems (IPCC 2014a), these often have much more weight in decision making than individual models. This does not mean that all models are equally good. As such, the models need to be thoroughly tested with data and an evaluation of the strengths and weaknesses of models should be included when presenting model outcomes. The following chapters provide more specific guidelines for model selection, and for evaluation of model strengths and weaknesses.

For the global and regional assessments as envisioned in the IPBES work programme, various modelling approaches can be applied. For example in previous global assessments combinations of quantitative, dynamic and spatial models were used to explore socio-economic scenarios (e.g. UNEP GEO4 20, MA 2005, SCBD GBO4 2014). In addition, qualitative models were used to explore and suggest policy responses.

It should be noted that all models have limitations and no model can perfectly explain or predict observed dynamics of nature or nature's benefits. This is an unavoidable outcome of many factors, including: lack of knowledge about key variables and relationships; loss of information when simplifying complex real world systems to models; uncertainty in estimating the values of parameters and variables; and error propagation, especially within complex models.

1.2.6 Case studies

Three contrasting case studies are presented in the Boxes 1.1 to 1.3, illustrating how scenarios and models have been combined to address real-world assessment and decision-support needs at different scales and in different policy contexts. The first of these (Box 1.1) involves the use of backcasting scenarios, combined with modelling of mean species abundance, to assess development pathways for achieving global sustainability goals. The second study (Box 1.2) was implemented at watershed scale in Thailand and evaluates the consequences of alternative land-use scenarios for the provision of ecosystem services, through modelling of impacts on water yield and sediment load. The third study (Box 1.3), implemented at national scale in South America, models impacts of alternative road infrastructure projects on deforestation rates and associated greenhouse gas emissions.

Box 1.1: Case study – Rio+20 scenarios

Project Title	Rio+20 scenarios
Type of value	**Global terrestrial and aquatic biodiversity**
Driver	**Human pressures**
Temporal extent	**Current to 2050**
Spatial extent	**Global**
Model use	**IMAGE, GLOBIO3**
Client	**CBD, National governments**

Multiple challenges, multiple targets

In 1992, governments worldwide agreed to work towards a more sustainable development that would eradicate poverty, halt climate change and conserve ecosystems. Although progress has been made in some areas, actions have not been able to alter the trends in other critical areas of sustainable development, such as providing access to sufficient food and modern forms of energy, preventing dangerous climate change, conserving biodiversity and controlling air pollution. Without additional effort, these sustainability objectives also will not be achieved by 2050.

Different pathways towards the targets

To jointly reach the long term targets on human well-being (eradicating hunger and ensuring full access to modern energy sources), climate change (temperature rising less than 2 °C) and biodiversity conservation (no further loss by 2050), three scenarios were developed. The long term targets for sustainability were the objective set for 2050 in these backcasting scenarios (van Vuuren et al., 2012, see). Three types of scenario were defined based on different strategies of sustainable development as follows (PBL, 2012):

- ***Global Technology***: focus on large-scale technologically optimal solutions, such as intensive agriculture and a high level of international coordination; for instance, though trade liberalization
- ***Decentralized Solutions***: focus on decentralized solutions, such as local energy production, agriculture that is interwoven with natural corridors and national policies that regulate equitable access to food
- ***Consumption Change:*** focus on changes in human consumption patterns, most notably by limiting meat intake per capita, by ambitious efforts to reduce waste in the agricultural production chain and through the choice of a less energy-intensive lifestyle

These pathways towards the 2050 targets use different mixtures of policies to enhance productivity and reduce biodiversity loss (Figure Box 1.1), as well as different mixtures to enhance the use of modern energy and reducing climate change.

Models

The scenarios were evaluated up to 2050 using the IMAGE modeling framework (Stehfest et al., 2014) combined with the GLOBIO3 model (Alkemade et al., 2009). IMAGE is an integrated assessment model of global environmental change, and enables assessment of the impacts of socio-economic development on the environment, including land use, climate and water flow and pollution. GLOBIO3 is linked to IMAGE and calculates the impacts of environmental changes on some biodiversity indicators by using cause-effect relationships.

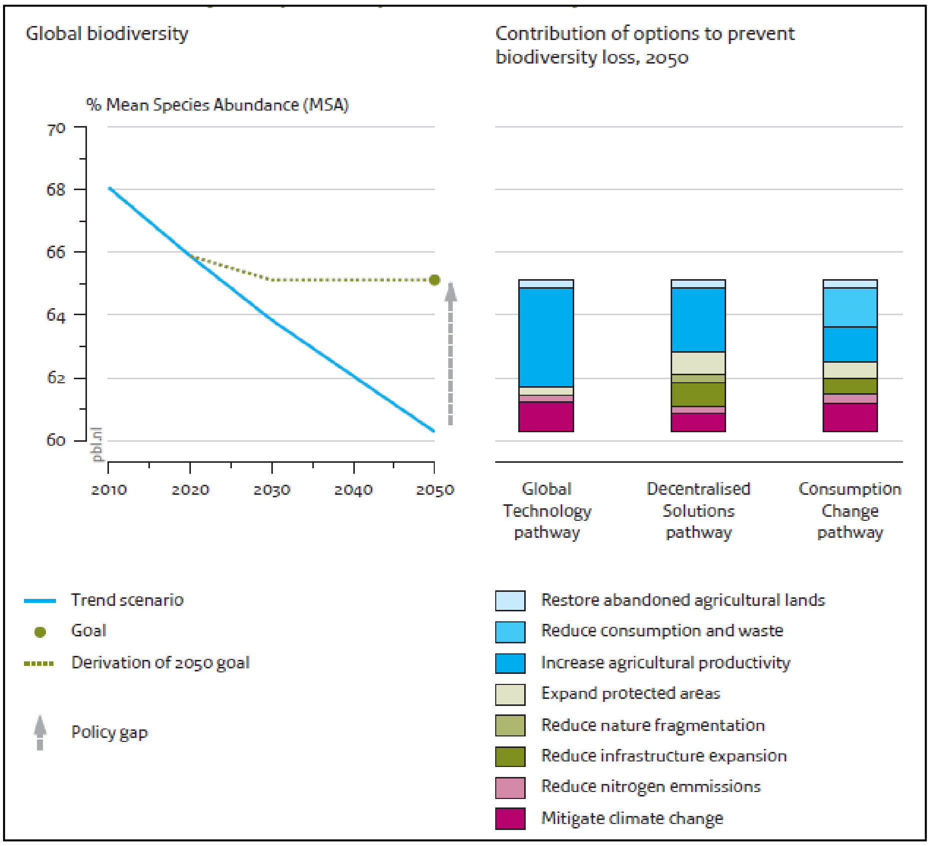


Figure Box 1.1.: The left-hand graph indicates the response of biodiversity (as measured by Mean Species Abundance) of a business-as-usual development pathway ("Trend") and the pathways (green dotted line) that achieves a stabilization of biodiversity at the global scale by 2050 (green dot). The right-hand graph indicates the contributions of different components of the three biodiversity stabilization pathways "Policy gap" refer to the challenge for policy makers to achieve the goal (PBL, 2012).

The results of scenario analyses show that different combinations of policy actions, grouped in the three scenarios, may lead to achieving the sustainability targets of eradicating hunger and maintaining a stable and sufficient food supply, and ensuring the access to modern energy sources; conservation of biodiversity; and to limit global climate change and air pollution. So these quantitatively coherent scenarios indicate that eradicating hunger as well as providing full access to modern energy, on the one hand, and achieving environmental sustainability, on the other, is possible. However, marginal improvements will not suffice; large, transformative changes are needed to realize sustainable development.

The role of the Rio+20 scenarios in policy support

Initially a contribution to the Rio+20 conference held in Rio de Janeiro in 2012, the scenarios and their main messages were taken up in the 4th Global Biodiversity Outlook or GBO4 (SCBD, 2014). The parties to the CBD adopted the conclusions of the GBO4, and committed to step up actions to achieve the Aichi Biodiversity targets, including a pledge by national governments to double funding for necessary actions (CBD, 2014a). Additional initiatives were launched to enhance the biodiversity perspective in sustainable commodity production (CBD, 2014b). The outcomes from the scenario analyses provided underlying arguments for these decisions and initiatives.

Box 1.2: Case study – Thadee watershed, Thailand

Project Title	Thadee watershed, Thailand
Type of value	**Watershed services**
Driver	**Land-use change**
Temporal extent	**2009-2020**
Spatial extent	**Catchment (112 km2)**
Model use	**CLUEs, InVEST, RIOS**
Client	**Local stakeholders, local government**

The Thadee watershed located in southern Thailand covers approximately 112 km^2. Water supply from the watershed is mainly used for agriculture by upstream farmers and household consumption by downstream people in the Nakhon Srithammarat municipality. However, natural forests in the watershed have been degraded and transformed to monocultures (fruit trees and rubber plantations) due to a governmental subsidy program. The ECO-BEST project co-funded by the EU, German Government (GIZ) and Thailand (Department of National Parks, Wildlife and Plant Conservation and Kasetsart University) worked with scientists to quantify water yield and sediment load according to different land use and rainfall scenarios during 2009-2020 (Trisurat, 2013). The conversion of land use and its effects (CLUE-s) model (Verburg and Overmars, 2009) was used to allocate future land demands based on three scenarios – trend, agriculture development and conservation. In addition, InVEST (Nelson et al., 2009) and universal soil loss equation (USLE) models were employed to estimate water yield and soil erosion, respectively. The modeling results clearly showed that intensifying land use change due to rapid expansion of rubber plantation and extreme rainfall will generate a high risk of major sediment loadings and overland water-flows due to the force of rainfall and decreased evapotranspiration from vegetation. With the application of an economic model "Resource Investment Optimization System" (RIOS, Vogl et al., 2013), the project team together with stakeholders could identify which conservation activities (e.g., protection, reforestation and promotion of mixed-cropping system) should be implemented, and where, to yield the highest return on investments and to enhance watershed services. The municipality has agreed in principle to find the best practical mechanism for collecting payments from tap water clients and downstream, so called "payment for watershed services", to implement the above activities.

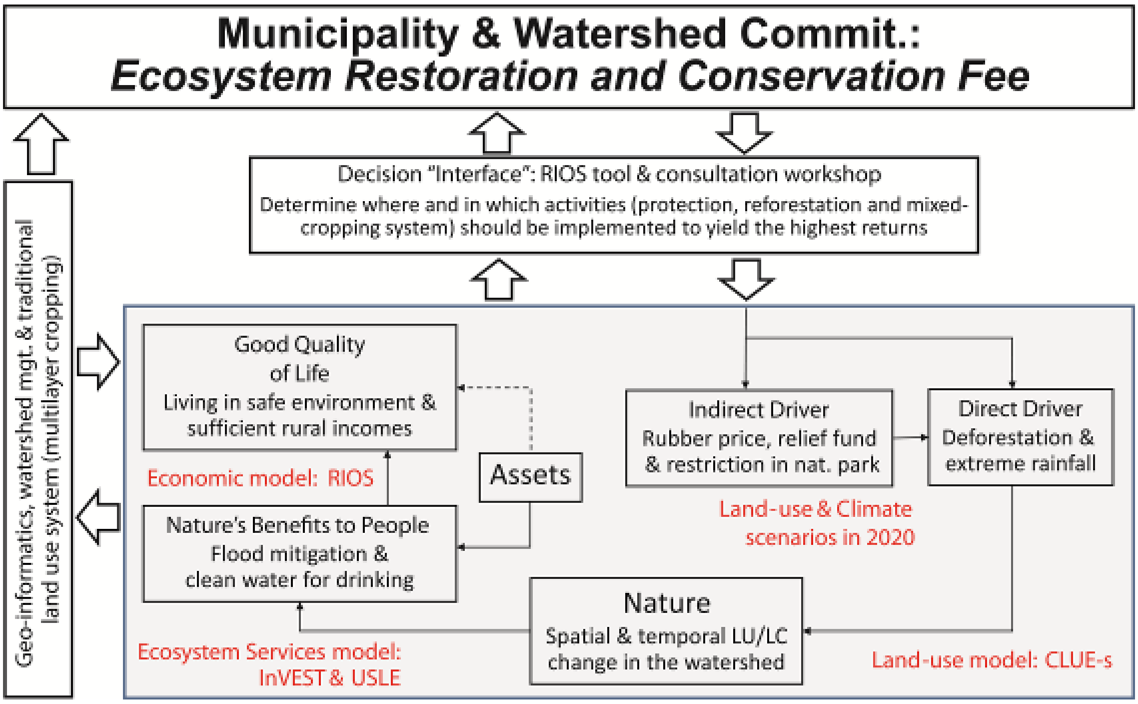


Figure Box 2.1.: Integrated scenarios and modelling in ecosystem services assessment for the Thadee Watershed, Thailand.

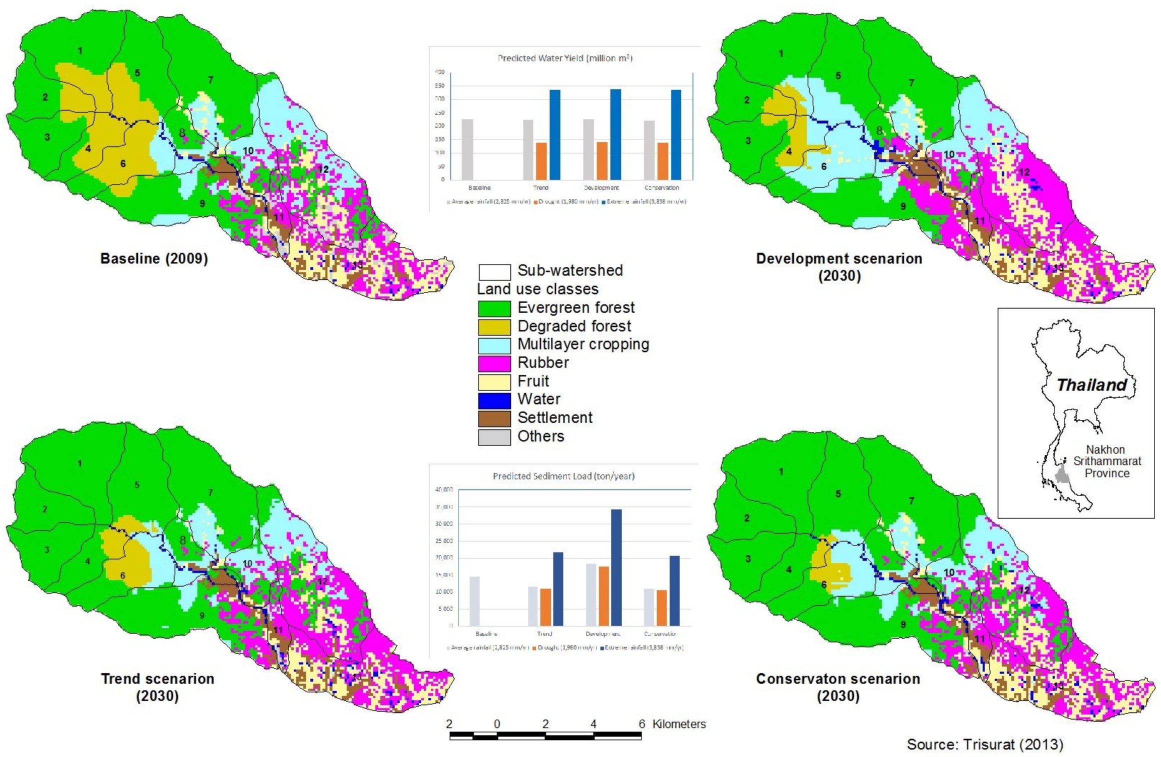


Figure Box 2.2.: Three scenarios of land use for 2030 within the Thadee watershed in Nakhon Srithammarat Province and consequences on water yields and sediment loads.

Box 1.3: Case study – Guyana Road Projects Impact.

Project Title	**Potential Impact of Road Projects on Habitat Loss and Greenhouse Gas Emissions in Guyana**
Type of value	**Tropical forest**
Driver	**Mining and road development**
Temporal extent	**2012 to 2022**
Spatial extent	**Country (211,000 km2)**
Model use	**Terra-I, "Training Models"**
Client	**Government, Inter-American Development Bank**

Guyana covers approximately 1% of the terrestrial surface of South America (21.1 million ha). The country has one of the most intact tropical forests and has lower deforestation rate (0.020-0.056% per year) than most countries in South America (0.41% per year, on average) partly due to its low population size. The main drivers of deforestation include mining and road development.

Potential deforestation and its consequences on green house gas (GHG) emission for the year 2000 were assessed (Reymondin et al., 2014) based on three road development scenarios: 1) improvement of the Georgetown-Linden corridor; 2) linking Linden with the Amaila Falls; and 3) paving of the Linden-Lethem corridor (Figure Box 3.1). In addition, two models of recent deforestation rates (model 1: similar to Guyana's region; model 2: growing mining in the Peru's Madre de Dios region) detected by satellite-based rainfall and vegetation data (Terra-i; Reymondin et al., 2012) were combined to map deforestation risk areas.

The results derived from the scenarios on a national scale show that the implementation of the explored infrastructure projects alone may result in a deforestation rate of 0.04% (best-case scenario) to 0.09% (worse-case scenario) per year. Although deforestation and its consequences for GHG emission rates might look low in comparison with other countries in Latin America, it is higher than the current rate in Guyana. It is important to maintain emission levels at low levels in order to receive the full compensation payment from the REDD+ scheme (Parker et al., 2008) agreed to with Norway. An increase of deforestation more than 0.09%, as seen in the worse-case scenarios, will mean a loss of more than 70% in payments. Therefore, in order to reduce the risk of losses in REDD+ payments, it is highly important to design and enforce a careful mining licensing and land management policy in the event that the roads are built or upgraded.

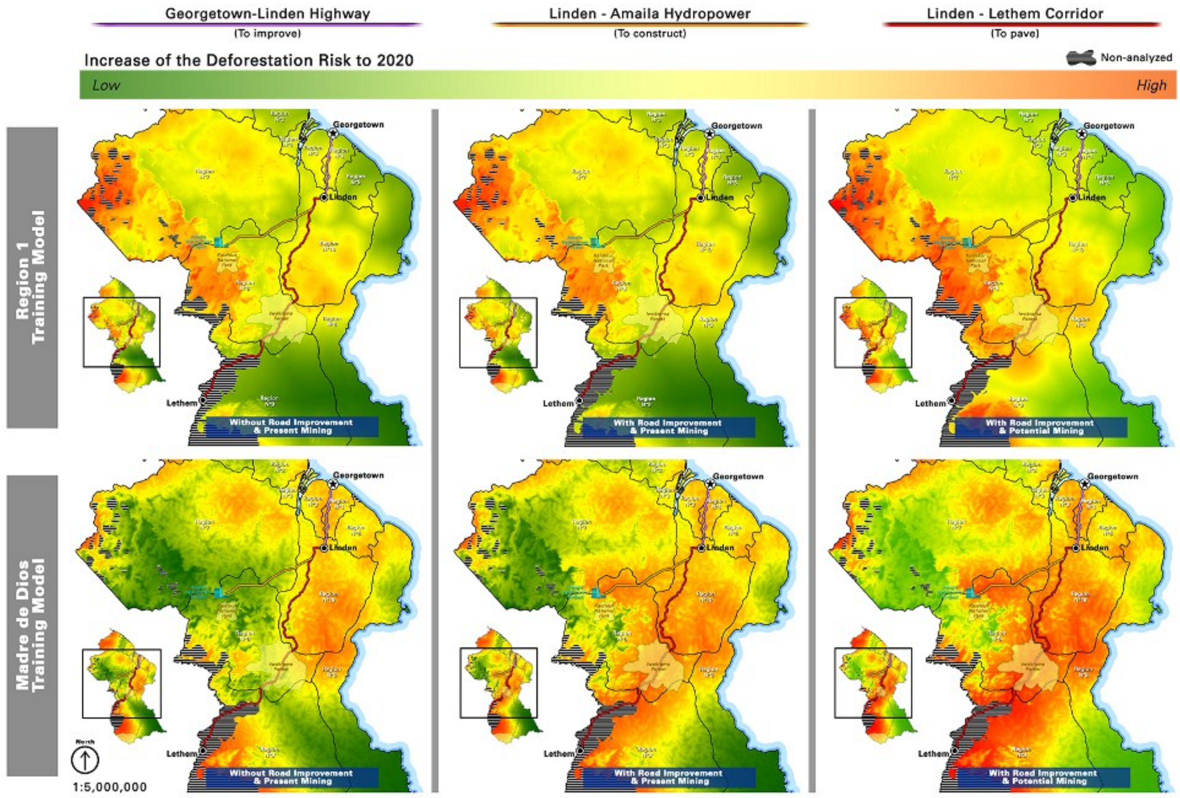


Figure Box 3.1.: Potential Deforestation under Scenario of the baseline (left) and under Scenarios of Improvement and Construction of Both Roads with Current Mining (middle) and Potential Mining or the worst-case scenario (right).

The study provides results useful for joint work of Government of Guyana and Inter-American Development Bank (IDB) on coordinating plans for providing a transportation link between Brazil and Guyana and other ongoing IDB projects in Guyana. It further explores the possibility of using the scenarios and models as a basis for land-use management and in the development of infrastructure projects and maintaining intact tropical forests in Guyana (Reymondin et al., 2014).

1.3 Structure of this report

Methodologies for modelling different components of socio-ecological systems (i.e. elements of the IPBES Conceptual Framework) are increasingly being integrated within a single modelling framework (e.g. through so-called "integrated assessment models", IAMs). Likewise, the boundary between methodologies for modelling, and methodologies for scenario development, assessment and decision-making, is becoming increasingly fuzzy as a result of closer coupling of approaches across these domains. However, in the interests of breaking the overall challenge down into manageable pieces, Chapters 2 to 5 each focus, in turn, on a particular aspect or component of this challenge (Figure 1.6.). Linkages and dependencies between these topics, and the need for any given application of scenarios and models to consider these issues together, rather than sequentially, are emphasised throughout.

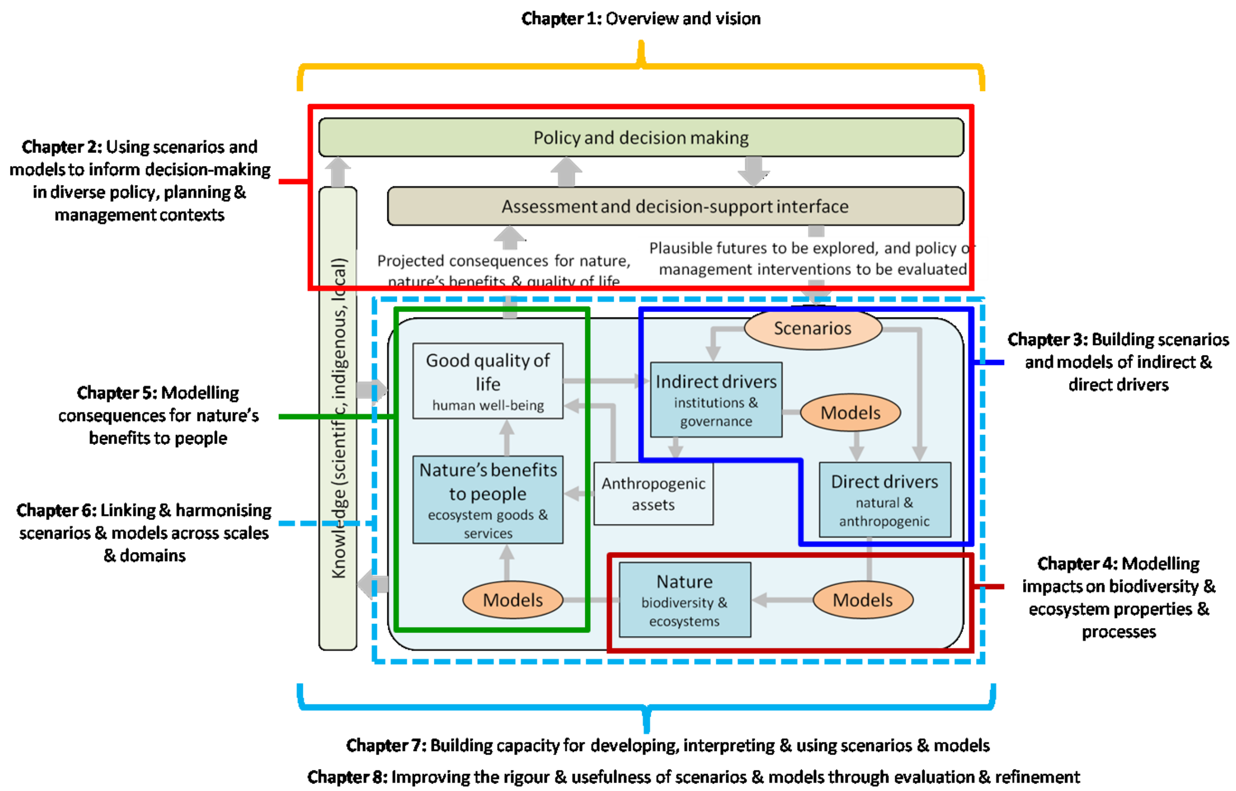


Figure 1.6.: Relationship of chapters to the components depicted in Figure 1.3

Chapter 2 examines issues around "using scenarios and models to inform decision-making in diverse policy, planning and management contexts". It provides an overview of policy, planning and management contexts in which scenarios and models can aid assessment and decision-making, and considers lessons learnt from established decision-support paradigms and frameworks that make strong use of scenarios and models. Particular emphasis is placed on the importance of aligning the design of scenarios and models with the particular needs of assessment and decision-making processes associated with different phases of the policy cycle, and of dealing with uncertainty in scenarios and models employed in decision-making.

Chapter 3 addresses challenges associated with “building scenarios and models of indirect and direct drivers of change in biodiversity and ecosystems” to address the assessment and decision-making needs identified in Chapter 2, and presents a typology of exploratory and intervention scenario sub-classes linked to major phases of the policy cycle. It reviews approaches to developing plausible scenarios of indirect drivers and lessons learnt from previous development and application of such scenarios in assessments at global and regional scales. It then reviews methods for modelling expected consequences of indirect-driver scenarios for direct drivers of change in biodiversity and ecosystems across terrestrial, freshwater and marine systems (as input to models of biodiversity and ecosystem responses considered in Chapter 4).

Chapter 4 deals with “modelling impacts of drivers on biodiversity and ecosystem properties and processes”. It explores existing and emerging approaches (both correlative and process-based) to modelling impacts of a broad range of direct drivers (from Chapter 3) on: biodiversity across multiple levels (e.g. population, species, community) and dimensions (e.g. composition, structure, function) of biological organisation; and ecosystem properties and processes (e.g. biomass, primary production).

Chapter 5 focuses on “modelling consequences of change in biodiversity and ecosystems for nature’s benefits to people”. It explores challenges associated with translating modelled biophysical changes in biodiversity and ecosystem properties and processes (from Chapter 4) into expected consequences for benefits to people (including ecosystem services), human wellbeing, and good quality of life. It emphasises the importance of recognising that different decision-making processes may require careful consideration of differences in the values that people involved in these processes place on, or derive from, nature.

The remaining chapters of the report explore, in greater depth, three particularly important cross-cutting challenges facing the ongoing development and application of scenario analysis and modelling from an IPBES perspective (Figure 1.6).

Chapter 6 articulates the need for better “linking and harmonising scenarios and models across scales and domains” and proposes practical strategies and solutions for achieving this in both the short and longer term. These include approaches to: more closely linking and harmonising scenarios and models across different scales of assessment and decision-making; achieving closer coupling of scenarios dealing with different drivers, and models focusing on different dimensions or levels of biodiversity, or on different ecosystem functions or services (as covered separately in Chapters 3, 4 and 5).

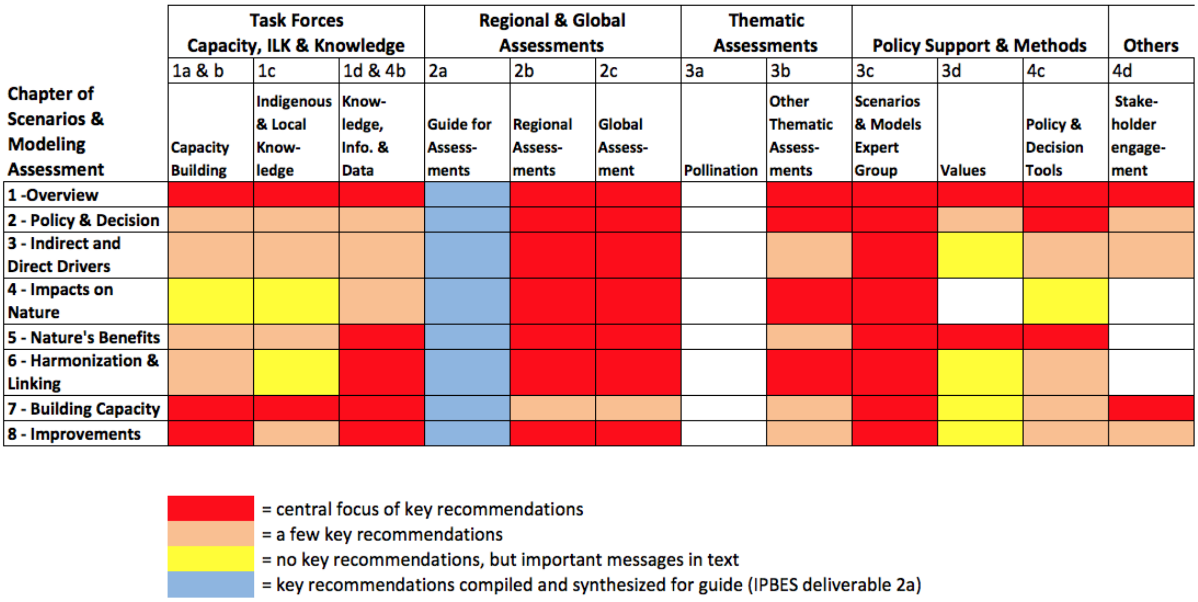
Chapter 7 addresses the challenge of “building capacity for developing, interpreting and using scenarios and models” by proposing practical strategies that account for regional and cultural diversity in perspectives on, and capacity for, scenario analysis and modelling. These include approaches to: improving regional and national access to, and training in, appropriate data-sets and software tools; developing methods for better incorporating local data and knowledge; and developing effective strategies for mainstreaming scenarios and models into assessment and decision-making processes across scales and across different policy, planning and management contexts.

Chapter 8 adopts a forward-looking perspective in addressing the challenge of “improving the rigour and usefulness of scenarios and models through ongoing evaluation and refinement”. It lays out a comprehensive vision and strategy for taking scenario analysis and modelling of biodiversity and ecosystem services to a whole new level of rigour, credibility and utility by: more closely linking this field to parallel initiatives in biodiversity/ecosystem data acquisition, and thereby establishing a rigorous foundation for ongoing model evaluation and calibration; and advancing the fundamental science underpinning development and application of scenarios and models through carefully prioritised research activities.

1.4. High-level messages from this assessment

This assessment provides guidance on the contributions of scenarios and models to the four functions of IPBES: assessment, capacity building, policy support and knowledge generation. It also provides specific recommendations for experts involved in task forces and expert groups in nearly all of the IPBES deliverables. For this reason, the Summary for Policy Makers and the summaries for each chapter include a set of "Key Findings" and "Key Recommendations". Key findings are principal general messages that arise from the critical analyses in this assessment and are aimed at a broad audience. Key recommendations are based on the key findings and specifically address IPBES and experts involved in its deliverables. The key recommendations provide explanations of a wide range of actions that could be undertaken or stimulated by IPBES. The IPBES deliverables and contribution of each of the chapters in this assessment to these deliverables are summarized in Table 1.1.

Table 1.1.: Relevance of the Methodological Assessment of Scenarios and Models for the other deliverables in the IPBES work programme. Colours indicate the strength of the recommendations from each chapter in this assessment for the other deliverables. The pollination thematic assessment is not addressed because it is already nearing completion. The catalogue of assessments (deliverable 4a, not shown) is also not addressed.



There are three high-level messages for IPBES emerging from this assessment:

Message 1: Scenarios and models can contribute significantly to a diverse range of assessment and decision-support activities undertaken or facilitated by IPBES.

Assessment deliverables of IPBES include global, regional and thematic assessments (pollination, land degradation and restoration, and potentially invasive species and sustainable use of biodiversity). Many of the recommendations from this assessment directly address experts involved in these deliverables. Given the highly technical nature of scenarios and models and the breath of the literature that is to be surveyed, this assessment is essential reading for these experts. In addition, the most important messages from this assessment have been summarized in a chapter of the Guide for Assessments. Experts involved in the Scenarios and Models assessment will also provide "hands-on" advice for the global, regional and thematic assessments through workshops and providing advice from members of the expert group on Scenarios and Models.

The potential contribution of scenario analysis and modelling to achieving the overarching goal of IPBES extends beyond regional and global assessments. Such assessments will play an important role in agenda setting – by appraising the need for action, and by shedding light on the likely efficacy of broad types of action. But to directly support subsequent decision-making in policy formulation and implementation, scenario analysis and modelling need to be embedded and undertaken within individual decision-making processes across a wide range of institutional/governmental contexts and scales. To extend the benefits of scenario analysis and modelling to the broadest possible range of decision-making processes, IPBES will therefore need to complement its own use of these approaches in regional and global assessments with promotion and facilitation of their uptake by other processes, through IPBES activities such as the Taskforce on Capacity Building, and the Taskforce on Policy Support Tools and Methodologies.

Policy support activities of IPBES include identifying policy relevant tools/methodologies, facilitating their use, and promoting and catalysing their further development. This assessment illustrates the broad variety of ways in which scenarios and models can contribute to decision-making. Because of the key role of scenarios and models in policy support tools, ties with the Task Force on Policy Support Tools and Methodologies have been established and will be pursued.

Message 2: Many relevant methodologies and tools are already available, but these need to be matched carefully with the needs of any given assessment or decision-support activity, and applied with care. The needs of policy and decision makers should play a strong role in guiding the development and use of scenarios and models.

Given the breadth of potential applications of scenario analysis and modelling, it is vital that approaches used to address different assessment and decision-support demands are well matched to the particular needs of these processes. Different processes can differ markedly in terms of, for example: spatial scale; policy-cycle phase; values being considered; and availability of data, knowledge and expertise.

Capacity building activities of IPBES include prioritizing key capacity building needs, providing IPBES financial and other support for these priority needs, and establishing mechanisms to mobilize additional support. This assessment highlights the capacity building that is required to specifically meet the needs for scenarios and modelling, which are highly technical and less familiar to many scientists, stakeholders and policy makers than those related to data collection and the evaluation of the status and trends of nature and nature's benefits to people.

IPBES also focuses on mobilising indigenous and local knowledge (ILK) as part of efforts to strengthen the capacity and knowledge foundations to implement key functions of IPBES. This assessment provides guidance on the contribution of ILK to scenarios and models as well as their use by indigenous and local communities. Several chapters highlight the importance of ILK in the context of scenarios and models, in particular Chapter 7.

Message 3: Significant challenges remain in developing and applying scenarios and models for biodiversity and ecosystem services, but these can be overcome with appropriate planning, investment and effort.

Despite recent advances in this field, significant gaps and weaknesses still remain in currently available data and methodologies, and much further work is therefore needed to ensure that scenario analysis and modelling can effectively serve the needs of assessment and decision-making into the future.

Knowledge generation activities of IPBES focus on identifying knowledge needs of policymakers, and catalysing efforts to generate new knowledge. As such, the methodological assessment of scenarios and models does not outline research to be carried out by IPBES. However, IPBES will seek to fill key research gaps identified in this assessment by engaging actively with the scientific community and funding agencies through the Task Force on Knowledge, Information and Data. This includes gaps in scenarios and models and in data collection and monitoring to support scenarios and models.

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