Scenarios and models for exploring future trends of biodiversity and ecosystem services changes

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SCENARIOS AND MODELS FOR EXPLORING FUTURE TRENDS OF BIODIVERSITY AND ECOSYSTEM SERVICES CHANGES

EXECUTIVE SUMMARY

This report provides the full results of the European Commission (DG Environment) contracted study on "*Scenarios and models for exploring future trends of biodiversity and ecosystem services changes*". The overall purpose of the study is to clarify which models and scenarios are being used and can be used to explore the developments of biodiversity and ecosystems in light of different assumptions of drivers and policies. This will be of general use for policy analysis and reflection, and it will also be of specific use to the second phase of the initiative on *The Economics of Ecosystems and Biodiversity* (TEEB). TEEB aims to build future visions and projections taking into account alternative policies and assess their potential impacts on ecosystem services and the cost of their loss, both in biophysical and in monetary terms.

This study has built on previous supporting studies for TEEB, in particular the *The Cost of Policy Inaction (COPI): the Case of Not Meeting the 2010 Biodiversity Target* (Braat and ten Brink, 2008), and recent key global and regional environmental assessments, which have included model and scenario based projections of changes in biodiversity and ecosystems and their impacts on ecosystems services and human well being. In particular, this study has:

- Reviewed the different scenarios and models used to explore future trends in biodiversity loss and ecosystem change and their associated impacts on ecosystem services (see Section 2.6 for detailed conclusions).
- Summarised the key findings from recent global and regional assessments (see Section 3.11 for detailed conclusions).
- Assessed the limitations of existing models with respect to their suitability for producing robust projections of changes in biodiversity and ecosystem services (see Section 4.4 for detailed conclusions).
- Instigated a peer-review of the study's' initial conclusions during an expert workshop (see meeting report in Chapter 5).
- Proposed a set of options for suitable models and scenarios to be used in future studies for TEEB and beyond (see Chapter 6).

The key overall conclusions and recommendations from this study are:

- There are a large number of modelling tools available today (which differ in focus, timeline, assumptions, spatial resolution, sensitivities and in choice of indicators of biodiversity and ecosystem services), and most are able to capture various forms of ecosystem service provisioning to a reasonable degree. However, ecosystem service coverage tends to focus on provisioning services and carbon sequestration. Furthermore, the linkage between ecosystem services and biodiversity is not well understood and models currently use indicators that are based on limited knowledge of service supply in different natural, semi-natural and human-managed systems. Furthermore, many biodiversity processes require spatially explicit modelling and operate at smaller scales than can be practically analysed in global studies.

- The key finding from the use of such models and scenarios in recent global and regional environmental assessments is that substantial biodiversity loss will continue under all the considered policy scenarios. It is also clear that ultimately the drivers such as increasing population growth and per capita resource use have an overwhelming influence on biodiversity outcomes. Their impacts currently vastly outweigh specific measures that attempt to protect biodiversity. A further problem is that the full socio-economic values of biodiversity are underestimated and not captured in market systems. Furthermore, the full impacts of biodiversity loss tend to be overlooked by politicians and other decision makers, especially when decisions are overly reliant on narrowly focused and incomplete cost-benefit assessments. As a result many of the biodiversity conservation measures are not implemented fully. Thus, given the projected expansion of the global economy to 2030, it seems inevitable that further impacts on biodiversity and ecosystem services will occur in the future, unless stronger measures are taken to conserve biodiversity and ensure that economic growth is truly sustainable in environmental terms.

- Most assessments make optimistic assumptions about the increased productivity of agriculture, which could significantly reduce the need for expansion of agricultural land into natural areas. The assessments therefore suggest that productivity increases are key to ensuring that biodiversity losses are not even greater than those forecast in the models. They also suggested that the designation of additional protected areas will have little impact on biodiversity (largely due to external pressures on them). However, these conclusions may be too simplistic and a result of the limitations of the models and biodiversity indicators that have been used.

- Although it is reasonably certain that future biodiversity losses will be substantial the consequences for ecosystem services is unclear. There is evidence to suggest that ecosystems may require a minimum quality (e.g. abundance and diversity of species) to maintain the ecosystem functioning that underpins many important ecosystem services. Below such critical thresholds, ecosystems reach a tipping point, and may suddenly switch their character, no longer providing the same kind, or level, of ecosystem service. Furthermore, the restoration of such ecosystems, if possible at all, is likely to be very difficult and costly.

- In practice the current choice of models for further TEEB work on biodiversity and ecosystem services is much more limited than it might seem. There is no single model that covers the whole range from socio-economic developments, policy inputs, environmental and land use change, and biodiversity and ecosystem services for terrestrial and aquatic systems together. Therefore multi-model combinations are needed to generate comprehensive and internally consistent results. However, new tools such as Meta-models like MIMES or InVEST and the vulnerability tool of ATEAM provide some promise for future use.

- At the moment, few models include adequate feedbacks from changes in biodiversity and ecosystem services to socio-economic development, and therefore do not show the negative effects of reductions of ecosystem services on human well-being. Furthermore, model results can estimate only partial costs but not the full benefits of management/policy options.

- This study was not designed to empirically test the effect of changes in key study assumptions. Nevertheless, findings from the review indicate that the numerical values of drivers applied as different scenarios in the assessments have a crucial influence on projected changes in land use and their impacts on biodiversity and indicators of ecosystem services, such as agricultural production, carbon sequestration and water availability. In addition, the framing and design of assessments as a whole are at least as important factors in terms of their influence on the uncertainty and potential bias of results.

- None of the individual tools is sufficient to meet TEEB's entire needs in the short term, but many offer useful elements. Nevertheless the integrated assessment models reviewed and selected as most promising for TEEB ambitions (IMAGE for Terrestrial and EwE for Marine) are developed in such a way that they can be relatively easily adapted to accommodate questions regarding ecosystems, ecosystem services and economic indicators. A number of theme-, sector- or region-specific models exist which can be used to achieve this.

- An assessment of the Mean Species Abundance (MSA) indicator was included in the study because the Globio model that incorporates it is used in most global assessments to assess likely impacts of land use and climate change on biodiversity. It was also used to adjust per hectare values of ecosystems services in the COPI supporting study for TEEB Phase 1. It appears that despite various limitations it is currently the best means of modelling global biodiversity impacts and is a suitable metric for use in TEEB. Nevertheless, the way it was used in the COPI study is a critical issue and needs to be re-examined. The approach needs to be validated and if appropriate the MSA / ecosystem functional relationships adjusted accordingly. The use of other indicators should also be considered where more appropriate, e.g. including Human Appropriation of Net Primary Production (HANPP). It is also important to point out that some ecosystem services may be better modelled directly, as they are not necessarily affected by biodiversity or ecosystem intactness as characterised by the MSA.

- Another ongoing limitation of most models and model/scenario combinations is that the impacts of changes in biodiversity and several ecosystem services, cannot easily be expressed in meaningful terms for economic sectors, countries or target groups of policy. The current models are physically based and do not integrate economic factors, such as the values of biodiversity and costs of action and inaction. This is likely to remain problematical because of the typical complexity of interactions amongst physical, biodiversity and economic impacts.

- Overall it is clear that in the short-term further work should be based on upgraded and integrated versions of currently available models, to extend the assessment work carried out so far. In particular future assessments need to cover all ecosystems and ecosystem services, be global and build in a diverse set of indicators for biodiversity. A fully functional link to economic values and social impacts also needs to be developed. This is will entail:
    - Using existing models and exploring ways to enhance or add new indicators:
        - IMAGE-GLOBIO and COPI upgrade and scenarios; and
        - Marine (EwE set and MSA indicator to match GLOBIO land assessment).
    - Promoting efforts to validate GLOBIO (and other models) through observation and experiment.
    - Incorporating a wider range of drivers into existing models (e.g. urbanization).

- As a result of the current model limitations, it is also concluded that the ideal approach for future modelling, for TEEB and similar studies, should be to combine different models and compare several approaches. Comparing the results of these different approaches would give an indication of the gaps and uncertainties in the underlying mechanisms and consistent results between the different models would provide a greater confidence in the results. It would also be useful to compare several different model-combinations such as one 'traditional' integrated assessment model linked with several sectoral models currently under development (such as MIMES and/or InVEST).

- The most useful scenario-approach (trends with policy options, explorative or normative) will depend on the specific questions being addressed by TEEB as well as the time and resources available. These factors will also determine whether the inclusion of more detailed sectoral or region-specific models is needed. Exploratory scenarios (e.g. GEO4) are able to "create and illustrate the virtual future space in which conflicts between population and economic growth versus ecosystems and sustainable use will take place". However baseline scenario approaches (e.g. OECD EO-2030) are more useful for examining the economic consequences of alternative policy options.

- Very few scenarios are available that deal with biodiversity and ecosystems explicitly. More biodiversity-relevant scenarios are needed that reflect "real" policy options (e.g. with respect to issues such as REDD and the production of biofuels). It is therefore also recommended that a policy dialogue be set up to develop Policy Action Scenarios which have a broad support across stakeholders and regions. The scenarios need to build in the key drivers behind ecosystem and biodiversity loss, and there still may also be a need for policy measures, both in business-as-usual scenarios and to develop different policy action scenarios.

- Further recommendations are provided in Chapter 6 for future TEEB work, including work for the Science and Economics report (to be produced in September 2009) and work up to the 2010 CBD CoP 10 in Nagoya. This work may also inform a broad range of biodiversity policy issues, including discussions concerning the development of global and EU post 2010 biodiversity targets. Some recommendations are also made for longer-term work beyond TEEB, for example related to the 2015 MDG agenda.

1 INTRODUCTION

1.1 Background and aims of the study

Computer based models have become important tools for examining the way that systems are likely to react to changes, including deliberate manipulation. They are therefore increasingly being used to study the possible effects of human actions on the Earth and its biodiversity and associated ecosystem services. Such models are typically based on scenarios, which provide an approach for examining how plausible alternative futures may unfold and comparing the potential consequences of different decisions in different future contexts. These modelling and scenario tools have formed the basis of a number of recent global and regional assessments that project future environments on the basis of changes in drivers of ecosystem change and biodiversity loss according to various development scenarios, including the *Millennium Ecosystem Assessment* (MA, 2005), *The Global Biodiversity Outlook* (2006), the *Intergovernmental Panel on Climate Change Fourth Assessment* (IPCC 2007), the *Global Environment Outlook 4* (UNEP 2007), the *International Assessment of Agricultural Knowledge, Science and Technology for Development* (IAASTD 2008), and the *OECD Environmental Outlook* (OECD, 2008).

The Economics of Ecosystems and Biodiversity (TEEB) initiative is also highly dependent on the use of models and scenarios to assess the likely benefits of biodiversity with respect to its ecosystem services and the potential costs of losses in services. However, supporting studies for Phase 1 of the initiative were only able to provide preliminary and incomplete estimates of the possible impacts of ecosystem services losses. The TEEB interim report (TEEB 2008) therefore recognised the need to address in the second phase of TEEB aspects regarding different uses and utilisation levels of biodiversity that affect the future state of biodiversity and the levels of ecosystem's services provisions. The need for further development and use of scenarios and models was also recognised and discussed during an expert workshop hosted in Brussels in March 2008[1].

The second phase of TEEB is currently underway, and this will include the development of scenarios and models that will build future visions and projections taking into account alternative policies that may create these environments. This is a crucial step in assessing ecosystem benefits and the cost of their loss, both in biophysical and in monetary terms. To support this work the European Commission (DG Environment) commissioned this study on "*Scenarios and models for exploring future trends of biodiversity and ecosystem services changes*". As noted in the Terms of Reference (ToR), this study had the following three aims:

- "*to review the different scenarios and models used to explore future trends of biodiversity loss and ecosystem change and the impacts on the ecosystem services they provide;*
- *to review how these models have factored in policy action, notably environmental and conservation policies;*
- *to propose a set of options for suitable models and scenarios to be used in a global assessment and discuss them in a workshop*."

[1] http://ec.europa.eu/environment/nature/biodiversity/economics/pdf/workshop_proceedings.pdf

The Terms of Reference for each specific task within this study are documented at the beginning of each chapter in this report.

This study builds on the work carried out within the wider context of the Phase 1 of TEEB and is focused on providing outputs of value to Phase 2. Within TEEB Phase 1, the following three projects were of particular relevance to the development of models and scenarios for Phase 2:

- *The Cost of Policy Inaction (COPI): The Case of Not Meeting the 2010 Biodiversity Target* (Braat and ten Brink, 2008). This project assessed the cost of not halting biodiversity loss – by looking at the range of ecosystem service losses that will result from the loss of biodiversity and hence the losses to the economy and society. This built on the GLOBIO model that focused on land-use and used an OECD baseline scenario for projecting into the future. The work underlined the benefit of large scale modelling work for TEEB, and identified needs for model/scenario work to update the land-use based work and, at least as importantly, to look at models/scenarios for other biomes, notably marine and wetlands. It also underlined the need for sensitivity/scenario runs using different assumptions.

- *Review on The Economics of Biodiversity Loss – Economic Analysis and Synthesis*; a synthesis report of the call for evidence and workshop (Markandya *et al*., 2008). This work underlined, inter alia, the need for scenario/sensitivity analysis that allows a range of assumptions (and their effects) to be appropriately characterised and analysed, and the need for this for all biomes and regions. It also emphasised the importance of both global and national level studies, requiring global/national model/scenario applications.

- *Review on the Economics of Biodiversity Loss: "Scoping the Science* (Balmford *et al*., 2008). This work provided both a framework for analysis - how scenarios can be used, what issues need addressing etc – and also provided specific insights into models / scenarios and teams working on the different benefits arising from ecosystem services.

Each of these projects, and the others within the TEEB Phase 1, therefore provided a useful basis and background for work within this new study. In addition, the TEEB study has built on a wide range of recently published large-scale assessments which have used scenarios and models to develop projections of human impacts on biodiversity and ecosystem services. In particular the following assessments are reviewed in detail with respect to their use of models and scenarios and their projections for biodiversity and ecosystem services:

- *Millennium Ecosystem Assessment (MA)* assesses the consequences of ecosystem change for human well-being and sets out to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems *(MA, 2005)*.

- *Global Biodiversity Outlook 2 (GBO-2)* from the CBD looks at progress to date in achieving progress towards the 2010 Biodiversity Target and investigates the policy options that could have major positive or negative impacts on biodiversity in the future up to 2050 (sCBD, 2006).

- *UNEP Global Environmental Outlook 4 (GEO-4)* looks at how deterioration of the environment can limit human development and reduce quality of life. It examines the opportunities that the environment provides for improving human well-being (UNEP, 2007).

- *Ecosystem-based Global Fishing Policy Scenario*, analyses marine policy options under the GEO-4 scenarios (Alder *et al.*, 2007).

- *OECD Environmental Outlook to 2030 (OECD)* analyses the costs of inaction in addressing environmental issues to emphasise the economic rationale of ambitious environmental policy and examines the potential impact of policy interventions *(*OECD, 2008*)*.

- *International Assessment of Agricultural Science and Technology for Development (IAASTD)* examines how agricultural knowledge and technology can be used to meet the challenges of development and sustainability, addressing issues such as poverty, malnutrition, rural livelihoods and environmental sustainability. It focuses on the multi-functional use of agriculture to deliver social, environmental and development goals *(IAASTD, 2008)*.

1.2 Structure of this report

This report builds on a previous Interim Report (of 31st May 2009) and provides a complete account of the work carried out as part of the study. The subsequent chapters report on the results of specific tasks (described in the study terms of reference) as outlined below:

- **Chapter 2** (Task 1) provides an overview of the "state of the art" of forward-looking large-scale models and scenarios that may be used by TEEB and similar studies. It also identifies and explains the significance of strategic gaps between the "state of the art" and priority needs for TEEB and further assessments. Basic descriptive information is also provided to underpin the analysis in this and other chapters, most of which is tabulated in a separate Technical Appendix (Appendices 1.1 – 1.5).

- **Chapter 3** (Task 2) reviews the key results and overall conclusions of the recent global environmental assessments (as listed above), with respect to their impacts on terrestrial, freshwater and marine biodiversity and ecosystem services.

- **Chapter 4** (Task 3) provides a qualitative assessment of the limitations of the current models' capabilities and the relevance of existing scenarios with respect to the requirements of TEEB. The selected models were scored in relation to their potential use for TEEB and these scores are provided in Tables in Appendix 3.

- **Chapter 5** (Task 4) provides an account of the study workshop that was held with invited experts in Brussels in May. The aim of the workshop was to obtain feedback on the results of Tasks 1 and 3 and to develop preliminary recommendations for the development of models and scenarios for future work.

- **Chapter 6** (Task 5) builds on the analysis carried out in Tasks 2-4 and the results of the workshop to provide general recommendations together with more specific recommendations relating to work for the following three key timescales: for the Science and Economics report to be produced in September 2009, work up to the 2010 CBD CoP 10 in Nagoya and longer-term work beyond TEEB (e.g contributing towards the 2015 MDG agenda).

2 IDENTIFICATION AND OVERVIEW OF AVAILABLE MODELS

2.1 Description of Task 1 from the ToR

"The contractor should provide an overview of the models that have been built to identify the main drivers of the loss of biodiversity and natural ecosystems and forecast their impact on:

- *the level of biodiversity (in biophysical or other terms); or*
- *the level of ecosystem services provided*

The term 'model' should be interpreted widely, and should cover also the scenarios which the models are deploying, where these are considered to offer some robust assessment of future trends.

In identifying models, the following points are relevant

a. *The overview should mainly focus on models used for large-scale or global assessments. However, it should also cover, in a more selective way, models used at different spatial levels (local, biome, etc.). So, where there are a number of local models then the identification should limit itself to providing a few examples and a generic description. It should be explained how global models take account of and relate to models that address specific biomes (i.e. forests, fisheries) or that are exploring a more detailed spatial level (i.e. if they are bottom-up, aggregated versions, etc). Of course, within global models there will usually be some regional breakdown that needs to be reflected.*

b. *The overview should include the attempts made to assess the wider economic impacts of the loss of biodiversity and ecosystems (e.g. with CGE models).*

c. *The overview should aim at covering all main types of biomes and ecosystems (terrestrial, freshwater and marine).*

d. *The overview should take on board the work produced for the preparation of the Interim report of TEEB and in particular the COPI and Scoping the Science studies.*

e. *Of particular interest is the provision of ecosystem services. Modelling the provision of services is generally less advanced than modelling the status of biodiversity and ecosystems, so that available models are expected to be fewer, but the overview should cover recent and on-going developments.*

f. *The overview should also examine whether there are models that assess the economic costs of policies, including the opportunity costs of conservation. This can cover models that look at the economic value of ecosystems in a static sense (so, for example, there are analyses setting out the net present value of alternative land management systems for tropical forest biomes).*

g. *Attention should be paid to analysing the conditions required for designing scenarios and models that are relevant for each ecosystem service (e.g. what is the spatial resolution needed, what major factors need to be taken into account, etc).*

h. As far as is possible, the inventory should include a forward look i.e. address on-going model developments (models that could be expected to be operational in one-two years time).

i. It should be examined to what extent the costs and benefits of policies can be jointly assessed.

The contractor should develop a number of criteria for making a structured inventory of the main models. This should include an overview of the strengths and weaknesses of these models (and the data available for such modelling). It should also include an overview of the key drivers and assumptions involved in such models and their respective scenarios."

2.2 Introduction

2.2.1 Definitions/logical background

Decision makers need to understand what impacts the implementation of policies has on the Earth. Policy interventions at local to global scales therefore require knowledge of how the Earth works. Scientists usually gain understanding of a system and its components by experimentation and observation. The Earth can be viewed as a system consisting of the unified set of physical, chemical, biological and social components, processes and interactions that together determine the state and dynamics of Planet Earth, including its biota and its human occupants (ESSP, 2009). Because manipulative experiments on a global scale are not feasible, we rely on models to test sensitivities of the Earth system to modified components, processes and interactions. Models based on scientific foundations can help to understand and forecast environmental changes and become useful for policy analysis at local to global scales. However, the use of models is just one of the options to make predictions about the future, and models are limited to information that can be quantified, expressed in numbers.

A *model* is a simplified abstract representation of the complex reality. Models mathematically and logically represent a system of entities, phenomena and processes using statistical and computational methods. Models allow simulation, visualization, and manipulation of the entities, phenomena or processes represented by the model. Earth system models often incorporate several models of sub-systems or components (e.g. socio-economic and earth systems make up integrated assessment models). Mathematical (statistical/quantitative) models usually represent a system by a set of variables and a set of equations that describe the relationships between the variables. Variables include at least input variables (e.g. observed land use/cover, species abundance), "variables that are part of the equations" (e.g. parameters relating land use intensity to species abundance), and output variables (e.g. modelled land use/cover, predicted species abundance). Models, through the type of equations used, can be linear, non-linear, deterministic, probabilistic, static or dynamic or a combination of these. The functions/equations relating variables can be derived from empirical observations or heuristically derived. Models can be built for different purposes, as scoping models, often built with a high degree of stakeholder participation, research models that incorporate more detail and are focussed on calibration and testing of parameters and assumptions; and finally management tools that aim to compare the outcomes of different management options.

Scenario building and analysis is a way to investigate the unpredictability of future developments, and can be used to formulate robust policy-options. A s*cenario* is a systematically crafted story about the future. Scenarios are not necessarily the most likely, or plausible possible futures. Scenarios do not forecast or predict the future, as the future development of systems that scenarios address is highly complex and inherently unpredictable. Scenarios, or some aspects thereof, may be described by variables for use in quantitative analysis and models. A scenario can be implemented in multiple models resulting in scenario- and model-specific output variables (e.g. the GEO Sustainability First scenario implemented in the IMAGE model).

Assessments are wide ranging consultations and overviews on a particular topic that incorporate models and scenarios. While scenarios pose questions for future developments, models are the tools by which these questions are explored and the answers are compiled in assessments (Figure 2.1).

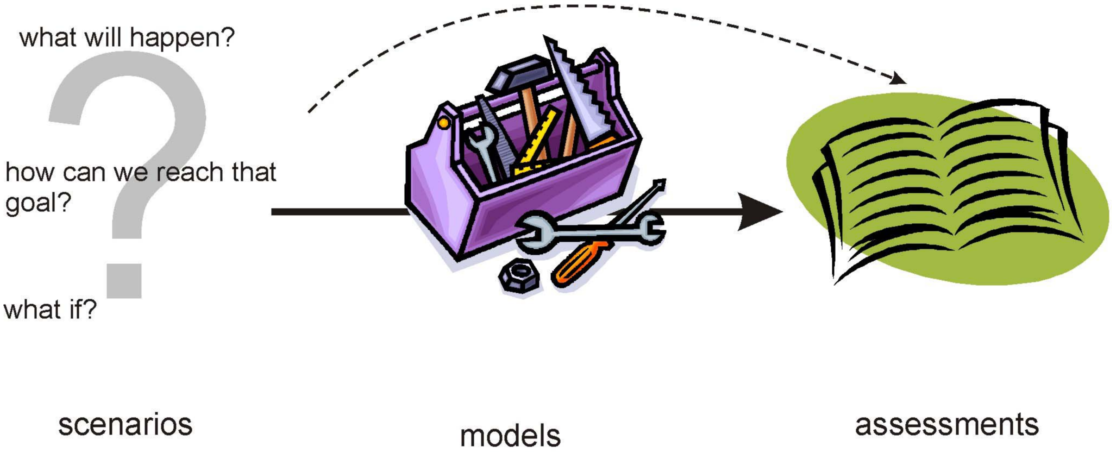


Figure 2.1 The link between assessments, models and tools: Assessments summarize the answers provided by modelling exercises on questions posed by scenarios. But not all questions can be answered by models.

This review focuses on models and scenarios for exploring future trends of biodiversity and ecosystem services. *Biodiversity*, or biological diversity, is defined as the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD, 1992). *Ecosystem services* are the benefits people obtain from ecosystems (MA, 2005a). An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit (MA, 2005a), including systems that are impacted or managed by humans like agro-ecosystems. Ecosystem services include provisioning services such as food, water, timber, and fibre; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling (MA, 2005a).

2.2.2 Structure of this review

This review is structured along the lines of the driver-pressure-state-impact-(response) framework (Figure 2.2). In this DPSI(R) scheme, the drivers represent socio-economic activities (e.g. energy consumption) which exert a certain pressure (e.g. emission greenhouse gases). This then leads to an altered state of one or more environmental domains (e.g. temperature and precipitation change). This change in the state can have multiple impacts on ecosystems and/or human systems (e.g. loss of biodiversity; spread of vector-borne diseases. On the basis of observed and/or projected impacts, humans may choose to respond by taking deliberate corrective action to redress negative impacts. The Millennium Ecosystem Assessment (MA, 2005a) identified as the main pressures on biodiversity and ecosystem services habitat change, climate change, invasive species, over-exploitation and pollution (see Chapter 3).

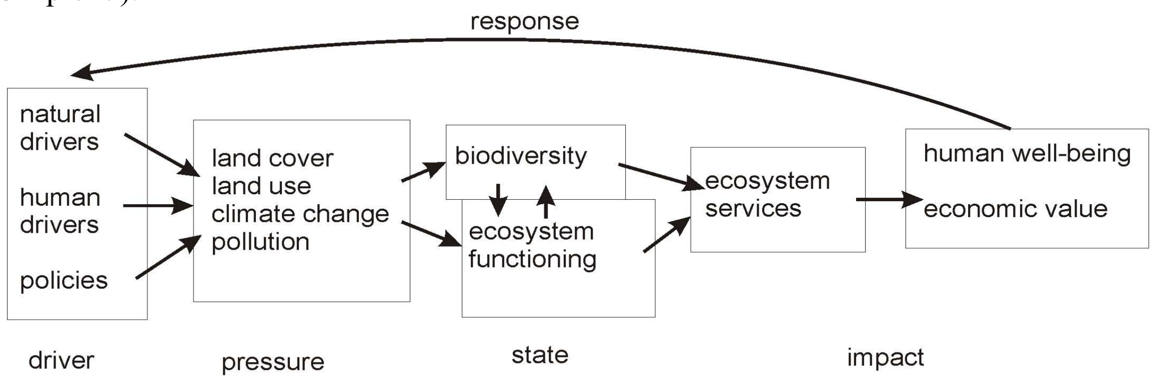


Figure 2.2: Driver-pressure-state-impact-response framework for ecosystem services and biodiversity change

For this review, models were selected and analysed on the basis of the drivers and pressures they incorporate and the output-variables (ecosystem services and biodiversity) which relate to state/impact estimates. Summaries of the analysis of the selected models and scenarios are tabulated in Appendices 1.1 to 1.5 (and provided in separate Excel tables).

The central questions that were considered in this review of models and scenarios were:

- What types of models are needed?
- Which models and scenarios are useful for predicting future developments of biodiversity and ecosystem service provisioning?
- What kind of questions can be answered by different modelling approaches?

2.2.3 Ecosystem services

The Millennium Ecosystem Assessment (MA, 2005a) raised concern about the current and future state of ecosystem services due to human impacts on ecosystem and the severe effects of declining ecosystem services on human well-being. They provide qualitative trends in anthropogenic pressures (habitat change, climate change, invasive species, over-exploitation, pollution) that are assumed to affect ecosystem services. Detailed information on the provision of ecosystem services by different ecosystems remains, however, scarce (but see COPI-scoping study: Balmford *et al*., 2008). Costanza *et al*. (1997) provided the first rough global estimates for the value of ecosystem services, aggregated by biome and land cover type. Despite increasing interest in ecosystem services in recent years, knowledge about ecosystem services remains limited, as pointed out by Naidoo *et al*. (2008):

> *"In contrast (to global estimates of biodiversity), the spatial estimation of global ecosystem service values remains quite crude. Similar to initial estimates of species richness, an early and controversial study on global ecosystem service values used localized, context-specific valuation studies to extrapolate economic values for the whole world (Costanza et al., 1997). Ten years after this study was published, global and regional efforts to map ecosystem services continue to use these estimates (Sutton & Costanza, 2002, Li et al., 2007, Turner et al., 2007), despite the well known limitations (Bockstael et al., 2000). In addition, few studies have taken advantage of recent technical advances in the selection of priority areas for biodiversity and*

adapted these advances to cover ecosystem services (but see Naidoo & Ricketts, 2006, van Jaarsveld et al., 2005, Chan et al., 2006)".

To be able to quantify ecosystem service provision, suitable indicators for the different services have to be defined that can be mapped and modelled. Table 2.1 gives an overview of the most common indicators used for different ecosystem services. For some ecosystem services finding the appropriate measure is quite straightforward (e.g. food production, timber production, primary productivity), as these are the already marketed services while for others, especially regulating and supporting services it is more difficult to find suitable indicators (e.g. disease regulation, natural hazard regulation).

There are different approaches to studying ecosystem services ranging from aggregated estimates like those of Costanza *et al.* (1997), spatial explicit mapping of current ecosystem services and studies that try to forecast effects of different policy/management options on future ecosystem service. Some approaches aim at quantifying ecosystem service provision in biophysical terms, others provide monetary values. Most studies focus on a region and on a few ecosystem services only (Table 2.2, Figure 2.3). For some ecosystem services like carbon sequestration or storage as well as food production global maps are available, but for most ecosystem services global studies commonly provide aggregate number instead of maps (Costanza *et al*., 1997). However diverse the approaches, there are some general similarities. Some services like carbon sequestration, food production and water supply are covered by most studies while others are rarely considered. The approaches for estimating food production, carbon sequestration and water supply are similar between studies: food and timber production estimates are mostly taken from local or global databases (e.g. FAO statistics) while estimates for carbon sequestration, carbon storage and (surface) water supply are derived from biophysical models (mostly WaterGAP, SWAT or WBM for water supply and CENTURY or TEM for carbon sequestration) based on climate and land cover information. Land cover/land use maps and changes in land use are the basis for all studies on ecosystem services and biodiversity loss (Tscharntke *et al*., 2005, Pereira & Cooper, 2005, Foley *et al*., 2005, Metzger *et al*., 2006, Nelson *et al*., 2008, Egoh *et al*., 2008).

Table 2.1: Categorisation of ecosystem services and indicators commonly used. For each ecosystem service an indication is given how often it is included in ecosystem service studies (based on those regional studies listed in Table 2.2)

Ecosystem service	Number of studies out of 24 (from Table 2.2) that include this ES	Indicator
Provisioning		
Food	10	Agricultural production (crop yield)
		Grassland livestock production
		Forage production
Timber	3	Timber harvest
Fuel	0	Fuel wood energy
Fresh water	8	Surface runoff
		Stream discharge
		Water surplus (rainfall-evapotranspiration)
Biochemicals, natural medicines, pharmaceuticals	1	Bioprospecting
Regulating		
Climate regulation	12	Carbon sequestration
		Carbon storage
Water flow/flood regulation	5	Contribution of groundwater to baseflow
		Vegetation cover in watershed, water storage in wetlands
Natural hazard regulation	1	Avalanche protection
Disease regulation	0	(no indicator yet)
Water purification/quality	2	water N or P content
		water sediment loading
Air quality regulation	2	N emissions
Erosion control	3	Soil erosion potential and vegetation cover
		Soil erosion
Waste treatment	1	Removal of nutrients, pathogens metals and sediments
Supporting		
Nutrient cycling	3	Soil fertility
Soil formation	2	Soil organic matter accumulation
		Sedimentation
Primary production	1	NPP
Pollination	3	Distance to natural habitat/proportion of natural habitat
Pest control	2	Distance to natural habitat/proportion of natural habitat
Cultural		
Aesthetic	5	House prices
Recreational	5	Site visitation rate
Spiritual	1	(not specified, value transfer from individual studies)
Educational	0	(No indicator yet)

Pollination and pest control were classified as regulating services by the MA while others consider those to be supporting services (supporting food and timber production). Both pest control and pollination are known to be dependent on animal (mainly insect) abundance and distribution, and can be modelled in relation to distance to natural habitat or landscape composition on the scale of about 1 km (Klein *et al.*, 2003, Kremen *et al.*, 2007). These structures and distances are too small to be considered by global models due to their coarse resolution. Furthermore, pollination is only important for certain crop species and does not apply to cereals and tubers, which constitute the largest amount of food production (Klein *et* *al*., 2007). Most models focus on these staple crops and do not consider other, pollinator-dependent crops. Because of the small scale at which they operate, pollination and pest control are rarely considered in ecosystem service inventories and modelling approaches. The same holds for disease regulation which is hardly explored as an ecosystem service (but see Xu *et al*., 2008). However, all three ecosystem services are closely linked to species diversity (Klein *et al*., 2003, Brownstein *et al*., 2005, Bianchi *et al*., 2006, Jactel & Brockerhoff, 2007) and biodiversity may therefore be a suitable indicator for pest control, disease control and pollination. As an independent analysis the global valuation study of pollination by Gallai *et al*. (2009) can be used to complement a modelling assessment of other ecosystem services. The small scale of these particular services is not only an obstacle to incorporating them into global models/assessments as there are also gaps in knowledge of processes involved (e.g. disease control, air quality regulation by trees).

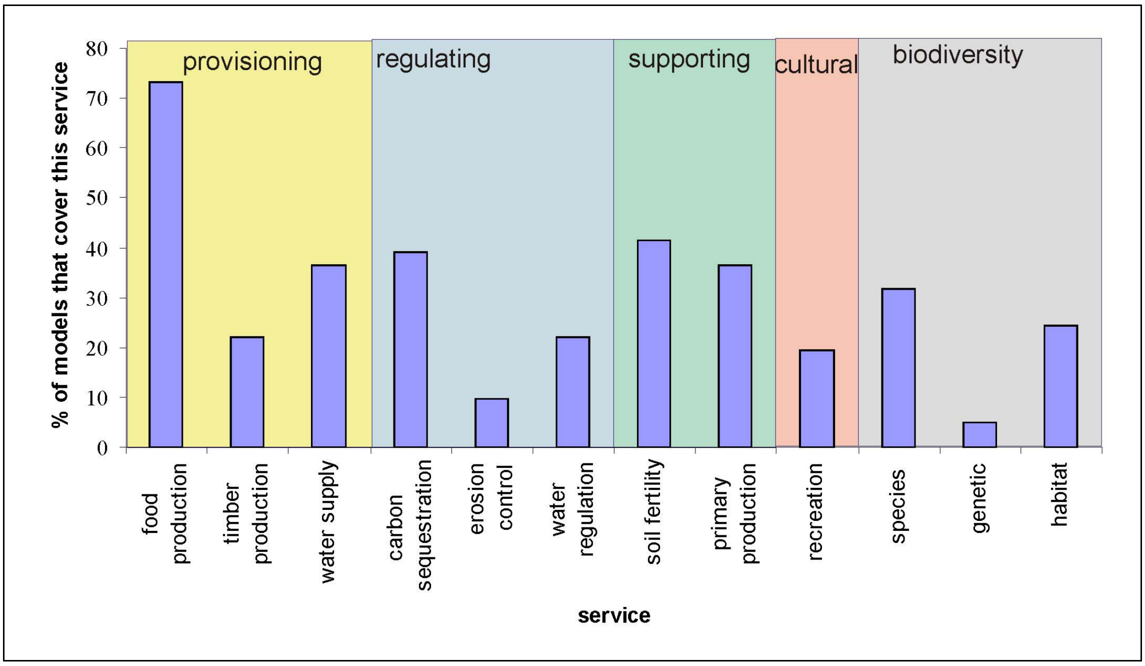


Figure 2.3: Coverage of the different (groups) of ecosystem services and biodiversity measures by the models reviewed. While food production is covered by most models all other services are only included in a small number of models.

Table 2.2: Some examples of regional models/mapping approaches with information about the services covered by the different studies.

Region	**Ecosystem services/indicators covered (either modelled or mapped)**	**Do the models consider future scenarios and if so, which ones?**	**Reference**
Willamette Basin, Oregon	Carbon sequestration, biodiversity conservation, soil conservation, food and timber production	Stakeholder-defined scenarios	InVEST Nelson *et al*., 2009a, Nelson *et al*., 2008
Central Coast ecoregion of California, United States	Carbon storage, flood control, forage production, outdoor recreation, crop pollination, and water provision, biodiversity	No	Chan *et al*., 2006
European Alps	Avalanche protection, timber production, scenic beauty and habitat function	Human development and climate	Gret-Regamey *et al*., 2008
Patuxent River Watershed, Maryland	Water supply, soil nitrogen emission, NPP	18 scenarios	Costanza *et al*., 2002
New Jersey	Climate regulation, disturbance regulation, water regulation, water supply, soil formation, nutrient cycling, waste treatment, pollination, biological control, aesthetic and recreation, cultural and spiritual, habitat function with average annual monetary values	No	Costanza *et al*., 2002 http://www.nj.gov/dep/dsr/naturalcap/
Southeastern Australia	Biodiversity, soil erosion, carbon sequestration, water supply, economics	No	Crossman & Bryan 2009
Uganda	Soil fertility-poverty link (crop yields, labour costs)	No	Schreinemachers *et al*., 2007
Eastern USA	Carbon sequestration, water supply, soil salinisation	No	Jackson *et al*., 2005
2 Minnesota watersheds	Water quality, fish populations, greenhouse gases, carbon sequestration, sedimentation, flooding, farm income	4 scenarios + baseline	Boody *et al*., 2005
Mbaracayu Biosphere Reserve, Eastern Paraguay	Wildlife yield, timber, bio-prospecting, existence value, carbon storage	No	Naidoo & Ricketts, 2006
Murray-Darling watershed	Climate, runoff, water supply	No	CSIRO (http://www.csiro.au/resources/WaterAvailabilityIn Murray-DarlingBasinMDBSY.html)
Goulburn Broken Catchment	Ecosystem service models for different land use types and sub-catchments	Different management scenarios	CSIRO (http://www.ecosystem servicesproject.org/html /case_ studies/goulburn.html)
Piedmont headwater	Fish populations (environmental	10 scenarios	Nelson *et al*., 2009b

Region	Ecosystem services/indicators covered (either modelled or mapped)	Do the models consider future scenarios and if so, which ones?	Reference
streams in the Chesapeake Bay watershed	quality, recreational fishing)		
Organic and conventional farms in Canterbury, New Zealand	Pest control, pollination, soil fertility, food production, hydrological flow, aesthetic values, carbon sequestration, N-fixation	No	Sandhu *et al*., 2008
South Africa	Surface water supply, water regulation, soil retention, soil accumulation (fertility), carbon storage	No	Egoh *et al*., 2008
Massachusetts, Maury Island and 3 Californian counties	Valuation based on land cover mapping	No	Troy & Wilson, 2006
Yangtze River	Water flow regulation and hydroelectric power production, including valuation	No	Guo *et al*., 2000
USA	Carbon sequestration, land use change	Effect of different carbon sequestration policies	Luboski *et al*., 2006
Lake Greifensee, Switzerland	Landscape aesthetics	Effects of payments for farmers on land use	Schüpbach *et al*., 2008
Marine ecosystem, Alaska	Fish yield, wildlife watching, naturalness	Economic scenarios (laissez-faire, regulating taxes)	Eichner & Tschirhart, 2007 GEEM: general equilibrium ecosystem model
Spain	Water use	No	Pulido-Velazquez *et al*., 2008
Eastern Amazon, Brazil	Carbon storage, plant diversity, farm income	Baseline, alternative technologies, PES, taxes	Börner *et al*., 2007
Wells Creek, Minnesota, USA	Water quality, fish populations, greenhouse gas emissions, carbon sequestration, farm income	4 land use scenarios	Boody *et al*., 2005
Southeast Alaska	Fish and wildlife provision and harvest, recreation	No	Beier *et al*., 2008 Geospatial decision support tool

2.2.4 Factors affecting the amount of ecosystem service provision

To assess future conditions of ecosystem services it is important to capture all important processes that affect ecosystem service provisioning. Which ecosystem services and to what degree are provided by a system depends on the biotic and abiotic factors of the ecosystem, especially on climate, vegetation type and community composition. Human modifications of natural systems typically results in changes in vegetation which are therefore expected also to affect the provisioning of ecosystem services. Due to the lack of better approximations, and in accordance with the Millennium Ecosystem Assessment (MA, 2005), ecosystem services are often implicitly assumed to decrease when biodiversity is reduced due to human impact (Chapin *et al*., 2000). However, the relationship between biodiversity and different ecosystem services is not straightforward (Kremen, 2005, Balvanera *et al*., 2006, Chan *et al*., 2006, Naidoo *et al*., 2008). Even though primary production has been found to increase in experimental studies with increasing biodiversity this effect levels out at about ten different species (Hooper *et al*., 2005). Different services relate to different components of biodiversity (e.g. functional groups) and some of these relationships might be correlational rather than causal. For example, with increasing human management intensity both biodiversity and supporting and provisioning services, like climate regulation, decline (Tscharntke *et al*., 2005), while other services like food and timber production increase. The loss of biodiversity in agricultural systems is a direct consequence of the human enhancement of food provisioning services (Hooper *et al*., 2005). The COPI report therefore developed and applied differentiated relationships between biodiversity and ecosystem service provision (Braat & ten Brink, 2008).

Next to land use change, climate change will also affect the local provisioning of ecosystem services by changes in abiotic conditions resulting in shifts of species, ecosystems and biomes. Further pressures on ecosystem services are pollution, the introduction of invasive species (van Wilgen *et al.,* 2008) and ecosystem fragmentation. The main drivers behind these changes are human population growth and economic development, which stimulate the need for increases in agricultural land (i.e. expansion) and productivity (normally through intensification). Policies that aim to reduce the loss of ecosystem services and biodiversity currently tend to focus on alleviating pressures (e.g. by protected area designation) and on the remediation or restoration of sites as it is often less difficult to shield from the influence of global drivers than to reduce their pressure. Studies have shown, however, that the enforcement of protected areas is often insufficient (Soares-Filho *et al*., 2006, Western *et al*., 2009) and may increase the pressure on biodiversity in the surrounding area (ten Brink *et al*., 2007). Removing the pressures is not always sufficient for restoration success and active management is often needed to facilitate restoration and especially the establishment of specific species (Ormerod, 2003, Smith *et al*., 2003, Pywell *et al*., 2003, Sayer *et al*., 2004)..

2.3 Review of models

2.3.1 Model selection and typology

General

An inventory of existing models was made on the basis of expert judgements, recent large assessments (Kok *et al*., 2008) and additional literature and internet research. The models found were grouped and a selection of 41 models was made, including 5 regional studies for the comparison of global and regional approaches. Detailed information on these models is tabulated in Appendices 1.1 - 1.5. The information contained in these tables is further described in Section 2.3.2 together with examples of the tables.

The grouping of models is based on different categorisations:

- the spatial coverage and resolution they operate on:
    - spatially explicit versus non-explicit;
    - global coverage versus local models;
- computational complexity, detail of processes simulated: complex (mechanistic models) versus more simple (empirical-statistical) models;

- analytical technique (empirical-statistical models, equilibrium models); and
- thematic focus (socio-economic models, biophysical models and integrated models, Table 2.3, Figure 2.4)

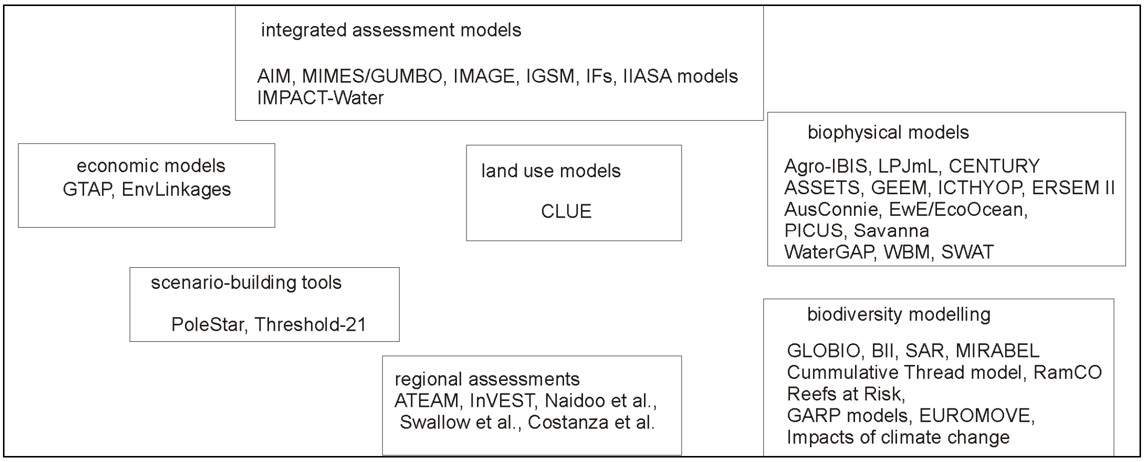


Figure 2.4: Grouping of models covered by this review.

As all of these categories provide important information they are all incorporated in the descriptive tables. A first classification of models was based on their thematic focus (see Table 2.3) as this is most closely related to the driver-pressure-state-impact approach.

Table 2.3: Different types of models based on their thematic focus and the system they depict with examples (bold = models covered in this review). Source: Advanced tools for sustainability assessment, http://ivm5.ivm.vu.nl/sat/

Model type	**Description**
Socioeconomic models	
General economic models	General economy models (GEM) are aggregated representations of an economic system, usually a nation state (or a group of nations). They are "closed" in a sense that they are based on a consistent accounting framework that covers the whole economy. Examples: **GTAP, Env-Linkages,** SNI-AGE, GEM-CCGT
Demographic models	Demography models provide long-term projections of future population changes, based on external scenarios on natural and anthropogenic influences. Examples: PHOENIX, IIASA population project (not explicitly included in the review although most integrated assessment models contain a demographic submodel)
Partial economic models	Partial economic sector models (PEM) have a focus on a certain sector of the economy, for which they provide much more structural detail than multi-sectoral general economy models can do. Sector models work on the simplifying assumption that major feedbacks between the specific sector and the economy as a whole, e.g. effects on employment and growth, can be neglected. Taking macroeconomic conditions and certain prices as given, the allocation and distribution effects within the sector can therefore be looked at more realistically. Moreover, specific environmental conditions and constraints can be taken into account. Examples: **IMPACT**, WATSIM, Poles, CAPRI
Biophysical models	
Climate models	Climate models simulate changes in atmospheric and ocean temperature, precipitation and atmospheric gas compositions of the past and in the future. Examples: HadCM, ECHAM, CLIMBER (these models were not included in the review)

Model type	Description
Hydrological models	Hydrological models contain mathematical descriptions of the major elements of the water system, i.e. rivers, lakes, groundwater, soil, snow. Oceans and atmosphere are usually not considered. They area able to capture the impact of natural (e.g. climate change) and/or anthropogenic (e.g. water withdrawals) disturbances on the fluxes and states of elements in the water cycle, e.g. runoff, evapotranspiration, groundwater recharge and soil moisture. Examples: **WaterGAP, Water Balance Model (WBM), SWAT**
Biogeochemistry models	Biogeochemistry (BGC) models (also called (global) vegetation models) explain vegetation processes (growth, mortality, competition between different vegetation types, disturbances) and related natural energy and matter exchanges (most important elements are H_2O, C, N) between vegetation, soil and the atmosphere, based on climate conditions, soil quality, nutrient and water supply. Some models focus on natural vegetation, while others deal with agricultural crops or forestry only. They can be used to simulate external effects, e.g. climate change, on vegetation growth and related material fluxes, e.g. change in soil carbon, water balances. They can also be used to simulate potential natural vegetation, e.g. for reconstructing past vegetation cover or for excluding current anthropogenic disturbance. Examples: **LPJ, IBIS, CENTURY, ASSETS, GEEM, ICTYOP, ERSEM II, AusConnie, EwE/EcoOcean, PICUS, SAVANNA,** BIOME-BGC, FORESEE, TEM
Integrated models	
Land use models	Spatially-explicit models of land-use and land-cover change (LUCC) typically begin with a digital map of an initial time and then simulate transitions in order to produce a prediction map for a subsequent time (Pontius *et al*., 2007). Land use activities are closely related to societal, environmental, institutional, and economic processes alike. The majority of the Land use change models (LUC) are therefore integrated and attempt to model the coupled human-environment system by including sectors such as agriculture, forestry, transport, or energy. Some LUC focus more on biophysical determinants of human land use activities, while others are more closely linked to economic decision models that treat biophysical conditions as decision constraints. LUC have been applied on very different spatial coverage, ranging from single farms to global coverage. Examples: **CLUE,** AgLU, MAgPIE/LPJ, SFARMOD, FARM, CORMAS
Integrated assessment models	Integrated assessment models try to link, within a single modelling framework, main features of society and economy with the biosphere and the atmosphere. Starting with a focus on the connection between anthropogenic greenhouse gas emissions and climate change, the agenda of Integrated Assessment Models (IAM) now includes aspects of land use, biogeochemistry, hydrology, demography and health. Examples: **AIM, IFs, IGSM, IIASA model family, IMAGE, MIMES/GUMBO, IMPACT-WATER**
Qualitative system analysis models	QSA approaches structure and analyses socio-economic processes and their environmental implications based on qualitative influence (system) diagrams and additional information linked to these. The required information (only the qualitative character of the interactions, like "A enforces the change of B") is less demanding for data providers and can be used under circumstances where quantitative assessments are not available, or where quantitative information is not strictly comparable. Examples: SYNDROMES, QSA-SCENE, QSSI (not included in this review)
Scenario building and planning tools	Scenario Building and Planning (SBP) models are highly integrative tools which are capable of representing a wide variety of social, economic, and environmental aspects of the Earth system. They can be used to develop and structure complex scenarios. Examples: **Threshold-21, PoleStar**

As ecosystem services are produced by the interaction of living organisms with their environment, biophysical ecosystem models are particularly appropriate for the modelling of ecosystem services. *Biophysical models* estimate processes like plant growth, water use, nutrient use, cycling of water nutrients and carbon that are the basis for most ecosystem services. These models include biophysical processes that are responsible for differences in ecosystem services between different natural ecosystems (e.g. forest versus grasslands) and model the effects of climate change on vegetation type. As we have pointed out, ecosystem services are assumed to be affected by human-induced changes in vegetation composition. However, many models of natural ecosystems do not include human-managed lands (arable crops, pasture, tree plantations) and *vice versa*. Biophysical models can forecast the effect of different pressures on ecosystem processes but for the determination of pressures they need input from other models that model pressures resulting from changes in drivers.

To assess the current provision of ecosystem services and to make estimations about future changes in the provisioning of ecosystem services in relation to different policies, the integration of many different models will therefore be necessary. There are few attempts to model ecosystem services spatially over large areas, but a range of sectoral models that could be used for the estimation of separate services. Provisioning services like food and timber production are covered by agricultural models and forestry models. *Biogeochemical models* not only cover plant production but also element cycling (supporting services) and partially water cycling. *Hydrological models* provide information on water supply and regulation and some also on water quality. However, to be able to account for multiple services it is necessary to integrate these sectoral models into a larger framework. Biophysical models have to be connected to *socio-economic models* that predict the drivers in land use change based on different scenario input and provide input for the sectoral models.

Integrated assessment models already provide this integration including feedbacks between different components. For example, the IIASA modelling family includes, next to the emission model group around MESSAGE and MAGICC (the IIASA-ECS modelling), a modelling suite around EUFASOM and EPIC (the IIASA/FOR modelling cluster) that have been used to predict deforestation trends under different carbon prices (Kindermann *et al*., 2006). Land use models can probably be linked with ecosystem services in a more straightforward way because the provisioning of ecosystem services is linked to land use and future changes in land use/land management will affect ecosystem service provision and biodiversity (Lambin *et al*., 2001, Foley *et al*., 2005). Land use models therefore do not only form an important bridge between socio-economic developments and ecosystem service provision but also provide key input-variables (Figure 2.5).

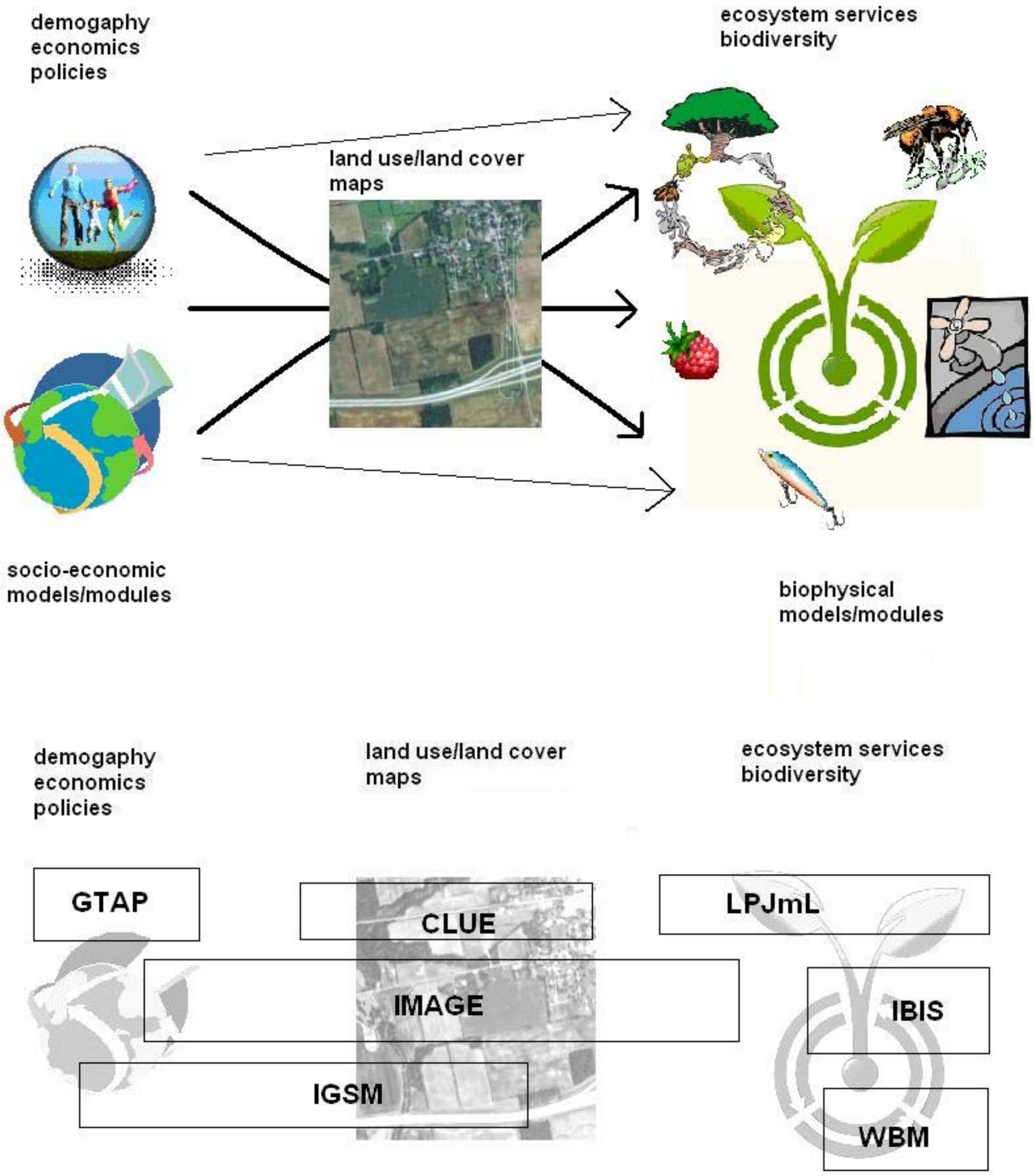


Figure 2.5: (a) Socio-economic and biophysical models can be linked via land use. (b) coverage of the different areas (socio-economics, land use, biophysical cycles) by different models (example).

There are three different approaches to modelling global ecosystem services with specific questions connected to each of them:

1. large, integrated models that have been used for other international assessments: (how can they be used for ecosystem service estimations? Can they be applied for regional assessments as well?);
2. a combination of small, "sectoral" models that model single or few ecosystem services: (how can they be combined to give a consistent picture?); and
3. local modelling approaches: (how can results be upscaled to provide a global picture?).

These three groups of models are, however, not mutually exclusive and do sometimes use the same basic tools.

Biodiversity models

Next to the socio-economic, biophysical and integrated models there is the group of biodiversity models. Biodiversity models may play two distinct roles within the TEEB framework. First they provide estimates/indicators of biodiversity itself. However, biodiversity models have also been used to estimate ecosystem service provision, by either using biodiversity as a direct indicator of ecosystem services or by using functional relationships to translate biodiversity into ecosystem services as in the COPI study (Braat and ten Brink, 2008). Biodiversity models can be separated into indicator-based models (e.g. GLOBIO, BII, SAR, MIRABEL, Cumulative Thread model, RamCO, Reefs at Risk) and species-distribution/climate envelope models (e.g. the GARP model type, EUROMOVE and Impacts of Climate Change). While the first estimate an indicator of biodiversity relative to environmental pressures without considering individual species, the latter predict the distribution of a defined group of species based on their specific climatic niches in relation to changes in the environment. These models require a large detail of information and are mainly used for regional studies; EUROMOVE covering the whole European continent being an exeption.

Selection of models to be described in detail

There are very few global models that have been specifically constructed to predict ecosystem services, except for GUMBO and MIMES. Therefore a broad range of models was reviewed with respect to their suitability for estimating ecosystem services provision. An extensive search of models was performed to gain on overview of models available, based on published scientific articles, handbooks and information from websites. The models were characterised by thematic coverage, input and output variables. A selection was made on the basis of thematic relevance to ecosystem services and biodiversity, frequency of use in global assessments, possibility of calculating different policy scenarios and upscaling (local models) and downscaling (global models) of results. Care was taken to include models from all relevant categories in Table 2.3 and all currently applied integrated assessment models were included that were relevant to ecosystem services (Table 2.1). Furthermore one land-use model, two scenario-building tools and two general economic models were included. For biodiversity models three indicator-based models and two models that estimate species distributions were selected. Biogeochemical models were chosen that incorporate human-modified land as well. Five regional studies of ecosystem services were selected in order to compare their potential with the results from large, global modelling approaches. One of those regional modelling tools, InVEST, is currently used to provide a global assessment of ecosystem services, which has not been published yet, but will be very relevant for TEEB as soon as it becomes available.

Table 2.4 gives an overview of models used in different assessments, providing information on which models have been combined before and the scenarios that they were used together with.

Table 2.4: Overview of combinations of models and scenarios used in (large) assessments

Assessment	Model used	Spatial coverage	Scenarios used	Description
OECD environmental outlook	ENV-Linkages, LEITAP, IMAGE, GUAM, FAIR, WaterGAP, N-balance, GLOBIO,	Global	Single baseline scenario with policy variants on climate policies and different types of carbon taxes	The OECD *Environmental Outlook to 2030* explores possible ways in which the global environment may develop, emphasising the economic rationality of ambitious environmental policy and showing why it is desirable for the OECD to work with large developing countries such as Brazil, Russia, India and China (see also the MNP/OECD background report, MNP/OECD, 2008. Kok *et al*., 2008)
GBO-2 Global biodiversity outlook	GTAP, IMAGE, GLOBIO	Global	Preliminary version of OECD baseline	At the request of the Convention on Biological Diversity (CBD) MNP carried out an investigation on possibilities for limiting the loss of global biodiversity. This was done in preparation for COP8, the 8th Conference of the Parties to the Convention held in Brazil in 2006. (sCBD, 2006; sCBD and MNP, 2007) (Kok *et al*., 2008)
GEO 4	PoleStar, AIM, IMAGE, WaterGAP, EcoOcean, GLOBIO,	Global	Four contrasting scenarios: *Markets First; Policy First; Security First; Sustainability First*	UNEP GEO-*4: Environment for Development* shows how both current and possible future deterioration of the environment can limit people's development options and reduce their quality of life. This assessment emphasises the importance of a healthy environment, both for development and for combating poverty. (Kok *et al*., 2008)
Ag IAASTD	GTEM, G-CGE, CAPSIM-C, IMAGE, SLAM, IMPACT WATER, WATERSIM, GLOBIO, Eco-Ocean	Global	Single baseline scenario with policy variants	The *International Assessment of Agricultural Science and Technology Development* (short title: the *Agriculture Assessment*) assesses developments in agriculture in relation to policy goals, such as reducing hunger and poverty, improving living conditions in rural areas and preserving the quality of the environment and biodiversity. This assessment focuses strongly on the role of technology and agricultural expertise (Kok *et al*., 2008).
MA	IMPACT, IMAGE, WaterGAP, Ecopath, Ecosim, Species area	Global	4 scenarios: *Global Orchestration, Order from Strength, Adapting*	The Millennium Ecosystem Assessment set out to assess the consequences of ecosystem change for human well-being

Assessment	Model used	Spatial coverage	Scenarios used	Description
	relationship (SAR)		*Mosaic, TechnoGarden*	and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. Biological diversity plays a critical role in underpinning ecosystem services (MA, 2005).
WWDR-1,2 and 3	No model projections used	Global		The World Water Development Report of the United Nations looks at water demand and changing water supply due to different socio-economic drivers and climate change (World Water Assessment Programme 2009).
World Water Vision		Global	3 scenarios that focus on issues of water supply and demand, conflict over water resources, and water requirements for nature.	The World Water Vision was conducted by the World Water Council to increase awareness of a rising global water crisis (Cosgrove and Rijsberman 2000). While only a subset of water-related issues and variables were quantified, the scenario narratives extend beyond issues specific to water, including lifestyle choice, technology, demographics, and economics. Some of these additional themes were explored quantitatively in background studies (Kok *et al.*, 2008).
European Environment Outlook	PRIMES, POLES, Prometheus, TIMER, CAPSIM, IMAGE, FAIR, RAINS, EMEP, WaterGAP, UWWT	Europe	Baseline with policy variants	The European environment outlook report assesses the environmental consequences of key socio-economic developments in Europe, particularly with regard to climate change, air quality, water stress and water quality (EEA, 2005).
CA - Comprehensive assessmentof water use in agriculture	Watersim, APSIM	Global	One scenario	The Comprehensive Assessment addresses multiple use, feedbacks, and dynamic interactions between water for production systems, livelihood support, and the environment. It analyzes past and current water development efforts from the perspective of costs, benefits, and impacts, considering society (economic and rural development, increased food security, agricultural development, health, and poverty) and the environment (conservation and degradation of

Assessment	Model used	Spatial coverage	Scenarios used	Description
				ecosystems and agriculture, Comprehensive Assessment of Water Management in Agriculture, 2007)
COPI bio I	GLOBIO	Global	OECD baseline scenario	The COPI study estimated the costs of policy inaction in respect to ecosystem service loss by linking biodiversity loss to changes in ecosystem service provision (Braat and ten Brink 2008).
EURURALIS	LEITAP (modified version of GTAP), IMAGE, CLUE	Europe	4 scenarios with 12 different combinations of policy variants	EURURALIS is a scenario study on the future of rural areas in the EU, assessing the impact of policy measures like the Common Agricultural Policy and biofuel policies (Rienks, 2008).
INSEA Integrated sink enhancement assessment	AROPAj, EFEM-DNDC, EURO-FOR, PICUS, FASOM, AGRIPOL, EPIC			The INSEA focuses on the enhancement of carbon sequestration within Europe and its effects on land use (especially agriculture and forestry).
ATEAM	MAGEC, SUNDIAL, ROTHC, GOTILWA+, EFISCEN, FORGO-HYDRALL, LPJ, STOMATE, Mac-pdm,RHESSys, FORCLIM	Europe	4 scenarios with different policy options	The ATEAM developed a methodology to assess the vulnerability of ecosystem services to climate and land use change, biodiversity loss and pollution (Metzger *et al*., 2006).
Naidoo *et al*. 2008 (PNAS 105, 9495-9500)	TEM, WaterGAP	global		Ecosystem services modelling: Carbon sequestration (TEM model), carbon storage (Global Land Cover 2000 map), grassland production of livestock (FAO and other databases), water provision (WaterGAP)
Swallow *et al*. 2009, (Environ. Scie. & Policy, in press)	SWAT	Lake Victoria basin, East Africa		Ecosystem services: erosion regulation (SWAT), water yield (SWAT), agricultural production

2.3.2 Analysis of selected models

Information presented on the models in the Appendices

The sections below describe information presented on the models in Appendices 1.1 – 1.5 and summarises some of the findings from the analysis. Appendices 1.1 and 1.3 follow the format of a review of ecological models carried out by the EEA (EEA, 2008), and information on four of the models (IFs, EUROMOVE, IMPACT-WATER and CLUE) has been taken from that report. It was not possible to complete all the cells within the tables for all models, e.g.

because no information on that topic was found; indicated in the tables as "*unknown*" - or an empty cell. Other topics were not done or covered by the model (indicated as "*not available*") or refer to variables that are outside the scope of the model, e.g. cultural services for biodiversity models (indicated as "*not applicable*").

Technical description of models
Appendix 1.1 summarises technical information on the models, including their developmental history, accessibility, calibration, validation, spatial coverage and resolution. Most important is the information on data input (i.e. key drivers of the model), model output and level of integration within the model (i.e. the degree to which different modules/submodels are interlinked and feedbacks between components incorporated). An example of the information provided is given in Table 2.5 for IMPACT-WATER, an integrated assessment model that consists of a hydrological and a partial economic model related to agriculture. The row "model type" gives the categorization of the model according to Table 2.3.

The row "input (key drivers)" gives information about which main drivers and input variables are needed. IMPACT-WATER focuses on agriculture and like many other models requires information about future population trends to determine food demand, while climate and water availability limit plant (crop) production. While socio-economic models and integrated models generally all start from population development (from scenario-inputs) biophysical models start from climate and land use change. The next row "output" presents the variables that are generated by the model, including biodiversity and ecosystem services related variables if available. IMPACT-WATER covers food production from crops and livestock and also gives information about per capita food supply.

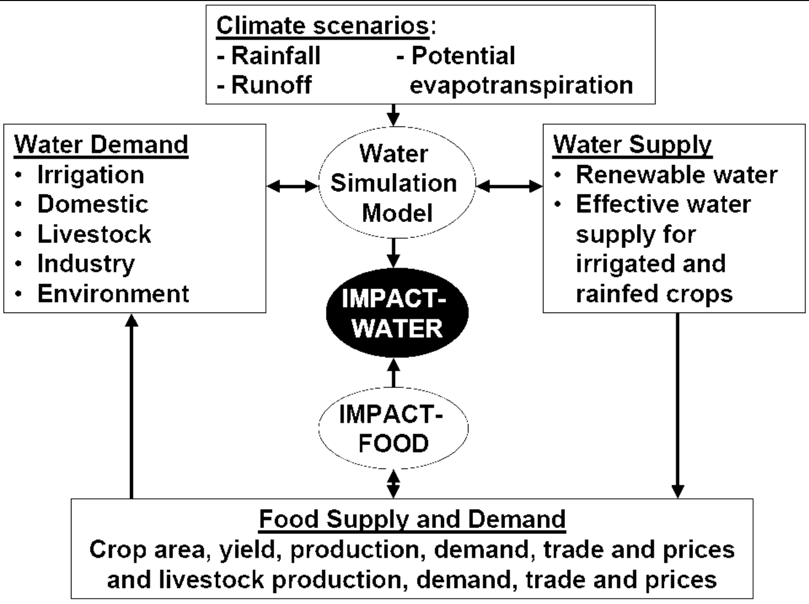
Key input and key output variables give information on how different models might be linked, for example biodiversity or biochemical models for which land use change is the key driver might be linked via land use models (key output: land use change) to socio-economic models that predict the effects of policy scenarios on the socio-economic drivers of land use change. Different types of biodiversity models focus on different key pressures; while land use change is used as the main input for most models that calculate biodiversity indices, climate change is the key driver of the species-distribution models (GARP and EUROMOVE).

It is important to consider the spatial and temporal scale a model works at (for input and output variables) relative to the scale relevant for ecosystem services, and to consider issues involved in upscaling and downscaling of results. The different models have to be compared in terms of detail they can provide relative to what is required for different purposes. Geographical and temporal resolution is covered in the next two rows. Most models are spatially explicit with grid sizes of 0.5 to 5º. Others like IMPACT-WATER aggregate data on a national (especially economic models, GTAP, EnvLinkages, IFs) regional or ecosystem/biome scale (CENTURY, GUMBO) or use more natural units like catchments (especially for hydrological models: SWAT, WaterGAP). Some models like SAVANNA are more flexible in their spatial resolution but covering a large area leads inevitably to a coarser resolution. Temporal resolution varies between daily, monthly or annual time steps. While the model might use daily time steps for calculation, output might be aggregated on an annual level. Biophysical models generally use smaller time steps related to the processes modelled while crop or economic models work with annual time steps. This does not necessary cause any problems when linking models as socio-economic models would predict annual land-cover while biophysical models use this as an input for modelling daily or weekly nutrient and water balances.

“Analytical technique” refers to the type of maths behind the model. Economic models are mostly equilibrium models. Empirical-statistical models are based on statistical relations from a dataset. Dynamic system models are complex models based on causal processes and also include internal feedbacks. Interactive models require participation of users or expert judgment (EEA, 2008).

Table 2.5 Example table from Appendix 1.1 (for all other models see Appendix)

Model name	**IMPACT –WATER**
Full model name	International Model for Policy Analysis of Agricultural Commodities and Trade
Model type	Integrated model (partical equilibrium + hydrological model)
Subtype	Agriculture
Thematic coverage	Agriculture, fishery, water (related to agriculture)
Input (key drivers)	Income, and population growth (to determine food and non-agricultural water demand), Crop productivity (depends on various drivers, incl. agricultural research), Change in available agricultural area over time, climate parameters, plus irrigation and water supply information, trade policies
Output (key variables)	Crop area, yield, production, demand for food, feed and other uses, prices, Livestock numbers, yield, production, demand, prices, Net trade in 32 agricultural commodities (virtually all global food trade), Percentage and number of malnourished preschool children, Per-capita calorie availability from foods
Geographical coverage and resolution	Global: 115 regions and countries, intersected with 126 river basins (281 spatial units), including EU-15 and eastern Europe
Temporal coverage and resolution	Base: 2000 until 2020/2025/2050, with annual time steps
Analytical technique	Partial equilibrium model (sectoral agricultural model)
Model developers and/or owners	International Food Policy Research Institute (IFPRI) of the CGIAR Network
Model development history	1st version of IMPACT was developed 1990-2000, latest version: 2005 The partial equilibrium model IMPACT was coupled to the hydrological model WSM to create IMPACT-WATER to be able to include climate change effects (water availability) on agriculture production.
Target Group/users	Aim was to help achieve long-term vision and consensus among policy makers and researchers about the actions that are necessary to feed the world in the future, reduce poverty, and protect the natural resource base. IMPACT has been used in numerous international environmental assessments (such as World Water Vision, Millennium Ecosystem Assessment). Currently being used in UNEP's Global Environmental Outlook (GEO-4) and the International Assessment of Agricultural Science and Technology for Development (IAASTD).
Calibration	Model uses the UN Medium Variant Population growth projections, and follows the global hydrology patterns embodied from the climate data provided by the Climate Research Unit of the University of East Anglia. The streamflow and runoff data have been calibrated to WaterGAP of the University of Kassel.
Validation	IMPACT has been used in a historical counterfactual analysis that accurately produced the historical record of agricultural production and consumption from 1970 to 2000.
Uncertainty analysis	Climate uncertainty is explored with the use of alternative GCM scenarios, which are downscaled to the spatial units of IMPACT.
Key reference	Rosegrant *et al.* (2005) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT-WATER): Model Description (available at www.ifpri.org/themes/impact/impactwater.pdf)
Level of integration	Water is the key environmental component which is directly integrated into the model structure. Response to water availability is measured in terms of yield loss (relative to full potential). IMPACT-WATER is the only model that takes into

	account water availability for food production (other models assume that water for irrigation is available).
Links to other models	The IMPACT model has been linked to a range of models in international assessments, such as GTEM (AustraliaBARE), IMAGE (PBL, Netherlands), AIM (Nat'l Inst for Env Studies, Japan) and WaterGAP (Univ. of Kassel).
Ease of use/accessibility	Ease-of-use is very limited (i.e. referring to the full version of IMPACT). IFPRI has developed a distributional version (IMPACT-D) that can be downloaded free of charge (www.IFPRI.org/themes/impact/impactd.asp).
Website	http://www.ifpri.org/themes/impact.htm
Comments/remarks	Description has been taken from EEA, 2008
Model structure	

The rows "calibration", "validation" and "uncertainty analysis" provide information about whether or not such analyses have been done and give references if applicable. The "level of integration" refers to the interlinkages between the different components and submodels and the internal feedbacks. IMPACT-WATER for example is the only model that considers water availability for irrigation purposes when estimating crop yields while the other models assume that sufficient water is available for agriculture. The "link to other models" gives studies in which the model has been linked (or used together with) other models, providing information about which models can be used in combination. IMPACT-WATER for example has already been combined with two of the large assessment models, IMAGE and AIM. The row "ease of use/accessibility" mainly indicates whether the model is freely available (either on a website or on request from the authors). However, training is required for all models to be able to operate them and interpret their results. Hence, in case one wishes to use a certain model for an assessment contact and cooperation with the developers/owners is essential.

Key references and the link to the model website are given for a more detailed description of the model and its outputs. The publication record differs for the various models. Some like AIM and PoleStar have little or no publications in peer-reviewed journals but they have been used in global assessments. Others, such as many biophysical models have many peer-reviewed publications but they have not been included in global assessments yet. For MIMES no outputs have been published although global maps are available in a PowerPointpresentation on the web, which indicates that a global analysis has been done with this model[2].

The diagram within the row "model structure" gives an overview over the different model components and the links between them. For the IMPACT-WATER model it can be seen that water supply is calculated based on a hydrological model with climate as main driver while water demand is estimated from food demand and production via a socio-economic module. Ecosystem services can be approached from two different directions. One can estimate service demand (e.g. food or water demand based on human population size and water needed for agriculture and industry) or service supply (e.g. carbon sequestration, erosion control). The relationship between supply and demand is needed for economic valuation of services and it is also necessary to differentiate between potential services and services that actually benefit humans. While mangrove forest have been shown to reduce flood risk at coasts this only benefits humans if the area they protect is actually inhabited. Pollination and pest control services also only apply to land used for agriculture or forestry. The models differ in whether they approach a certain service from the supply or demand side or both. While WaterGAP, IMPACT-WATER and the IIASA models estimates both water supply and water demand separately, IMAGE estimates global food demand and allocates land accordingly to agriculture to match this demand.

Coverage of ecosystem services

Appendix 1.2 provides details on the ecosystem services covered by the models either explicitly or implicitly. Ecosystem services (and indicators of ecosystem services) listed here can either be input or output variables, as well as intermediate variables. Some of these ecosystem service indicators might be estimated by the model while not commonly extracted as key output variables. For example biogeochemical models usually contain a water cycle module and enable the calculation of water supply (precipitation minus evapotranspiration), and hydrological models contain a vegetation-submodel, that estimates primary production. As an example the table is shown for three of the biogeochemical models (Table 2.6). While PICUS focuses on forests and therefore only provides information about timber production, Agro-IBIS is a general vegetation model that includes next to plant production also a hydrological module estimating water supply. SAVANNA is a whole biome model including crop, timber and livestock production as well as water supply. The supporting services covered within the biogeochemical models are quite similar; most include a nitrogen cycle module and estimate primary productivity. An exception is LPJmL which currently does not include nitrogen although this is an important factor limiting plant growth (LeBauer & Treseder, 2008). Currently, joint research between PIK, WUR and PBL is started to redress this missing factor in conjunction with other yield limiting and reducing factors such as water (like already covered in IMPACT-WATER), pests and land management (included in CENTURY) in a combination of IMAGE and LPJmL.

Next to the biogeophysical models (marine and terrestrial), supporting services are only covered by a few of the integrated assessment models, and mostly those also estimate nitrogen cycling, net primary production or soil formation. As regulating services, carbon sequestration and water regulation are mostly covered. Carbon sequestration and carbon storage has been the focus of climate change scenarios starting with IPCC and mitigation strategies and

[2] http://www.gulfofmaine.org/EBMWorkGroups/docs/Roelof-Boumans-presentation-at-Oct2007-WorkGroup1-2-meeting.pdf

different policy options have been examined by most integrated assessment models as well as global vegetation models. Cultural services are only covered by MIMES/GUMBO and several of the marine models, and mainly refers to recreation. The marine models selected are generally biophysical models with complex biotic interactions and focus on the effects of fisheries on the trophic system.

Table 2.6. Example of Appendix 1.2 tables for some biogeochemical models

	Model name	PICUS	Agro-IBIS	SAVANNA
Ecosystem services	**Provisioning services**	timber production	water supply, crop production,	livestock production, grass and timber production, water supply (runoff, deep drainage)
	Supporting services	nitrogen cycling in forests	NPP, SOC, N balance	NPP, nutrient cycling
	Regulating services	carbon sequestration, soil moisture (water cycling)	carbon flux, N leaching, water regulation	water balance
	Cultural services	Not available	Not available	Not available
biodiversity	**Species diversity**	forest species composition (diversity, naturalness indicators)	Vegetation composition (functional types)	Species distribution and abundance (plants + animals)
	Genetic diversity	Not available	Not available	Not available
	Ecosystem diversity	forest species composition	Vegetation composition	community composition

Appendix 1.2 also contains information on measures of biodiversity, split into species diversity, genetic diversity and ecosystem diversity. Most biodiversity models focus on indicators of species diversity, while genetic diversity is hardly incorporated into biodiversity modelling. For studies on genetic diversity on the species level look at Watson-Jones *et al.*, (2006), Silvertown *et al.*, (2009, experimental) and Avise (2008).

Ecosystem/landscape diversity modelling is seldom explicitly included as well (Roy & Tomar, 2000); however, it should be possible to derive an index of landscape diversity from spatially explicit land cover models. Global vegetation models (biogeochemistry models) provide an indication of natural vegetation composition, although commonly limited to some different functional groups of plants that are distinguished. On the species level there are two different approaches for deriving indicators of species diversity, while climate envelope models actually model the distribution of specific species. The later require detailed information on species presence for model calibration. As biodiversity is generally not covered by any of the other models, one of the biodiversity models has to be linked to one of the other general models to provide an indication of biodiversity if required.

Usability of selected models for TEEB

Appendix 1.3 summarises the most important information from the first tables on drivers, pressures and ecosystems services, and the detail and range of those covered by the different models. For an example see Table 2.7. "International acknowledgement" includes information on the use of the models in assessments and the amount of publications available. MIMES is a relatively new model which has not been published or used in any assessments yet, which makes it difficult to evaluate its strengths and weaknesses. Other models like AIM have been used successfully in global assessments, but have not resulted in many publications in peer-reviewed journals. Biogeophysical models have an extensive publication record, but they have not been included in global assessments yet (presumably because crop production is covered by all integrated models as well, although mostly less detailed and mainly from the demand side), while hydrological models are often included in global assessments. Biogeochemistry models have been used mainly for carbon sequestration and climate change effects on vegetation distribution and crop production.

The "width of spectrum of drivers" summarizes the information on input/drivers from tables in Appendix 1.1 and gives an indication whether the model is mainly driven by socio-economic (directly, integrated assessment models, socio-economic models), land use change (biodiversity models and biophysical models) or climatic and environmental variables (rainfall, soil fertility, biophysical models) and whether there are several independent drivers.

Table 2.7: Example of Appendix 1.3 tables for some of the integrated assessment models

Model name	**MIMES**	**AIM**	**IGSM**	**IIASA Integrated Assessment Modeling Framework**
International acknowledgement	Not published yet, large number of collaborators, high level of publicity, including politics (see website)	Has been used in many assessments (IPCC, GEO), widely accepted (esp. in Asia), little scientific literature.	Widely accepted, many publications	Widely accepted, many publications, used in IIASA assessments (e.g Global Energy Assessment)
Width of spectrum of drivers	Key drivers are human population development and investment	Broad range of socio-economic drivers	Broad range of socio-economic drivers	Broad range of socio-economic drivers
Width of spectrum of goods and services covered	Very large, all areas covered	Provisioning (water, timber, food), and regulating (climate regulation, air quality, human health, flood damage)	Agriculture, climate regulation , air quality, human health, sea level	Provisioning, climate regualation
Richness of detail including sectoral detail	Very high: large number of variables and parameters	High	High amount of sectoral detail, especially in the energy sector (different energy sources), agriculture, transport, plus biogeochemical modelling	High
Possibility of upscaling/ downscaling	The MIMES at this stage represented a general model scalable in time and space to be applied in global, regional and	5º by 5º resolution, application on scale close to this or lower does not provide useful results	0.5º by 0.5º resolution, application on scale close to this or lower does not provide useful	5' by 5' resolution, application on scale close to this or lower does not provide useful results

Model name	MIMES	AIM	IGSM	IIASA Integrated Assessment Modeling Framework
	local models		results	
Effects of European policies on global level?	Unknown	Yes	Yes	Yes
Operational access for TEEB	Model is available for download: http://www.uvm.edu/giee/mimes2/downloads.html	Model not available online	Model not available online	Models not available online
Known plans for maintenance and development	The different submodels for the ecosystem services are constantly improved by the users	Improvement of carbon cycle module; estimate the impacts of climate change on water resources, flood risks, forests, agriculture, coastal zones, human health (vector-born diseases) (especially in Asia); further developments concern water demand and trade modelling and a detailed crop production model with fertilizer and pesticide loads and N_2O emissions; fruit production.	Improvements on the resolution of the climate submodel	Various activities are ongoing related to modelling of bio-energy production, REDD-related carbon trade options, analysis of organic and precision farming and natural hazard mitigation strategies.

"Width of spectrum of goods and services covered" again gives the services that are explicitly or implicitly covered by the model. AIM and IGSM for example include indicators of flood damage and respectively sea level rise and they also include air quality and human health effects. Like MIMES, the regional approaches cover a wider range of ecosystem services, including tourism and pollination services. Naidoo *et al.* (2008) present a mapping rather than modelling of ecosystem services that is partly based on biophysical models but does not contain any predictions for future changes. However, their approach is based on land use and could therefore be linked to a land-use model to create a predictive model. The InVEST model has also been applied at a regional as well as on a global scale and demonstrates the possibility of using basic regional level models for global assessments.

"Richness of detail" refers to the amount of detail incorporated in the different submodules, e.g. the number of different economic sectors considered as well as the detail within the biogeochemical processes.

"Known plans for development" were inferred from statements placed on the model‘s websites as far as available, expanded with personal information. The time and resources for this study did not allow for a more systematic consultation of all models. Some models, such as EUROMOVE or MIRABEL, are not developed any further, but most others are constantly updated with enhanced and additional modules and more detailed information. For MIMES, users are constantly adding their own submodels therefore there are for instance several different modules for cultural services (R. Bouwmans, pers. com.) and a marine application is also forthcoming.

Important developments within the described models in terms of economics of ecosystem services are the development of a water quality module for WaterGAP and AIM, further additions to the human health/disease module and inclusion of water demand in AIM; the integration of a general equilibrium interface into IMPACT-WATER and natural hazard mitigation modelling at the IIASA. At the IIASA work is focussing on carbon-related policy options like REDD, but also on organic agriculture and precision farming. Various institutes are working on the link between biophysical models (especially LPJ) and land use and economic models (IMAGE, MAgPIE). Within EcoOcean/EwE an MSA-like indicator for marine biodiversity is being developed. Earlier work on coupling EcoOcean with IMPACT is scheduled to be revisited, allowing for incorporation of feedbacks between ecosystem services and economics. Coupling of IMAGE with agro-econmic models, e.g. LEI-GTAP and IMPACT, has proved instrumental in exploring trade-offs between expanding some ecosystem services (e.g. bio-energy production, carbon storage and biodiversity) and others such as food provisioning. Ongoing and planned projects aim to extend and improve these analyses.

New models specifically focussed on ecosystem services are currently being developed at the PIK Potsdam in collaboration with other institutes and organisations. Their approach is to combine LPJ with forest models (4C), hydrological models (SWIM) and further new models to assess the effects of changes in land use and climate on biodiversity and the provisioning of ecosystem services on a regional to continental scale.[3] At Lund University the focus is also on climate change and land use change effects on biodiversity and ecosystem services, for example carbon stocks, water availability and air quality. One of the models used in Lund is LPJ-GUESS which will be improved in terms of carbon-nitrogen coupling and plant dispersal[4].

It seems that the current development is generally focussed towards the inclusion of (more) detailed biophysical models for an estimation of ecosystem services. Addressing effects of changes in ecosystem services (other than food production) on socio-economic developments will probably only be the next logical step after an increased understanding of the supply, demand and changes in ecosystem services as well as their substitutability has been reached.

Summary of models with respect to drivers, pressures and impacts

Appendix 1.4 summarizes the models with respect to the driver-pressure-impact framework: including which drivers and pressures are taken into account, which ecosystem processes are modelled and which indicators provided, and whether there a link to human well-being or monetarisation. Information is also included on land-use and whether models focus on natural land and/or managed land. Land-use is a key variable linking scenarios/policies/socio-economic developments with effects on biodiversity and ecosystem services provision.

[3] http://www.pik-potsdam.de/research/research-domains/earth-system-analysis/projects/biodiversity/goal-statement

[4] research program of Lund University, see: http://lucci.lu.se/wp5.html

Ecosystem services and biodiversity are also directly affected by changes in land-use (Foley *et al*., 2005, Metzger *et al*., 2006). An example of Appendix 1.4 is shown below for some of the (terrestrial) biodiversity models (Table 2.8). The main drivers included in most biodiversity models are climate change and land use change (habitat loss). Other pressures such as pollution are only covered by GLOBIO, MIRABEL and the SAR approach of the MA (MA, 2005d). None of the models deals with the effects of invasive species, despite their well documented impacts on global biodiversity. Biodiversity models do not directly include explicit policy options; instead these are fed into the models via their impacts on climate or land use. Next to biodiversity no ecosystem services or ecosystem functions are covered by the current terrestrial biodiversity models and no link with human well-being is provided. On the other hand, all other terrestrial models do not provide indications of biodiversity. There are, however, several marine models, that cover both biodiversity and ecosystem services.

Table 2.8. Examples of Appendix 1.4 tables for biodiversity models

Model name	**GLOBIO**	**Biodiversity intactness index**	**Species area relationship (SAR)**	**GARP-based species distribution models**	**EUROMOVE**
Natural drivers and environmental pressures	Climate change	None	Climate change	Climate change	Climate change
Human drivers	Land-use change, N deposition, infrastructure, fragmentation	Land-use	Habitat loss and fragmentation (land use change), N deposition	None (via greenhouse gas emissions)	Land-use
Policies	Via IMAGE	Via land use	Via land use	Via climate change	Via climate change and land use
Land-use	Spacially explicit (input variable)	Spatially explicit, classification: from protected to moderate use, degraded, cultivated, urban and plantation	Not spatially explicit (aggregated biogeographical units)	Spatially explicit	Spatially explicit
Biodiversity	MSA (mean species abundance of original species)	Biodiversity intactness index	Number of species	Number of species, species distribution	Number of species, species distribution
Ecosystem function	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Ecosystem services	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
Economic value/human well-being	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

Land-use has been pointed out as the crucial link in modelling before, not only between socio-economic factors and ecosystem services but also as a potential handle for policy options (e.g. limiting land-use change by prohibiting deforestation, or creating protected areas). Most policy options (e.g. carbon taxes, subsidies, targets for use of biofuel) directly result in land use change by changes in the trade-off between different land uses. To effectively influence global habitat conversion these trade-offs between different land uses (e.g. agriculture versus forests) need to be explored more thoroughly.

2.4 Review of scenarios

2.4.1 Selection of scenarios

There are three different types of scenarios (Börjeson *et al*., 2006):

- **Baseline trend scenarios** (predictive scenarios) assume that current trends will continue in the future, and may include policy variants for different likely developments of sectors based on near-future decision alternatives. They address the question ‘what will happen?’

- **Normative scenarios** (or pathway or vision scenarios) describe a desirable future or set a specific goal for the future (e.g. halting biodiversity loss by 2010 or stabilizing greenhouse gas emissions at 450 ppm CO_2 equivalents) and explore possible ways to reach that goal. They address the question ‘how do we get there?’

- **Explorative scenarios** (forecasting, descriptive scenarios) work the other way around, they are created to forecast the effect of specified measures (policies) on future development and conditions. They address the question ‘where do we end up?’ Explorative scenarios either address the effects of different policies or other measures (strategic) or alternative developments of other factors (external).

There is a gradual difference between predictive/trend scenarios that incorporate possible future decisions and explorative scenarios, the latter considering longer time scales and more profound changes. They are usually more “visionary” than trend scenarios and divert from current developments, by not aiming at what is most likely to happen but to look at other, less likely options (plausible alternative futures).

The focus of this scenario review was on scenarios that were used in combination with the selected models to ensure that a discussion of results and assumptions of model and scenario outputs is possible. Further criteria for scenario selection were the international acknowledgement (frequency of use/reference) and the scenarios had to be relevant in terms of a focus on policy options instead of a focus on changes in lifestyle (e.g. diet change scenarios, Stehfest *et al*., 2009).

2.4.2 Review of scenarios

Description on scenarios

Following a similar format to the model descriptions, Appendix 1.5 (for example see Table 2.9) presents general information on the different scenarios, while Table 2.10 summarises the information relevant for the TEEB. The tables start with a general description of the narrative behind the selected scenario and the ‘correspondence with other scenarios’. Most scenarios used are based on the four normative scenarios of the Global Scenario Group (GSG) with some variation in the implementation.

There are three ‘types of scenarios’: normative, explorative and trend scenarios. The GSG scenarios are the only normative scenarios considered; however, some of the climate policy variants of the OECD baseline (which is a trend scenario) also use a normative approach. Global assessments mostly use explorative scenarios that are formulated in a narrative way (e.g. Millennium Ecosystem Assessment, Global Environmental Outlook). Another common approach is to compare a baseline that assumes business as usual with a number of specified policy variants (e.g. OECD Environmental Outlook, IAAST Ag Assessment).

The next row gives the ‘type of policies’ that have been specified within the scenario. The descriptions of most scenarios are rather vague, with little detail specified on which policies or developments are considered for specific sectors. For the implementation of these scenarios a large amount of work is necessary to translate those general, qualitative trends with quantitative model inputs. The focus of most scenarios lies on trade restrictions (none in GSG ‘open market’ and related scenarios versus national trade restriction in GSG ‘fortress world’ and related scenarios) and policies related to greenhouse gas emissions.

The following rows give information about the development of the scenarios, on aims, the developers and whether or not stakeholders were involved. ‘Domains considered’ refer to the areas that were considered during scenario development and incorporated in the models used. The row ‘main actors’ indicates which are considered to be the socio-economic drivers behind future changes. For most assessments narrative scenarios were formulated that had to be translated into drivers of change. Key drivers addressed in the scenarios were:

- population development;
- economic development, including changes in per capita GDP and economic structure;
- technology development, i.e. increased nutrient and water use efficiently, increased area-based crop yields;
- human behaviour (lifestyle); and
- institutional factors (trade barriers, taxes, subsidies).

For example GSG ‘open market’ and related scenarios consider economic issues and trade as the main determinants of future development, cost-benefit relations will determine land use allocations in these types of scenarios. The GSG ‘policy reform’ scenario assumes global policies to be most important, which can include the restriction of land use (e.g. ban on deforestation, creation of conservation areas/nature reserves). The GSG scenario ‘new sustainability’ or the related GEO-4 ‘sustainability first combine effects of governmental policies with individual life style changes (e.g. changes in diet) as main drivers for development.

Table 2.9: Examples of scenario characterisation tables from Appendix 1.5

Scenario name	**GEO-4: *Sustainability First***
Description	*Sustainability First* gives equal weight to environmental and socio-economic policies, accountability, and it stresses transparency and legitimacy across all actors. It emphasizes the development of effective public-private sector partnerships not only in the context of projects but in the area of governance, ensuring that stakeholders across the environment-development discourse spectrum provide strategic input to policy making and implementation.
Correspondence with other scenarios	GSG new sustainability, SRES B1, MA *Adapting Mosaic*, WWV *Values and Lifestyles*, WBCSD *Jazz.*
Type of scenario	Explorative
Policies specified	Strong global management, climate mitigation, air pollution, protect species diversity and ecosystem services.
Purpose	UNEP GEO-4: Environment for Development shows how both current and possible future deterioration of the environment can limit people's development options and reduce their quality of life. This assessment emphasises the importance of a healthy environment, both for development and for combating poverty.
Authorizing environment	UNEP: The scenarios were developed through a lengthy collaborative process that began with four of the GSG scenarios, which were then refined through a series of regional and global meetings (Raskin and Kemp-Benedict, 2002), with input from the IPCC's Special Report on Emissions Scenarios. The emphasis of the process was on refining the narratives and giving them regional texture. A consortium of modeling teams elaborated on different aspects of the scenarios (Potting and Bakkes, 2004).
Stakeholders involved in the development	Expert Group Meeting
Time horizon and resolution	2050
Spatial coverage and resolution	Global
Domains mainly considered	Population, economic activity, government (energy prices, taxes, environmental policies), lifestyle, technology, land use limitations.
Main actors	Economy, government and individual behaviour
Comments	

Scenario name	**OECD-ccglobal2008**
Description	This policy variant implies an immediate implementation of carbon taxes worldwide.
Correspondence with other scenarios	GSG policy reform, MA *TechnoGarden*, GEO *Policy First*, WWV *Technology*, WBSCD *GEOpolity*,
Type of scenario	Trend (explorative)
Policies specified	Uniform global carbon tax, starting in 2008
Purpose	The focus of the Outlook is the critical environmental concerns facing OECD countries, but the study is global in scope. The aim is the exploration of options to reduce climate change and greenhouse gas emissions.
Authorizing environment	OECD
Stakeholders involved in the development	Unknown
Time horizon and resolution	2005 to 2030 (policies) respectively 2050 (impacts)
Spatial coverage and resolution	Global, for policies: OECD, BRIC and the rest of the world, spatial resolution of effects: 0.5º grid.
Domains mainly considered	Agricultural production and trade, energy sector (mitigation of climate change, control of urban air pollution), sewage treatment.
Main actors	Global policies
Comments	The Outlook examined drivers of environmental change, specific

	sectors that put the greatest pressure on the environment, and resulting environmental impacts. The focus of the Outlook is the critical environmental concerns facing OECD countries, but the study is global in scope. Global economic patterns were modeled using the OECD's JOBS model. These drivers were then used as inputs to the PoleStar System to assess potential environmental impacts in the scenarios.

The different baseline with policy options scenarios, for example the OECD-ccglobal2008 shown in Table 2.7, focus on the impact of policy options, therefore global or national governmental policies are the main actors in these. The focus of the OECD environmental outlook was climate change mitigation, therefore the policy options consider different targets for CO_2 emissions either globally or for the OECD countries. The consequences of land use changes resulting from the policies were examined.

Table 2.10 summarises the information for all groups of scenarios. Part of this table was taken from Westhoek *et al*. (2006). An estimation is given for the international acknowledgement and the richness of detail included, and also a list of models that have been used with the specific scenario, indicating for which models scenario inputs have been specified already. As the IMAGE model has been included in many assessments this model has also been used together with most of the scenarios.

Table 2.10 Scenario summary with information relevant for TEEB

Scenario name	Type	International acknowledgement	Width of spectrum of drivers	Richness of detail including sectoral detail	Models that have been used with scenario
IPCC-SRES	Explorative	Very high	Wide set of quantitative indicators	Limited	AIM, IMAGE
MA	Explorative	High	Wide set of quantitative indicators	High	IMPACT, IMAGE, WaterGAP, EwE, SAR
GEO-4	Explorative	High	Wide set of quantitative indicators	High	AIM, IMAGE, PoleStar, WaterGAP, EwE & EcoOcean
GSG	Normative	High, sres, ma and geo-scenarios are based on gsg scenarios, however, gsg scenarios are normative instead of explorative	Narrative	Limited	PoleStar
OECD baseline	Trend with policy options	High	Wide set of quantitative indicators	High	WaterGAP, IMAGE, GLOBIO
IAASTD baseline	Trend with policy options	Moderate	Wide set of quantitative indicators	High	IMAGE, IMPACT-WATER, GLOBIO, EcoOcean (EwE)
EURuralis	Explorative with policy options	Moderate (high within europe)	Moderate	Moderate	GTAP, IMAGE, CLUE
WWV	Explorative	Limited to water management community	Moderate	Moderate	
WBCSD	Explorative	Limited	Moderate	Moderate	
ATEAM	Explorative with policy options	Moderate	Moderate	Moderate	

2.5 Insights, gaps, strengths and weaknesses of the various approaches

2.5.1 Models

There are several approaches towards global mapping and modelling of ecosystem services. For example, Naidoo *et al*. (2008) combine databases on livestock production with GIS data on carbon storage and modelling of carbon sequestration and water supply for mapping purposes with no integration of the different components. The global ecosystem models GUMBO and MIMES are meta-models that make use of well-established correlative relationships between different variables that are incorporated in mechanistic models like AIM, IMAGE, CLUE, WaterGAP, CENTURY and BIOME. Their advantage is that by using this short-cut they require less computational effort, and the higher degree of inter-linkages between the different components as well as the inclusion of feedbacks between the different modules. InVEST and ATEAM take a similar approach for local/regional ecosystem service modelling. Common to all these modelling approaches is that they build on existing models by either incorporating them or equivalent modules, increasing mainly the inter-linkages and feedbacks between components.

MIMES is very flexible in the respect that different submodules exist for certain services so that the user can (and must) chose the most appropriate one. Furthermore, own modules can be constructed and included although this requires knowledge of the model construction and the relationships that are to be modelled. InVEST allows different levels of detail to be included depending on data availability for the specific region.

The incorporation and integration of the different components (modules) and the interactions and feedbacks between these is one of the crucial points in modelling. Some important points that need to be covered/addressed by the models are:

- Does irrigated agriculture take into account water availability? This is only done within IMPACT-WATER while many other models assume that sufficient water is available for irrigation (i.e. no link between water supply and demand)
- Are there feedbacks between changes in land use/climate/ecosystem services to socio-economic development? Most models do not include this crucial link, except for food and water provisioning. However, MIMES and GUMBO do include more feedbacks. These feedbacks are essential if one wants to examine the costs and benefits of measure that aim to maintain biodiversity and ecosystem services. If the feedbacks from services to economies are not included then only the costs of these measures can be estimated, and not the benefits.
- Are the drivers modelled explicitly or are they assumed to follow a long-term trend?
- Are differences in technology incorporated (i.e. fishing-techniques, grazing versus stable-fed livestock, irrigation and fertilization)? Different agricultural management systems are explicitly included in the CENTURY model.
- Are dynamic processes and time lags incorporated? Like feedbacks, these are little considered, also due to the fact that little is known about exact thresholds in ecosystem service provision and minimum requirements before an ecosystem service is lost.

Process-based integrated assessment models (which were usually developed for other purposes than ecosystem service modelling) include a variety of modules that are potentially relevant to ecosystem service estimation. Although many commonly used ecosystem service indicators are calculated, most are not key outputs but are included in some intermediate step.

Such general integrated models also contain socio-economic modules that cover the whole breadth of driver-pressure-state-impact relationships, although they often lack response feedbacks. The climate policy response model FAIR has been developed as part of the IMAGE framework and is used extensively to explore alternative international climate regimes with consideration of effectiveness, efficiency, equity and cost/benefit estimates. A somewhat similar response model is under development to address broader human development and sustainability policies such as the UN MDGs. MIMES and GUMBO are the only models that incorporate feedback from ecosystem services to economic development.

As integrated assessment models mainly consist of interlinked sectoral models, the use of separate sectoral models in general has no advantages over integrated models which are usually better linked than a collection of sectoral models. However, for specific questions the use of sectoral models that provide a higher level of detail (e.g. forestry models that include different management options) or incorporate relevant processes can be necessary. Figure 2.6 presents different ways of combining models for an assessment all with different advantages and disadvantages. Using a single model/model combination as in Figure 2.6 (A) has the advantage of ensuring the highest possible degree of consistency while depending heavily on the underlying assumptions. The other extreme would be to use a large number of specialized sectoral models (one per service) under the same scenario inputs and assemble the output of all models. This can be quite risky, however, as the assumptions (and therefore also the output) of the different model might be conflicting. The most advisable combination for the modelling of ecosystem services at the current stage would be to use a combination of different models unified by one central integrated assessment model to provide consistency between the models. The optimal approach would be to use two different integrated models (for examples MIMES and IMAGE with several other more detailed sectoral models linked to IMAGE) and compare the outputs of the two.

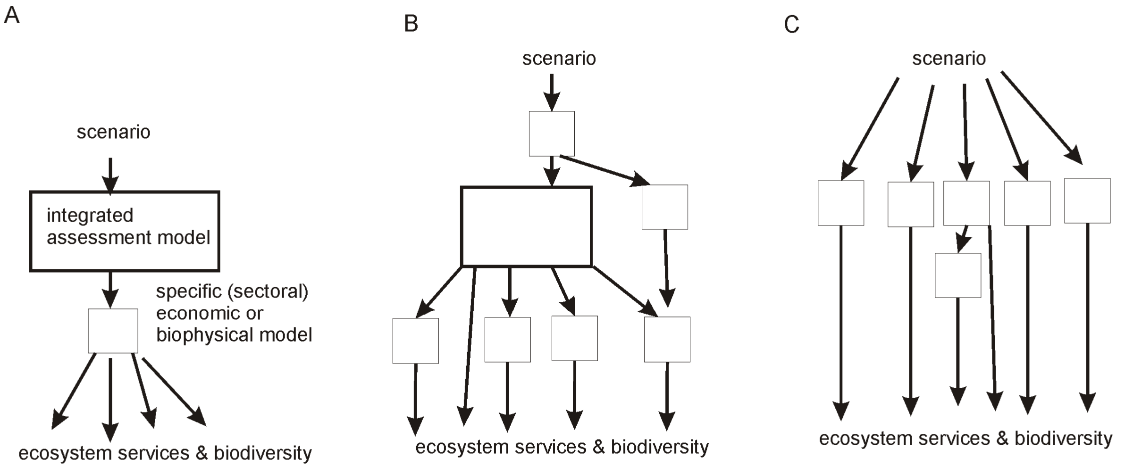


Figure 2.6: Different modelling options: (a) represents the COPI-approach of linking all ecosystem services to biodiversity derived from a combination of two models. (b) represents a combination of different sectoral models linked via an integrated assessment model to ensure the consistency of the scenario-input. (c) represents the modelling of ecosystem services by a series of sectoral models, that derive the scenario-input independently.

For different ecosystem services different spatial and temporal scales are relevant for supply and demand (Hein *et al*., 2006). Carbon sequestration is acting on a global scale, while water supply is a regional (watershed) phenomenon and soil fertility maintenance or food production occur at much smaller scales. One might expect that regional modelling approaches would be more suitable to capture small-scale processes/ecosystem services. For example, Graymore *et al.* (2008) found that indicators of sustainable development developed for national and global assessments were unable to capture processes on the regional level correctly. However, the different modelling approaches (regional versus global) do not differ in the components they use for different ecosystem services; both approaches mainly use similar/identical small-scale biophysical models (WaterGAP, CENTURY, LPJ) to estimate water use and carbon sequestration while deriving crop yields and economic data from national databases. Therefore only the spatial resolution (the level of landscape detail that can be incorporated) differs between regional and global models. Furthermore, although the different ecosystem services like climate regulation, water regulation and soil fertility act on different spatial scales (climate regulation via carbon fluxes is a global process, while water supply acts at a basin scale) but all three of them are based on processes on a much smaller scale, namely plant uptake of water and carbon within a patch. Biogeochemical models generally base their estimations on such small-scale processes.

Biogeochemical models like SAVANNA that have been developed for specific biomes mostly focus on specific processes considered relevant for that particular system (e.g. tree-grass competition in savannas, population dynamics of large vertebrates), while for other processes the level of detail might be equivalent or even lower compared to general vegetation models. It is therefore unclear whether they provide any advantages except in relation to very specific questions. However, a certainly relevant distinction between biomes/ecosystems would be the one between terrestrial and aquatic/marine systems.

The main difference between global and regional models lies in the development of scenarios and policy options and their effects on future land cover distributions. Local modelling approaches generally include more detailed information on current land cover. They frequently incorporate participatory modelling (expert judgements) for predictions of future land cover maps and determine which effects certain actions would have (e.g. Videira *et al.*, 2009). Regional models also focus more on lower-level, smaller-scale management options. Expert opinions and estimates are sometimes also the basis of ecosystem service quantification, instead of model estimates. These approaches are only feasible for rather small areas and it would be difficult to extrapolate such results to a global level, but on the local level they probably provide better estimates and by including stakeholders in the development of the assessment they also create a large base for actual measures.

The main constraint on ecosystem service modelling is that the data available for different ecosystem services are scarce and on a very coarse scale (Chan *et al.*, 2008); the same applies for information on human management practices. Little is known about critical thresholds and time lags between biophysical effects and ecosystem service impacts, and the possibility for and time-scale of the recovery of ecosystems. Consequently these issues/processes are not addressed in models.

One of the challenges in modelling ecosystem services is the incorporation of human managed lands, including various management options compared to natural systems (Kucharik and Twine, 2007). For the estimation of future ecosystem services and biodiversity land-use change is an important pressure, which must be spatially modelled. Agricultural models like the CENTURY model include this kind of detail for agricultural practices. Land cover models or modules within larger models are important intermediate steps/links between socio-economic and biophysical models/modules.

Another important point is that feedback links between environmental conditions and socio-economic development are usually missing (except in the cases of GUMBO and MIMES). While socio-economic developments affect ecosystem services, a reduction in ecosystem service provision does not result in any consequences for economic development. This lack of consequences (within the models) makes it impossible to estimate the benefits of measures to maintain ecosystem services and only the costs of those measures are included. The loss of ecosystem services might actually have no effect on economic development, but only as long as technological substitutions are available (e.g. soil nutrient loss can be compensated by fertiliser input as long as enough money is available to purchase fertilizers; Swift *et al*., 2004).

One of the ideas behind the concept of ecosystem services was to provide an argument for the conservation of biodiversity based on the assumed close link between the two. Recent studies have examined whether areas selected for biodiversity conservation are actually also beneficial for ecosystem service provision; which did not seem to be the case for the services considered by Naidoo *et al*. (2008). Both biodiversity and ecosystem services are tightly linked to land cover/land use issues although not in all cases in the same way. There are, however, ecosystem services that are very closely linked to biodiversity, for example bioprospecting, pollination and pest control. These include services that are difficult to quantify and biodiversity might be an appropriate indicator.

Assessment of costs and benefits of policies for ecosystem services and biodiversity

It has become clear from Task 1 that there is still limited knowledge on the consequences for human societies of changes in ecosystem services. Feedback of changes in ecosystem services and biodiversity on socio-economic developments is lacking within most of the current models. Quantitative information on this feedback, however, is crucial in estimating costs and benefits of different policies aiming at the conservation of biodiversity and ecosystem services. Up to now mainly the effectiveness (*i.e.* the consequences for biodiversity and some ecosystem services) and in some cases also the costs (Lewandrowski *et al*., 1999, Sathaye *et al.,* 2006, Naidoo & Adamowicz, 2006, sCBD, 2006, OECD, 2008, Kindermann *et al.,* 2008, Butler *et al*., 2009, Venter *et al*., 2009) of these policies have been assessed.

Within the Global Biodiversity Outlook (sCBD, 2006, sCBD & MNP, 2007) the effects of six different scenarios on global biodiversity, nitrogen deposition and GDP (the later as an indicator of costs) were evaluated. The OECD Environmental Outlook (OECD, 2008) looked at the effects of policy options on biodiversity, climate change, water and air pollution, fisheries and also made an effort to estimate the costs of policy inaction. However, the authors state that the estimated costs serve rather to identify problems than to provide policy guidelines. Costs of policy inactions were also estimated by Braat *et al*., (2008). The cost estimates these assessments came up with are discussed in Chapter 3. Lewandrowski *et al.* (1999) estimated the costs of increasing the amount of protected areas in terms of GDP and food production, focussing on the loss of certain provisioning services as a consequence of protection. The studies of Sathaye *et al.* (2006), Kinderman *et al*., (2006) and Venter *et al.* (2009) estimate the costs in terms of carbon pricing to effectively reduce deforestation. Other studies compare the economic effects of several management options for small areas (Naidoo & Adamowicz, 2005, Naidoo & Adamowicz, 2006). Gallai *et al.,* (2009) estimated the global value of pollination to agricultural production as the value of global production depending on pollination.

Valuation of ecosystem services is not so much about putting a number on global biodiversity or natural ecosystems (as done by Costanza *et al.,* 1997), but to compare the effects (in terms of costs and benefits) of different managements or different policies. Valuation of ecosystem services requires a detailed knowledge of the supply of and demand for ecosystem services and the substitutability of different services (Bockstael *et al*., 2000). Most current models focus on estimating ecosystem services in physical units which is sufficient to compare the positive and negative effects of different scenarios/policy options for separate ecosystem services. Trade-offs between different ecosystem services can be made explicit with these tools (Nelson *et al*., 2009a). These physical measures of ecosystem services may afterwards be converted to monetary values to facilitate comparisons of trade-offs between different options which result in changes in several services. Monetarisation is also important for comparing the costs and benefits of conserving/restoring certain ecosystem services with the use of substitutes (e.g. placement of bee hives versus use of natural pollinators, use of pesticides or biological control versus natural pest control, dams and dykes versus natural water storage and flood protection).

Issues of upscaling for economic values based on case studies are much more complicated than for biophysical units although biological processes are characterised by complex dynamics, interactions and non-linear effects of changes, which makes their modelling challenging, too (Chee, 2004). However, supply and demand functions necessary for the valuation of ecosystem services are often site specific and context-dependent (Bockstael *et al*., 2000, Woodward & Wui, 2001). Therefore cost-benefit analyses are always context-dependent, as they depend on the location and the surroundings, the specific conditions and alternatives (Bockstael *et al*., 2000) and results from case studies are difficult to apply for global modelling approaches. Butler *et al*. (2009) highlight that the effectiveness of carbon prices for reducing deforestations critically depends on the economics of alternative land uses. For global cost-benefit analysis therefore a much higher level of detail is required than for the estimation of the biophysical supply of most ecosystem services. More or less consistent data to support such detailed estimates, accounting for the highly inhomogeneous nature, are typically lacking.

Furthermore, for the estimation of costs of certain policies the issues and level of detail included varies greatly. For example, should the cost of increasing the extent of protected areas be measured mainly as direct costs of area purchase, establishment and maintenance (Balmford *et al.,* 2003, Naidoo & Adamowicz, 2005), are effects on reductions on other services (food production, timber production) the main costs (sCBD, 2006) and are secondary effects on food prices and global as well as local economies (social welfare costs, OECD, 2008) included?

Consequently models that address these issues have been applied at small scales. Balmford *et al.* (2002) reviewed five studies on the total economic value of different management/policy options, all of those came to the conclusion that the loss of ecosystem services was higher than the benefits of land conversion from low intensity use to high intensity use. Also general equilibrium ecological-economic models for the trade-off between different options have been used for smaller-system estimations. For example, Eichner & Tschirhart (2007) present a model of a marine ecosystem consisting of nine species to estimate optimal management for fish harvest and tourism. Another example is given in the study of Norgaard & Jin (2008) where they examine the effect of trade on the protection of domestic ecosystem services (*e.g.* food production) that can also be imported from elsewhere.

There is clearly an important role of cost-benefit analysis within the analysis of different policy options, however this may lie much more in the first phase of modelling the effects of policies on the decisions of individuals and companies to determine the effects of these policies on land use changes. Furthermore, valuation is necessary to effectively design measure like payments for ecosystem services to distribute costs and benefits evenly between the different stakeholders (users and providers). These valuation studies/models can and should be conducted on a local level to take into account local circumstances. However, in terms of effectiveness of measures and trade-offs between different services at a global scale other measures than monetary values may play a role (e.g. biophysical units of demand, sufficiency).

2.5.2 Scenarios

While for most models the pressures (in scenario terms: direct drivers) climate change and land use change were found to be the key input variables, the description of scenarios focuses on (indirect) drivers like technological development, human population development, economics including trade and policies. Socio-economic models are necessary to translate/link the scenario drivers to the pressures. However, deriving quantitative input variables from primarily narrative scenarios is a crucial task and the process is often not well documented (but see MA, 2005d: scenarios in chapter 2 and chapter 9).

Scenario-building tools like PoleStar and Threshold 21 are used to derive policy options for normative scenarios and are crucial for backwards-modelling approaches (starting from a desired/specified end-stage).

Several large assessments have used scenarios that were broadly similar (SRES, GSG, MA, GEO, MIMES; MA, 2005a). These scenarios build on the GSG scenarios and focus on economic development and economic policies (fast versus slow growth, trade liberalisation versus trade barriers). Another focus is the energy sector and climate mitigation (e.g. in terms of policies aimed at biofuels or carbon taxes). Both economic and energy developments can have large effects on land use and thereby affect ecosystem services in the future. However, there are also some examples where environmental policies are explicitly stated in scenarios (e.g. the sustainability first and policies first scenario of GEO 4, SRES B1 and EURuralis scenarios). Within each scenario it is important to realize which processes depend on policy options and for which factors it is assumed that they follow long-term trends.

Which kind of scenario approach is most useful depends on the questions that should be addressed. Tests of the effects of specific policies require scenarios that are based on historical trends with different variants (e.g. OECD baseline + policy options), while exploratory scenarios examine different possible futures (more and less desirable ones and their consequences). They need more elaborate ideas about changes in various sectors to be able to explore possible future directions. If the aim is to find a means to reach specified goals normative scenarios are necessary. None of the presented scenarios is more suitable for future assessments than others. However, the effects of different specified policies can best be compared by a single baseline scenario with different policy options specifically developed for that purpose and the models that are going to be used. The formulation of such policy options and their incorporation into existing models is the crucial step in such assessments.

Scenarios like those built for global assessments provide opportunities to assess the possible effects of different policies on land use and climate change, which have been identified as the main pressures on ecosystem services and biodiversity. Current approaches, however, do not adequately distinguish between different types of land management (tillage versus non-tillage, organic farming, or environmentally sensitive versus intensive production). These management types are expected to have important consequences for the delivery of ecosystem services within human-managed land. The global scenarios described (and the models they are used in combination with) do not incorporate sufficient detail to, for example, determine whether or not such measures are likely to be taken by individual farmers.

To develop meaningful scenarios to compare the effects of different policies on ecosystem services and biodiversity several factors have to be taken into consideration. The goal should be to assess the effects of different policy options on ecosystem services like water supply, agriculture, recreation, biodiversity and forest cover (i.e. carbon sequestration); therefore the scenarios should focus on the relevant drivers of biodiversity and ecosystem service change. The most relevant pressures differ between biomes and include habitat change, climate change, invasive species, overexploitation and pollution (MA, 2005). To be able to draw conclusions from the different options, the drivers need to be explicitly and separately included. The policy options should focus on the main pressures which have to be reduced/minimized. Possible policy options that could be compared are: payments for environmental services (PES), mitigation, off-setting, subsidies, caps and reduction of deforestation and degradation (REDD) options. The effects of most of these policies on and land and sea use changes and associated ecosystem services can be assessed by the models currently available.

2.6 General Conclusions and Recommendations

Available models: what they can do

Modelling tools available today are able to capture various forms of ecosystem service provisioning to a reasonable degree. Some services like water supply, carbon sequestration, food and timber production and erosion control are covered by most integrated approaches. However, other services like pest control and pollination as well as cultural services other than recreation are rarely included. These are assumed to be correlated to biodiversity, and could be addressed in models through a biodiversity indicator.

Meta-models like MIMES or InVEST and the vulnerability tool of ATEAM are promising approaches. They are accessible and user-friendly tools that provide estimates for a wide range of ecosystem services. They incorporate many feedbacks between sectors, including feedback from ecosystem services to socio-economic developments, but like all other models they rely on the same limited knowledge about ecosystem service supply in different natural, semi-natural and human-managed systems, and on process-based models to provide the basic physical relationships.

Alternative biodiversity indicators

An important point is the choice of appropriate indicators, which must be scientifically sound and also easy to understand in terms of relevance for impacts and responsive actions. Creating alternative biodiversity indicators based on existing model chains would enhance flexibility. There is a perceived limitation that a choice for a given model chain automatically means that one and only one (biodiversity) indicator can be used to express the modelling results. Providing a choice of indicators based on the same, existing model chains may remove this misconception.

It is important to keep in mind that even though biodiversity might be a suitable approximation for some supporting and regulating services like pollination and pest control there is no simple, linear relationship between ecosystem services and biodiversity, let alone the complex interplay of different services. Therefore, biodiversity impacts cannot generally be reliably used to estimate economic losses of reduced capacity to provide ecosystems goods and services. Although this area is full of conceptual and empirical difficulties as well as differences in viewpoint, there may be virtue in experimenting with a larger variety of indicators than just cost or GDP effect– for example, by incorporating risk assessment.

Marine models
Available ocean models show a good record in terms of ecosystem goods and services provisioning in close relation with biodiversity impacts, however, they are typically not well connected to broader, interlinked socio-economic and physical assessments and models for terrestrial systems. So improved links with more integrated approaches would offer important additional value. Especially important is the trade-off between food production from different marine and terrestrial sources (fish from catches and aquaculture versus arable crops versus livestock products) and the direct link to river and ocean nutrient loads. Some work is underway on this.

Other pressures on ecosystem services: Invasive species
None of the models cover biodiversity risks, and likely associated losses of ecosystem services, from invasive species with the exception of climate change induced biome changes. The main reason being that most observed invasive species related incidents are very specific for sectors, regions, species, invasion pathways and supporting vectors. This makes them hard to trace in more generic process-based models, and unsuited for forward looking assessments. Probabilistic methods, instead of firm causal relationships, might provide some guidance. This approach may, for example, capture the higher likelihood of transferring species to new environments from enhanced levels of trade and travel. Another starting point for modelling is the higher probability of establishment of introduced species in areas with reduced biodiversity.

Assessments require combinations of multiple tools
Although we reviewed a large number of different models, for a global assessment of biodiversity and ecosystem services the choice of models is much more limited than it might seem. There is no single model that covers the whole range from socio-economic developments, policy inputs, environmental and land use change, and biodiversity and ecosystem services for terrestrial and aquatic systems together. Therefore multi-model combinations are needed to generate comprehensive and internally consistent results. Preferably, the combination will include economic as well as biophysical modelling of water and plant growth and natural as well as agricultural systems. Obviously, these separate models have to be properly linked, and land-use is the most obvious linkage.

For assessments aiming at a global coverage it is convenient to use an integrated assessment model (IAM) framework, because these already contain well calibrated, hard-linked variables across a substantial range of relevant sectors. Besides they have a good track record in making valuable contributions in the vast majority of all recent comprehensive global assessments. However, even such large IAM models are currently insufficient to cover it all, and will need to be complemented further by additional components, such as linked marine models.

Teams rather than models
The appropriate unit to evaluate the sort of tools discussed in this study is a team, e.g. a group of model developers, – not a model. After all, the models reviewed here are most effective when used as combinations - combinations of models, of models with scenarios, and of

models, scenarios and other tools in the specific analytical setting of a specific assessment. Moreover, making forward looking assessments is not a science but a craft, with an important role for creative interpretation. All this points to the fact that the analytical team - or consortium of teams - is the locus of reproducible analysis. In other words, presenting models, scenarios and such as independently transferable units of knowledge is not realistic. However, these attempts at more objective evaluation of the models can only go so far. In the end, the track-record of the teams involved and their availability to contribute to new assessments on relative short notice are just as decisive, if not more, than the model features.

Scenarios: Construct new ones or use of existing scenarios?

Which scenario-approach (trends with policy options, explorative or normative) is most useful will depend on the specific questions and time and resources available. These factors will also determine whether the inclusion of more detailed sectoral or region-specific models is needed. Therefore, it is not useful to pre-empt a preference for certain scenario types without specific knowledge of its intended purpose and which options are to be compared. However, for the analysis of likely effects of specific policies the use of a baseline scenario with different well-specified policy options is generally the most suitable approach. Biodiversity and ecosystem assessments typically require the inclusion of slow cumulative changes and system inertia. Thus, biodiversity and ecosystem service assessments may well need to have an impact window that stretches further out in time than the policy window, in order to give a fair comparison of the impact of policy options. Therefore, a ‘good’ scenario for biodiversity and ecosystem service assessments includes projections of the basic drivers in the system some decades beyond the formal end date of the exercise.

Scale matters

While the key mechanisms and processes behind ecosystem service provision (water, carbon and nutrient balances, plant growth) and modelling thereof are the same at each scale, differences in the spatial resolution of the model determine the amount of detail that can be captured. Global models cannot practically include the small-scale heterogeneity of a landscape (e.g. presence of buffer strips and hedgerows) that is needed to be able to draw conclusions on pollination and pest-control effects. Socio-economic processes take place at a much larger spatial and temporal scale than the small scale of fields and watersheds that are relevant for ecosystem services, and the linkage of biophysical models with socio-economic models needs to consider feedbacks between both systems. The incorporation of feedbacks between biophysical processes/ecosystem service provision and socio-economic developments is an important step towards better forecasts of future developments not only related to effect of ecosystem service loss. Land cover and land use - in both quantitative and qualitative terms - form important intermediate parameters that do not only provide a linkage between socio-economic and biophysical processes but also direct links to ecosystem services. The detailed modelling of land use including agro-ecosystems, agroforestry and tree plantations with different management practices is a challenge for modellers but is necessary to improve the precision of estimates of ecosystem services as well as biodiversity. Making modern classifications (that build on the notion that human and natural systems are part of a fine-mesh mosaic of mostly cultural landscape) suitable for prospective modelling would help to make modelling results meaningful, especially in a European context.

Global or region-specific modelling?

Results from global models cannot be downscaled to regions or ecosystems that are in the same order of magnitude than the models’ resolution. In recent assessments, the land-use components of IAMs are typically addressed at 0.5x0.5 degrees grid-cells, approximately 50x50 km around the equator.

Advantages of regional models

Next to covering a finer resolution of the landscape, regional models have the advantage that they can account for relevant aspects of global economics and policies, and developments like climate change while they also relate to local processes and conditions (e.g. example different drivers that may be important for some regions but not for others). For example, agriculture expansion is the main cause of biodiversity loss in Brazil while in many parts of Europe it is urban sprawl. In addition, in some cases, region-specific models are more trusted by parties in the region. Nested models can be useful; and standard regional classifications would make nesting easier.

There is little difference between global and regional models in the approaches used but in the level of detail provided. Local (place-based) assessments have the advantage of incorporating small-scale heterogeneity that cannot be properly capture by coarse-resolution global models, however they require more detailed input data. Ideally therefore both approaches should to be combined when looking at large-scale and small-scale effects of policy decisions. An important factor determining their potential for disaggregating results from global to national or regional level, however, is that models should be spatially explicit, or should at least incorporate a link to land use. The most important difference is that models with a smaller geographic coverage offer the possibility to include much more meaningful management and policy options. Sufficient detail is not available at the global scale and effects of options and policies can only be estimated by crude proxies and general parameter estimates.

Ideal approach: combine different model and compare several approaches

Comparing the results of these different approaches would give an indication about the gaps and uncertainties in the underlying mechanisms and consistent results between the different models would provide a greater confidence in the results. The choice of which models to use and to link does not only depend on the quality of each separate model but also on the interactions between the different model components. Another important factor are the teams of people behind the different models and the cooperation between the different teams to combine the different model to create a meaningful, congruent assessment.

But it is not only the combination of different approaches that might help to overcome limitations of individual models. It would be very useful as well to compare several different model-combinations such as one ‘traditional’ integrated assessment model linked with several sectoral models, currently developing tools like MIMES and/or InVEST.

Impact of actions in the EU and elsewhere

One immediate advantage of tools with worldwide coverage is that they support discussion of EU actions (or non-action) in a worldwide framework. This is not to say that these models and scenarios automatically show causality between EU-based actions and biodiversity changes outside the EU.

Linkage to economic sectors and countries

Although most models and model/scenario combinations include causal linkages between activities in society and impacts on biodiversity and several ecosystem services, the effects cannot easily be expressed in meaningful terms for economic sectors, countries or target groups of policy. It is our impression that such a coupling – in a way that is flexible enough to support analysis of alternative policies - will remain problematic for biodiversity issues, because they typically are downstream in a complex web of relations.

Including feedbacks will remain difficult and controversial, but some experimentation can be useful

To make clear what ecosystems and biodiversity deliver to society and to provide incentives for policy interventions, it is crucial to include feedbacks from changes in biodiversity and ecosystem services to socio-economic development (*i.e.* negative effects of reductions of ecosystem services on human well-being, if and where those can be identified). Today these feedbacks are rarely considered at all, which leads to model results that can estimate only partial costs but not the full benefits of management/policy options.

3 OVERVIEW OF RESULTS FROM MODELS FOR THE LOSS OF BIODIVERSITY AND ECOSYSTEMS AND THEIR SERVICES

3.1 Description of Task 2 from the ToR

The contractor should provide an assessment of the main findings from the models identified as part of Task 1. This should include:

(1) an analysis of the impacts of current and future pressures on biodiversity and ecosystems and their services at the global level, and
(2) the impact of policies to reduce such losses.

3.2 Introduction

3.2.1 Purpose of this chapter

As stated in the study's terms of reference, this chapter aims to provide an assessment of the main findings of the models described in Chapter 2 as used in the recent key global assessments listed in Section 1.1. In addition, given the international interest in the potential of Reducing Emissions from Deforestation and Degradation (REDD) financial incentive mechanisms, this report considers a number of papers that model the potential impact that these policies could have.

This review focuses on the biodiversity and ecosystem-related messages of the assessments. In particular it looks at what the assessments say about the future trends and pressures on biodiversity and ecosystem services, and the impacts of pursuing different policy options on these. It also summarises some of the assessments' conclusions with respect to progress towards global policy goals, in particular the Convention on Biological Diversity (CBD) target and Millennium Development Goals. It is intended that these results will provide TEEB with a clear description of what the assessments say about policy options to reduce pressures on biodiversity and ecosystem services.

Brief assessments are given here of some of the limitations of the assessments and their underlying models, but these issues and the sensitivity of the models to key assumptions are described in detail in the Chapter 4.

3.2.2 Description of the assessments used in the report

The assessments reviewed here use a range of scenarios (indicated in this report in italics) with different underlying policy approaches and assumptions. These can be loosely grouped together given the similar characteristics of some of the scenarios used in different assessments (see Table 3.1). The GBO-2, IAASTD and OECD Outlook all use a 'business as usual' baseline scenario with variations to examine the impact of specific policies. These are not included in this table but are referred to in the body of the report where appropriate. The scenarios in the International Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) (IPCC 2000) are a well-known set of scenarios and although they are not referred to in this report they are included in the table as a reference.

Table 3.1. The most important parameters of the scenarios and examples of different categories of scenarios used in the assessments. Adapted from Kok *et al.* (2008)

For more details on the scenarios see Appendix 2.3.

Parameters of scenarios	**Categories of scenarios**					
	Conventional markets	**Reformed markets**	**Global sustainable development**	**Competition between regions**	**Regional sustainable development**	**'Business as usual'**
Examples in the assessments	IPCCA1, GEO-4 *Markets First*	GEO-4 *Policy First*, MA *Global Orchestration*, Policy cases in the OECD and IAASTD	IPCC B1, GEO-4 *Sustainability First*, MA *Techno Garden*	IPCCA2, GEO-4 *Security First*, MA *Order from Strength*	IPCC B2, MA *Adapting Mosaic*	OECD baseline scenario, IAASTD reference scenario and GBO-2 baseline scenario.
Economic development	Very rapid	Rapid	Slow to rapid (depending on the region)	Slow	From average to rapid	Average (globalisation)
Population growth	Low	Low	Low	High	Average	Average
Technological development	Rapid	Rapid	From average to rapid	Slow	From slow to rapid	Average
Primary goals	Economic growth	Different goals	Global sustainability	Security	Local sustainability	Not defined
Environmental protection	Reactive	Both reactive and proactive	Proactive	Reactive	Proactive	Both reactive and proactive
Trade	Globalisation	Globalisation	Globalisation	Trade barriers	Trade barriers	Weak globalisation
Policy and institutions	Policy creates open markets	Policy limits market failures	Strong global management	Strong national policy	Local management, local actors	Mixed

3.3 Methodology and structure of this chapter

This chapter builds on the results from Chapter 2. Each document listed in Table 2.4 of Chapter 2 was examined to identify the models which describe trends in biodiversity and ecosystem services. These models are listed in Appendix 2.1. Models were examined in more detail (Appendix 2.2) for which specific details of the impact on biodiversity and ecosystem services in relation to policy scenarios were available. The table provides projections under each scenario examined in the assessment and the pressures and drivers influencing those projections.

All of the reviewed assessments consider the likely trends in key drivers of biodiversity and ecosystem change, and therefore these are briefly reviewed first. The main part of this report then considers the results of the assessments with respect to terrestrial, marine and then freshwater biodiversity. These are reviewed in separate sections as they tend to be examined in different models. In each of these sections relevant assessments' results are discussed in relation to progress with the achievement of global policy goals (i.e. the CBD target and

MDGs), the main pressures on biodiversity, the impacts of policy interventions and finally the limitations of the assessments.

3.4 Drivers of changes in biodiversity and ecosystems

According to the Millennium Ecosystem Assessment (2003) a driver is: ‘any natural or human induced factor that directly or indirectly causes a change in an ecosystem’. In this review we follow the well known Driver-Pressure-State-Impact-Response, and refer to direct drivers as pressures. Such pressures are most commonly biological or physical in nature and include land use change, climate change and nitrogen deposition. The effects that pressures have on ecosystems can be more easily identified and measured (with differing degrees of accuracy) than drivers (indirect drivers in the MA terminology), which are most often the underlying cause of changes to ecosystems, acting on the direct drivers such as those stated above.

There are many important drivers of ecosystems which include population rise, economic growth, energy use, agricultural production and consumption as well as socio-economic change in marine and coastal ecosystems. The overall projected trends of a number of the important drivers according to some of the assessments are shown in Figure 3.1. Drivers can usefully be grouped into broader headings including: demographic drivers, economic drivers (such as consumption, production and globalisation), socio-political drivers and cultural and religious drivers (Nelson *et al.* 2006). In terms of demographic drivers, population projections for the year 2050 vary amongst the assessments studied from just under eight billion (GEO-4 *Sustainability First*) to nine and a half billion people (MA *Order from Strength* scenario).

Economic drivers are projected to play an increasing role in terms of their effect on ecosystems. Global economic activity increased nearly sevenfold between 1950 and 2000 and is expected to grow again by a further three- to sixfold as measured by gross domestic product (GDP) by 2050 (MA, 2005b). Global economic growth is projected under all scenarios up to the year 2050. The largest overall rise in GDP is projected under scenarios where maximising economic growth comprises a large part, or all of the primary goals (e.g. GEO4 *Markets First* and *Policy First* scenarios). Across all of the assessments, including baseline projections, energy use is expected to increase. Highest energy usage is projected under scenarios following a conventional markets approach (GEO4 *Markets First*, MA *Global Orchestration*) which see significant increases in global trade. Energy usage under these scenarios is projected to increase to over 1000 EJ (Exajoule or 10^{18} Joules) in 2050 (from a baseline of 400 EJ in the year 2000). In comparison, other scenarios project that energy use will increase to approximately 500 EJ (in sustainability focussed futures) to 800 EJ (e.g. GEO4 *Security First*, MA *Order from Strength*) by 2050. In terms of agricultural production and consumption, the baseline scenario projected under the OECD assessment sees global consumption increase 50 per cent by 2030 with a corresponding increase in production. The IAASTD projects that by 2050, agricultural land worldwide will have increased by ten per cent.

In terms of policy actions affecting indirect drivers on ecosystems, national and regional decision makers have more control than local decision makers through their influence over macroeconomic policy, technology development, property rights, trade barriers, prices and markets (MA, 2003). The indirect impacts that drivers exert on terrestrial, marine and freshwater ecosystems are explored further in Sections 3.5-7 below, in terms of the progress in achieving policy goals, pressures and policy interventions.

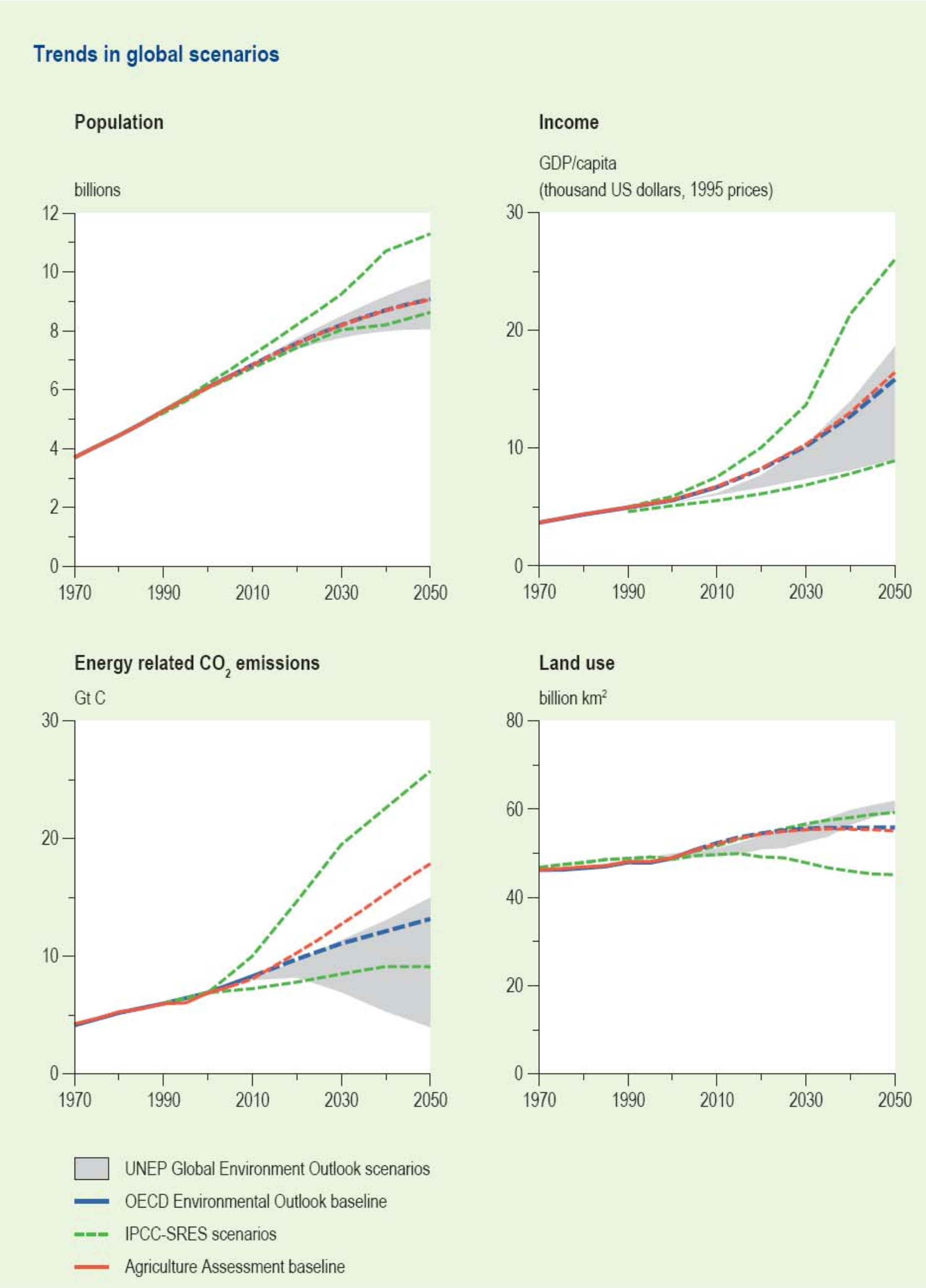


Figure 3.1 Projected trends in some key drivers of biodiversity and ecosystem change according to four recent global assessments. Source: Kok *et al.* (2008).

3.5 Terrestrial biodiversity

3.5.1 Progress on achieving goals

Goals and indicators

The assessment of biodiversity trends on a global scale presents significant challenges as it needs to cover a wide variety of features. Biodiversity as defined by the CBD encompasses the overall diversity found in the natural world and includes the variation in genes, species, populations and ecosystems. A range of indicators have been developed to attempt to describe biodiversity (see Table 3.2). Given the complexity of biodiversity, it is best described by a set of indicators rather than any one individual indicator.

In 1992, the CBD adopted the target '*to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth'*. Subsequently, the Millennium Development Goals adopted the target to reduce biodiversity loss, achieving a significant reduction in the rate of loss by 2010. In 2001 the European Union agreed a more ambitious target of halting biodiversity loss by 2010[5].

With respect to protected areas, a target was agreed during the third World Parks Congress (1982), to protect 10 per cent of the land area of all types of ecosystems.

The CBD has therefore established a work programme to identify a suitable set of indicators that can be used to assess progress towards the conservation of biodiversity and the attainment of the CBD biodiversity target. In 2004, the Conference of the Parties (COP) agreed on a provisional list of global headline indicators, to assess progress at the global level towards the 2010 target (decision VII/30), and to effectively communicate trends in biodiversity related to the three objectives of the Convention (Table 3.2). Subsequently decision VIII/15 of the 2006 COP distinguished between indicators considered ready for immediate testing and use and indicators confirmed as requiring more work.

Most of the indicators identified in the CBD process relate to pressures on biodiversity or responses to these and biodiversity loss rather than the actual status of biodiversity. Of the status indicators listed in Table 3.2, only trends in ecosystems and biomes are provided as outputs from the projections in the assessments covered in this review. None of the assessments are able to provide projections for threatened species etc.

Instead, all of the assessments, with the exception of the MA, use the Mean Species Abundance (MSA) metric as an indicator of the likely impacts of land use change and other pressures on biodiversity. The MSA metric was specifically developed as part of the GLOBIO3 model (by the Netherlands Environment Assessment Agency) to estimate future changes in terrestrial biodiversity, and is the only context in which the indicator is used (see Alkemade *et al*, 2009). With reference to Table 3.2, the first two "status and trends" indicators ("trends in extent of selected biomes, ecosystems and habitats" and "trends in abundance and distribution of selected species") are approximated with the MSA. Chapter 4 contains a more extended discussion of the MSA.

[5] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52006DC0216:EN:NOT

Table 3.2. Provisional indicators for assessing progress towards the 2010 biodiversity target
Source: CBD website, http://www.cbd.int/2010-target/framework/indicators.shtml

Indicators considered ready for immediate testing and use (green), indicators confirmed as requiring more work are in red text and placed in parentheses.

Focal area	Indicator
Status and trends of the components of biological diversity	Trends in extent of selected biomes, ecosystems, and habitats Trends in abundance and distribution of selected species Coverage of protected areas Change in status of threatened species Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socioeconomic importance
Sustainable use	Area of forest, agricultural and aquaculture ecosystems under sustainable management (Proportion of products derived from sustainable sources) (Ecological footprint and related concepts)
Threats to biodiversity	Nitrogen deposition Trends in invasive alien species
Ecosystem integrity and ecosystem goods and services	Marine Trophic Index Water quality of freshwater ecosystems (Trophic integrity of other ecosystems) Connectivity / fragmentation of ecosystems (Incidence of human-induced ecosystem failure) (Health and well-being of communities who depend directly on local ecosystem goods and services) (Biodiversity for food and medicine)
Status of traditional knowledge, innovations and Practices	Status and trends of linguistic diversity and numbers of speakers of indigenous languages (Other indicator of the status of indigenous and traditional knowledge)
Status of access and benefit-sharing	(Indicator of access and benefit-sharing)
Status of resource transfers	Official development assistance provided in support of the Convention (Indicator of technology transfer)

There are significant limitations of the MSA with respect to its appropriate use and what can be deduced from changes in its value. For example, MSA represents the average response of a selection of species belonging to an ecosystem and does not look at individual species responses. Therefore, an MSA of 50 per cent could mean that half the original species have gone extinct, or that all species are at half the original abundance, a major difference requiring different policy responses; therefore MSA does not capture extinctions. Nor is the MSA able to give weightings in terms of the importance of species (for example, giving higher importance to globally threatened species). Further, the MSA does not take into account the different levels of diversity in the intact habitats (such as intact habitats in Greenland and the Amazon have the same MSA value). The aggregation of average responses across species and ecosystems may also mask differences among regions or biomes. Projections of MSA changes therefore need to be carefully interpreted in terms of their biodiversity impacts. A more detailed discussion of the use of the MSA as a biodiversity indicator and its limitations is provided in Chapter 4.

Progress to date
According to the GEO-4 and OECD assessments approximately 73 per cent of the original global terrestrial biodiversity (as measured by MSA) remained in the year 2000. The largest declines have occurred in temperate and tropical grasslands and forests with the global annual rate of loss dramatically higher than previous centuries, particularly in Europe (see Figures 3.2 and 3.3 on the distribution of the world's biomes and the estimated global losses in biodiversity per biome). A very similar result was obtained in the GBO-2 (2006) assessment, using the same technique but with a less complete dataset (M. van Oorschot, pers. comm.). It estimated that 70 per cent of biodiversity remained in 2000. However, for the purpose of modelling policy scenarios, it is the relative differences between the scenarios that are more important than the absolute final figure for biodiversity.

All assessments are unanimous that the CBD target to significantly reduce the rate of biodiversity loss by 2010 will not be met by 2010 or in the long-term. In Europe, biodiversity will likely decline at a slower rate between now and 2050 but will not be halted. Under the baseline scenarios in the OECD and IAASTD, MSA is forecast to fall another 11 per cent to 62 per cent and by 7.5 per cent in the GBO-2 to 62.5 per cent by 2050. The GBO-2 projects a decrease of MSA to about 62.5 per cent under a business-as-usual scenario.

The MA estimates that 13.5 to 18 per cent of global vascular plant species will potentially be lost at ecological equilibrium as a result of altered habitat, climate change and nitrogen deposition between 1970 and 2050 (MA 2005d). The losses are least under the *TechnoGarden scenario* although the differences between the scenarios are relatively small as the 50 year modelling window may be too short for the various climate change scenarios to reveal their expected differences in long-term impacts.

The assessments differ to the extent to which biodiversity is expected to decline depending on different assumptions about agricultural methods, policies regarding biofuels and conservation efforts (see below). Some of these look at the potential biodiversity benefits of protected area designations. Projections from the GBO-2 assessment, suggest that even the most stringent conservation policy of protecting 20 per cent of every biome, results in only a marginal improvement in the MSA indicator to 63.5 per cent (a 1 per cent improvement on the baseline). However, it should be noted that several studies have suggested that a large proportion of the world's taxa could be secured by the protection of relatively small areas if directed to the most biodiversity rich areas, such as the biodiversity hotspots[6] identified by Conservation International (e.g. Myers *et al*. 2000, 2003). Therefore the results of the model assessments should be treated with caution as they may reflect weaknesses in the models or, more likely, the MSA metric as an indicator of biodiversity change.

A further concern is that the policy assumption of conserving 20 per cent of every biome within protected areas may be unrealistic. By 2003, the World Parks Congress goal of

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6 http://www.conservation.org/explore/priority_areas/hotspots/hotspots_revisited/key_findings/Pages/key_findings.aspx

achieving 10 per cent protection of the land area had been attained in nine of fourteen ecosystems. Overall a recent assessment (Coad *et al*. 2009) found that global terrestrial protected area coverage reaches 12.2 per cent. However, insufficient areas of lakes, coniferous forests and grasslands have been protected meaning that the 10 per cent goal cannot be considered to be fully achieved (Kok *et al.* 2008) and it has not been achieved for all ecosystems in all regions.

3.5.2 Pressures

The global loss of terrestrial biodiversity thus far has predominately resulted from habitat loss through conversion to agricultural land, which remains the case today (Braat and ten Brink 2008, p54). However, assuming significant advances in agricultural productivity continue into the future, the majority of the assessments expect that the major influences on biodiversity in the next century are likely to be infrastructure and climate change given current policies and trends (see Figure 3.4). Infrastructure is expected to account for approximately five per cent, followed by climate change at three per cent and then crop area at two per cent. However, agriculture is likely to be much more important in developing nations, where larger increases in population are expected, than in developed countries. This conclusion, however, differs from the MA, which predicts agriculture will remain the predominant pressure to 2050 (see Figure 3.5).

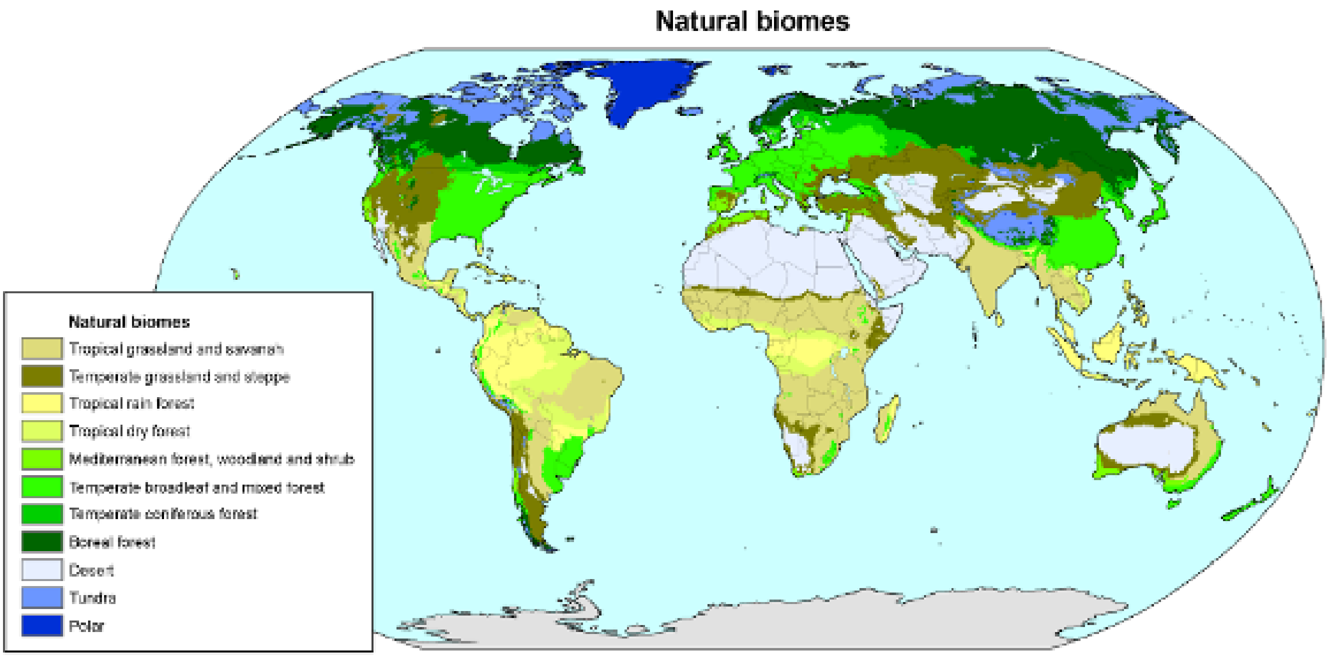

Figure 3.2. Geography of the world's major biomes, as used in the IMAGE and GLOBIO framework
Source: Bakkes & Bosch (2008)

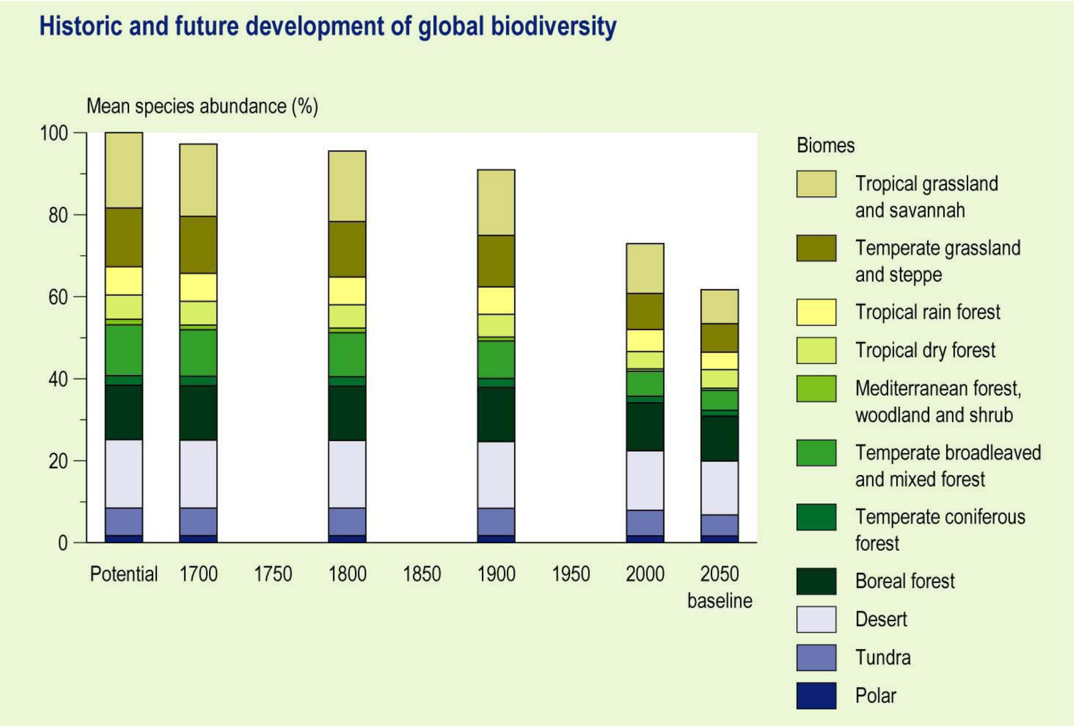

Figure 3.3. Global biodiversity from 1700 to 2050, OECD baseline.
OECD Environmental Outlook modelling suite, final output from IMAGE cluster
Source: Bakkes & Bosch (2008)

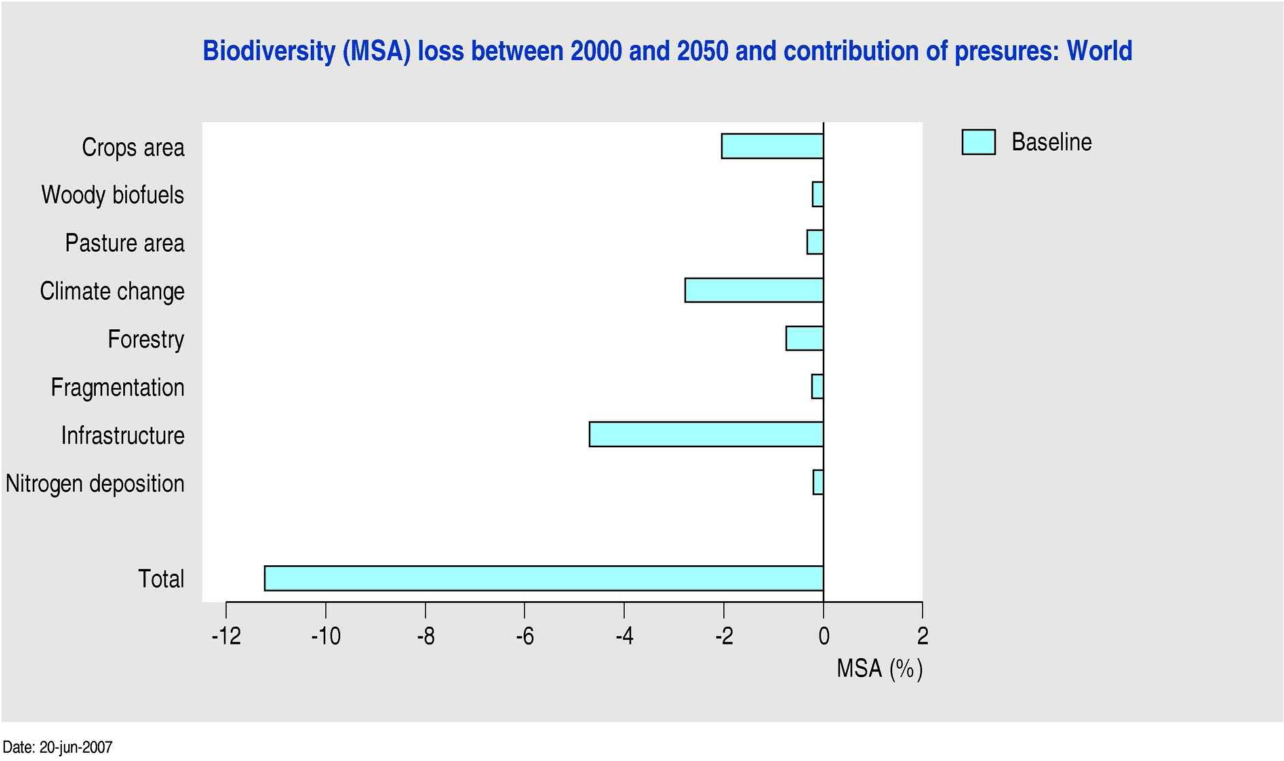

Figure 3.4. Contribution of different pressures to the global biodiversity loss between 2000 and 2050 in the OECD baseline.
Source: Bakkes & Bosch (2008).

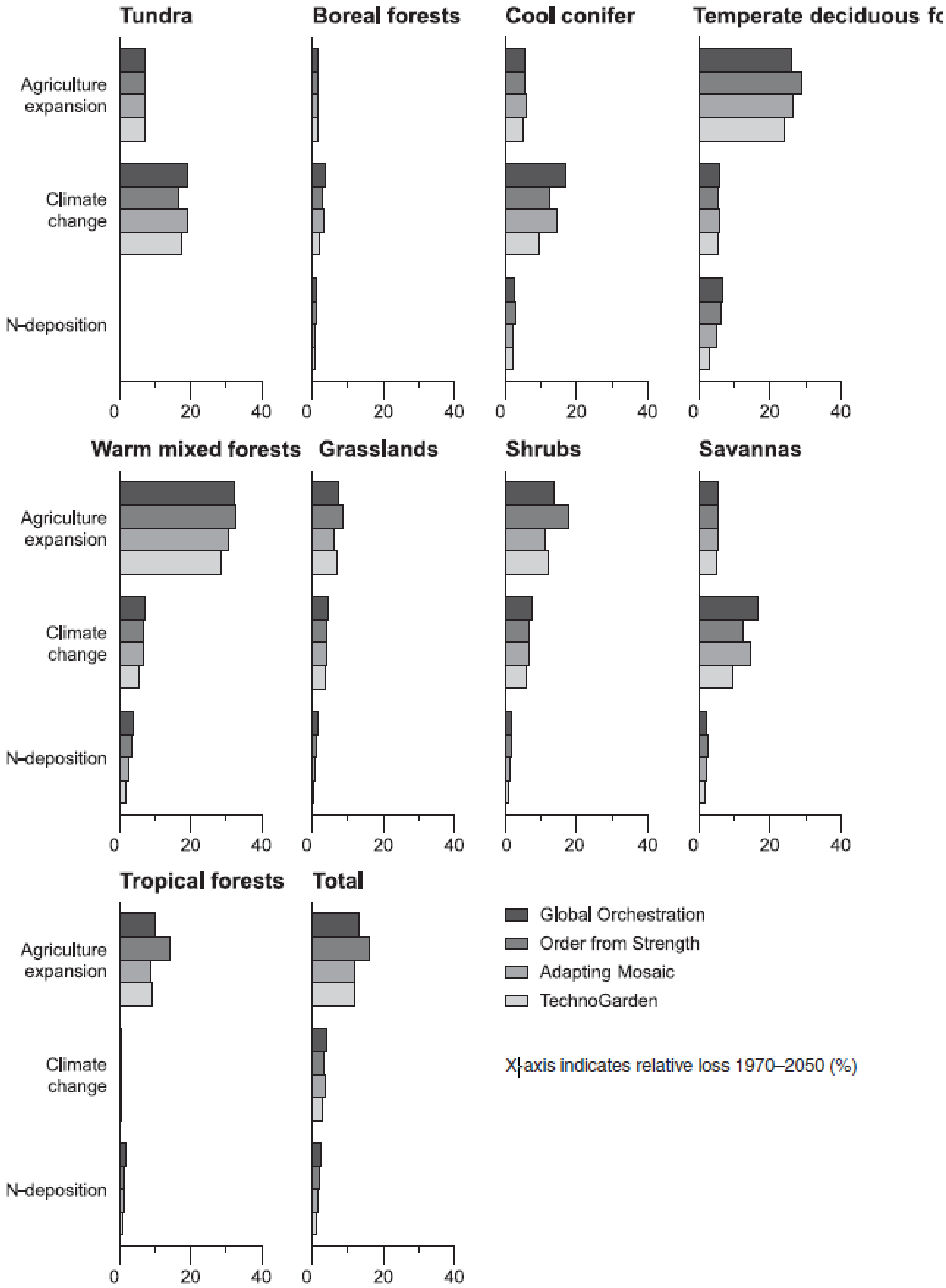

Figure 3.5. Comparison of effects of agriculture expansion, climate change and nitrogen deposition between 1970 and 2050 under four scenarios for different biomes and the World. Source: MA (2005d)

Agricultural expansion and intensification

All assessments predict an expansion of cropland and pasture land in response to increasing demand as a result of growing populations and further economic growth. The OECD predicts that by 2030 agriculture will have to produce 50 per cent more food to feed a population that is 27 per cent larger and 83 per cent wealthier. In addition there is agreement that developing countries will see far greater expansion than developed countries. The OECD expects land use to grow four times faster in developing countries due to faster population growth and the availability of land. The IAASTD projects a global increase of 10 per cent in agricultural land, provided significant improvements in food productivity are achieved. Sub-Saharan Africa is likely to have the largest increases with yearly expansion of 0.6 per cent, or 30 per cent by 2050. Latin America sees similar increases (Figure 3.6). The GEO-4 and MA similarly predict the biggest expansions in Africa highlighting the importance of ensuring yield improvements to reduce agricultural land expansion.

Expansion of agricultural land has significant implications for biodiversity as native habitat is converted to agriculture with consequent local extinctions of populations and species. The assessments all predict the largest biodiversity losses in Sub-Saharan Africa, where agricultural expansion is the predominant pressure. Population increase and economic growth remain important drivers in all scenarios.

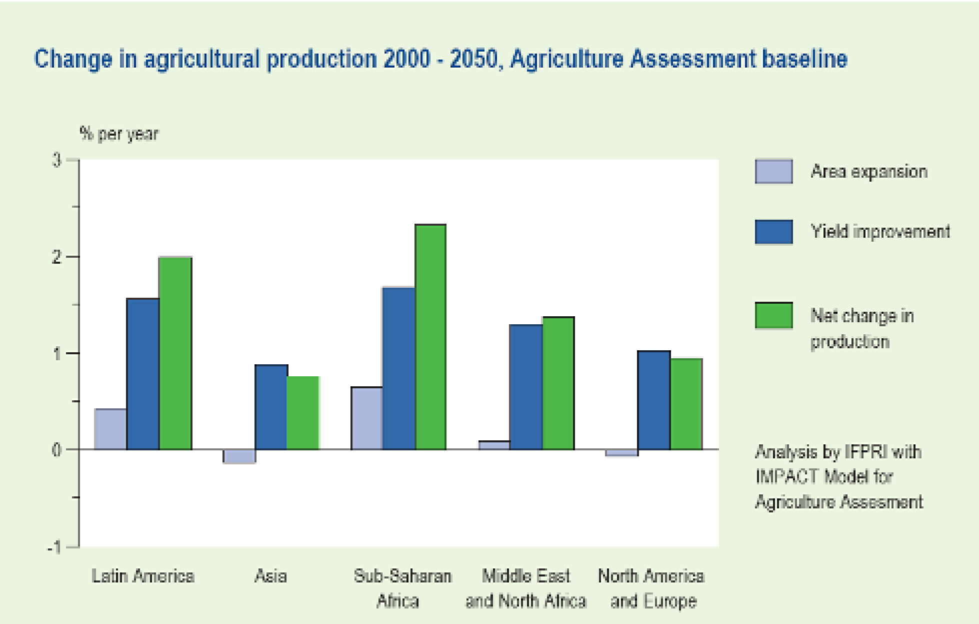

Figure 3.6 Causes of changes in agricultural production between 2000 and 2050 according to the IAASTD.
Calculations by IFPRI with the IMPACT model following the baseline scenario of the Agriculture Assessment. Source: Kok *et al*. (2008). Data from IAASTD (2008)

There are some significant differences between the assessments, regions and scenarios. The MA projects that, despite initial slow yield improvements, the lower population increases and locally successful developments in crop improvement under the *Adapting Mosaic* scenario would have benefits in Sub-Saharan Africa. This results in the lowest deforestation rates in the region under the MA scenarios. However a similar policy in South Asia, with corresponding low yields would lead to a virtual depletion of forests by 2100.

The most damaging outcome for forest cover occurs under the *Order from Strength* scenario, where large increases in population, coupled with poor technological innovation and the inability to import food (particularly in Sub-Saharan Africa) lead to rapid expansion of agriculture at the expense of forest. Asia and Latin America also experience high deforestation rates of 40 per cent and 25 per cent respectively. This is different to a similar scenario in the GEO-4 assessment, *Security First*, in which agricultural expansion is lowest and forest cover remains high due to lower economic growth maintaining a low demand for food and resources.

The assessments differ in their projections of the expansion of agricultural land. The GEO-4 projects the greatest expansion of land in the *Policy First* and *Sustainability First* scenarios due to concerns about food availability and strong targets for combating climate changes resulting in a rapid expansion of biofuels. This would result in a substantial loss of forest in Africa, Latin America and the Caribbean with almost all of Africa's forests lost under the *Policy First* scenario. The MA scenario *TechnoGarden*, despite describing a similar set of policy options as *Sustainability First,* projects the least amount of additional land conversion to agriculture, despite the increase in land for biofuels. The MA projects reduced demand for meat and improved yields due to technological improvements. This option projects by far the lowest forest loss overall amongst the MA scenarios but still significant losses of forest in Africa and Southeast Asia.

Climate change impacts

Climate change will have an increasingly significant impact on biodiversity over the coming century, with IPCC scenarios projecting temperature increases from 2000 to 2050 of between 1.7°C to 2.2°C (IPCC, 2007). In the GEO-4, biodiversity loss from climate change is the most consistent impact across all the scenarios and all the regions, accounting for approximately four per cent loss of MSA in every case. This is approximately twice as much as estimates of biodiversity loss that had already occurred due to climate change by 2000. The OECD baseline projects a slightly lower predicted loss of three per cent.

The MA is more detailed in its approach describing the impacts of climate change on each biome. The most impacted biomes, in terms of vegetation loss, include cool conifer forests, tundra, shrubland, savannah and boreal forest. Even under the best case scenario, *TechnoGarden*, climate change will have a significant impact. Protected areas do not necessarily provide species with respite; in the worst case scenario, a continued liberalised market scenario, *Global Orchestration*, will lead to the greatest losses of approximately 20 per cent in protected areas by 2050 (see Figure 3.5).

While the impacts of climate change are modelled as being similar in each GEO-4 scenario, in reality the impact will depend on the ability of the species and ecosystems to adapt and move in response to changes in climatic conditions (IUCN, 2004; IPCC, 2007). Resilient, well connected ecosystems are more likely to suffer fewer ill-effects than fragmented, over-exploited ecosystems such as those under the *Security First* and *Markets First* scenarios.

Air pollution and nitrogen deposition

Atmospheric deposition of sulphur and nitrogen can lead to substantial changes of ecosystems through the acidification and the accumulation of excessive nitrogen. Nitrogen is a limiting nutrient of the growth of many plants and its addition to an ecosystem often leads to eutrophication, which results in changes in species composition, structure and processes. The MA (2005d), using a species-area relationship (SAR) model, identifies atmospheric deposition of nitrogen as a significant driver of species loss in temperate forests, warm mixed forests (particularly Asia) and to a lesser extent in savannah (see Figure 3.5). This is based on a combination of the habitat's sensitivity to nitrogen and its exposure to high nitrogen loads. In contrast the assessments using MSA show nitrogen deposition to be a relatively unimportant pressure on biodiversity (Figure 3.4) on a global scale. Indeed particular scenarios (*Sustainability First* and policy scenarios in the OECD) project reduced impacts from nitrogen deposition in the future, particularly in developed countries.

Part of the large difference between the models could be due to the fact that SAR considers only natural areas, giving more weight to species diverse ecosystems, while MSA gives equal value to all ecosystems and includes areas of low diversity such as agricultural land. Nitrogen deposition is likely to have less impact on these areas that are already low in diversity and often already artificially enriched. Thus on a global scale, the impact in MSA appears small, but it is likely to still be an important factor in natural areas.

Infrastructure
Infrastructure (plus related settlement) is considered the most important driver of biodiversity loss under the MSA based analysis but is not specifically referred to in the MA. Its impact, however, varies considerably across the scenarios. Globally in the GEO-4, it accounts for seven per cent and five per cent MSA loss in the *Markets First* and *Security First* scenarios but contributes only one per cent loss in the other scenarios. This trend is repeated throughout the regions. While population growth is lower in *Markets First* and road construction and urban development are more regulated than in *Security First*, international markets for goods are strengthened and infrastructure is developed to promote access to natural resources.

3.5.3 Impact of policy interventions

Creation of an extensive network of protected areas
The GEO-4 and GBO-2 assessments investigate the potential impacts of effective conservation of 20 per cent each of the world's terrestrial ecosystems as a conservation intervention. In their projections the creation of an ecologically representative system of protected areas does not limit the overall amount of natural habitat converted to agricultural use, but might protect some of the most endangered species. But the use of protected areas results in so much demand for agricultural farmland that remaining habitats outside protected areas are crowded out, and the areas themselves become isolated in an agricultural matrix. This is particularly evident in the projections for Meso-America and Southern Africa. This suggests that sustainable agricultural practices that pay explicit attention to wildlife conservation would be particularly important under these circumstances (UNEP, 2007, p425).

Intensification and improvement of agriculture
The extent to which agricultural land expands depends on the degree of improved productivity, i.e. food output per hectare. The question as to whether agriculture will continue to intensify or will continue to require substantial increases in land is crucial to the issue of biodiversity. The GEO-4, IAASTD and OECD Outlook all look into the boosting of agriculture as a means to increase food production without increasing the area of land required. There are substantial differences between the assessments with respect to the projected growth in agricultural production per hectare. The IAASTD predicts that high investment in agricultural development will lead to substantial increases in yield of up to 300 per cent in Sub-Saharan Africa and 200 per cent in Latin America. Crucially while the IAASTD recognises the importance of technological innovation, it maintains that good governance and effective technology transfer will be vital to ensure yields improve.

The IAASTD suggests that poor agricultural practices associated with unfavourable socioeconomic conditions can create a vicious cycle in which poor smallholder farmers are forced to use marginal lands, thus increasing deforestation and overall degradation. Loss of soil fertility, soil erosion and breakdown in agro-ecological functions can result in poor crop yields, land abandonment, deforestation and ever-increasing movements into marginal land, including steep hillsides. Existing multifunctional systems that minimise these problems have not been sufficiently prioritised for research. There is little recognition of the ecosystem functions that mitigate the environmental impacts.

There are different views about how to best increase productivity and thus reduce the amount of land required. The OECD is confident of the benefits of the liberalisation of agricultural trade while the IAASTD contends that increasing trade will likely benefit the larger-scale farmers at the expense of smaller-scale farmers. It suggests that stagnating public finances are an issue and money would be well spent in investments in technology and knowledge to improve agricultural activity.

Liberalisation of trade
The OECD is relatively positive about the impacts of liberalised trade on sustainable development as it will stimulate the more efficient use of resources and connect more regions to world markets. However, its impact on global biodiversity is likely to be unfavourable. The results of the GBO-2 assessment suggest that liberalised markets would shift agricultural production to Southern Africa and Latin America driven by low labour costs and land costs at the expense of grasslands and forests (sCBD and MNP, 2007, p29). This shift could remove production from inherently more productive areas of North America, OECD countries in Europe, Canada and Japan and thus require more land overall. This shift could potentially increase biodiversity in these countries as baseline agricultural land is no longer required for agricultural production, with possible benefits to these developed nations. However, the authors of this report would question whether this land would necessarily be managed for biodiversity given other competing demands for land. Furthermore, abandonment of agricultural land would be detrimental in some parts of the world. For example, in parts of Europe many extensively managed semi-natural habitats are of high natural value (Baldock *et al.* 1993) and such marginally profitable farming systems could be at particular risk (Anon, 2005).

Under the *Markets First* scenario, which liberalises markets more than the baseline, GEO-4 similarly predicts greater losses in biodiversity than other options. Strengthened markets for goods drive infrastructure development to increase access to natural resources as wealth creation is valued more than conservation (UNEP, 2007, p423).

Under the GBO-2 scenarios, poverty alleviation measures in Sub-Saharan Africa through increased investment in combination with trade liberalisation of agriculture, similar to proposals in the Millennium Program, presents a particular dilemma for the Millennium Development Goals. On the one hand, assuming the effective implementation of these investments, this option leads to a 25 per cent GDP increase in Sub-Saharan Africa on top of the baseline scenario for 2030. However, this is the most damaging option for biodiversity of all assessed by the GBO-2, leading to 5.7 per cent loss in MSA in addition to the baseline in Sub-Saharan Africa as increased demand for food leads to rapid expansion of agricultural land at the expense of savannah, tropical forests and grasslands. This is likely to be an underestimate as the study did not assess the consequences of additional infrastructure, which will be required for an effective hunger alleviation and poverty program (ten Brink *et al.* 2007, p 8).

Impacts of climate change policies
According to all the assessments projections, effectively mitigating climate change does reduce climate change impacts on biodiversity, but this positive effect is offset by increased land-use for bio-energy production. The balance is not expected to be beneficial for biodiversity. It follows that only by combining climate change mitigation with increased land-use efficiency (i.e. compact agriculture) can the negative effects on biodiversity be counterbalanced. This was found to be the case across the assessments.

Under the *Sustainability First* scenario demand for cropland and pasture would increase from around 50 million km^2 to over 60 million km^2 (a 20 per cent increase) by 2050; second only in demand for land to the *Security First* scenario. Increases in technological developments are counterbalanced by greater concerns for food availability and the need to produce biofuels to counter climate change. This demand is also reflected in the changes in forest cover. Latin America and Africa would be expected to see significant declines in forest land in all scenarios as demand increases for food and biofuels. However, Europe and North America would see small increases (GEO-4).

An ambitious climate change mitigation package is assessed in the OECD Outlook analysis that is specifically designed to stabilise the atmospheric concentration of carbon dioxide equivalents at 450 ppm by 2100. This target can only be attained if deforestation is slowed down, as deforestation results in large carbon emissions. Therefore, land-use changes for bio-energy production and other increases of agricultural production have to be accommodated within the present total agricultural area ('compact agriculture'). This requires a strong increase in agricultural productivity (Bakkes and Bosche, 2008, p112).

Reducing deforestation and forest degradation through carbon pricing mechanisms
Several models of deforestation exists, most of these have so far investigated the drivers of deforestation (e.g. Laurance *et al*, 2001; Soares-Filho *et al,* 2006), but have so far not addressed the responses to deforestation. The IIASA models presented below are an example of a spatially explicit model attempting to address responses to deforestation. Other recent studies that have investigated responses include Butler *et al* (2009) and Venter *et al* (2009). These studies explore the opportunity costs of avoiding deforestation, but these are not equivalent to the real costs which need to investigate the effectiveness of the suggested interventions and the opportunity costs.

Since it was proposed by the delegations from Papua New Guinea and Costa Rica in 2005, the payment for the reduction of emissions from deforestation and forest degradation (REDD) has been much discussed as a potentially cost-effective way to achieve global carbon savings. While much of the debate currently is focussed around the carbon sequestration and storage potential of tropical forests, the by-product of these measures might be protection of biodiversity and ecosystem services that the forests provide (see Miles & Kapos, 2008).

None of the global assessments model the impacts of carbon pricing on deforestation rates. However, the literature on the topic is becoming more extensive. This section looks at specific model results from the IIASA family of models and is presented as an example of policy options available rather than a comprehensive review of the literature on REDD. The studies presented both look at the payments required to prevent deforestation, although focussing on different scales. Kindermann *et al.* (2006) used a spatially explicit biophysical and socio-economic land use model to investigate the impact of carbon price incentive schemes and payments on global deforestation. The model simulates land-use changes as a decision based on the difference between net present value of income from production on agricultural land versus net present value of income from forest products. Using a baseline scenario, i.e. assuming a price on carbon of 0 US$/tC, close to 200 million hectares (or 5 per cent of the forests in 2006) were projected to be lost between 2006 and 2025, resulting in the emission of 17.5GtC. The model distinguishes between a taxation system on the removal of biomass (which is paid once the harvested biomass has been detected) and an incentive payment contract to preserve standings of forest (which is renewed every five years based on the remaining standing biomass). To reduce deforestation by 50 per cent a taxation system would require 12 US$/tC (assuming a mix of slash-and-burn and selling the biomass as wood products) costing 6 billion US$ per year in 2005, reducing to 4.3 billion US$ by 2025 and 0.7 billion US$ by 2100 due to decreasing deforestation speed. Incentives of 6 US$/tC of vulnerable stands of biomass would also reduce deforestation by half, costing 34 billion US$ per year.

A more recent study by Kindermann *et al.* (2008) examined three economic models of global land use (GCOMAP, DIMA and GTM) to examine the potential contribution of mechanisms for avoiding deforestation of tropical forests to reduce greenhouse gas emissions. The models use different assumptions on the extent of carbon stored in the world's tropical forests and the area that they cover, accounting for some of the differences between them. According to this analysis, a 50 per cent reduction in deforestation would cost between 9 and 21 US$/tC and require 17 and 28 billion US$ per year.

According to two of the three models, the cost of protecting forest in Africa appears to be significantly lower than the global average (see Table 3.3).

Table 3.3 Carbon price necessary in US$ per tonne of CO_2 necessary to generate a 10 per cent and 50 per cent reduction in deforestation in 2030.

	10% reduction, US$			50% reduction, US$		
Area	GCOMAP	DIMA	GTM	GCOMAP	DIMA	GTM
Central and South America	3.98	8.03	1.48	19.86	24.48	9.7
Africa	1.04	3.5	1.63	5.2	12.3	9.6
Southeast Asia	8.42	8.73	1.24	38.15	19.56	8.31
Globe	3.5	4.62	1.41	16.9	20.57	9.27

It is important to note that the IIASA models only consider the cost of REDD based on the price of carbon on the global markets. They do not consider the additional costs of monitoring, reporting and implementation, including additional security and protection. These costs are likely to be very significant, and may incur similar costs to those required for the expansion of protected areas (for example, see James *et al.*, 2001). Therefore, any calculation of the costs of REDD schemes must consider the costs of implementation alongside the cost of carbon.

3.5.4 Gaps and limitations of the assessments

Invasive alien species

Invasive alien species were not considered in the models, and the assessments point out that its inclusion would likely increase biodiversity loss. As global trade increases, the number of intentional and unintentional introductions will increase in terrestrial, freshwater, and marine biomes. Unless greater management steps are taken to prevent harmful introductions that accompany increased trade, invasive species will cause increased ecological changes and losses of ecosystem services in all scenarios. Because of differences among scenarios in economic growth and openness to foreign trade, invasive species increase most in Conventional and Reformed Markets scenarios, followed in order by Global Sustainable Development, Regional Sustainable Development and Competition Between Regions (see Table 2.4 and Appendices 1.5 and 2.3 for a descriptions of the scenarios).

Infrastructure and related settlement
Increased infrastructure pressures are modelled in the GLOBIO model by MSA by expanding the influence zone around current infrastructure rather than predicting future growth. Thus it does not take into consideration the possibility of new infrastructure developments. The impacts of infrastructure are not realistically represented within GLOBIO as expanding influence zones are not region specific and impact zones are different in different regions. In addition, the urban area in GLOBIO does not change, due to the lack of an adequate urbanisation model, thus potentially underestimating some additional negative impacts of land conversion.

3.6 Marine biodiversity

3.6.1 Progress in achieving policy goals

The 2002 World Summit on Sustainable Development agreed to maintain or restore fish stocks to maximum sustainable yields by 2015 where possible, with the aim of achieving these goals for depleted stocks on an urgent basis. The Summit, along with the CBD, also called for a representative network of marine protected areas (MPAs) of 10 per cent of marine habitats to be established by 2012. A year later the fifth IUCN World Parks Congress reiterated the goal with a further commitment to strictly protect at least 20-30 per cent of each marine habitat type closed to all forms of extractive use.

It is too early for the assessments reviewed in this study to meaningfully assess progress towards these goals, especially given the lag in available data. However, key trends are highlighted in a number of the assessments. The GEO-4 presents data on marine fish stocks that have been exploited for at least the past 50 years, which shows the dramatic increase in stocks that are fully exploited, over exploited or have crashed (Figure 3.7). Of the 1,400 stocks that were fished in 2000, almost 20 per cent (240) had crashed. Furthermore, the trophic level of fish captured for human consumption has been decreasing, indicating a decline in top predator fish catches (such as marlin, tuna) which are being replaced by fish such as mackerel and hake, high value invertebrates such as shrimp and squid and aquaculture products such as salmon and tuna.

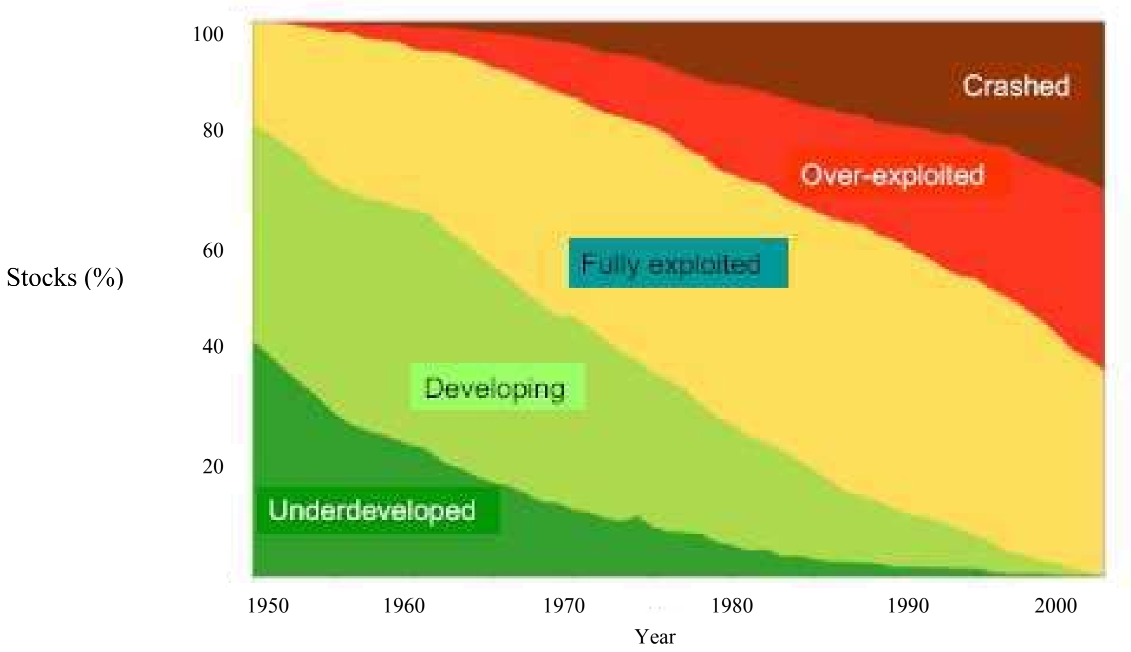

Figure 3.7 Changes in degree of exploitation of stocks of marine fish species (source: Alder, Trondheim/UN conference on Ecosystems and people, October 29-November 2, 2007. Original source: Sea Around Us project, 2007: Cited in Braat & ten Brink, 2008)

Although the GEO4 accepts that the number and sizes of MPAs have been increasing, targets for MPAs will not be met within the targets under current trends (GEO4, 2007, p149). Marine ecosystems therefore remain greatly under-represented by protected areas. The OECD concurs that too few MPAs exist and points to evidence that suggests they do deliver benefits in terms of density, biomass, size of organisms and diversity (see Halpern, 2003). The MA suggests that MPAs provide striking examples of synergies between consumption and sustainable use as appropriately placed MPAs can significantly increase fishery harvests in adjoining areas (MA, 2005b, p11).

3.6.2 Pressures

Marine fish stocks show evidence of declines from a combination of unsustainable fishing pressures, habitat degradation, eutrophication from terrestrial activities, coastal conversion for aquaculture, invasive species and global climate change (UNEP, 2007, p145).

Wild capture fisheries

Overfishing emerges from the assessments as the dominant driver of change of the marine environment. Over much of the world the biomass of fish targeted in fisheries (including that of both the target fish and those caught incidentally) has been reduced by 90 per cent relative to levels prior to the onset of industrial fishing (MA, 2005b). Amongst others, the assessments point to advanced fishing technology which has contributed significantly to the depletion of marine fish stocks (UNEP, 2007, p28).

The MA, GEO-4, IAASTD and the *Ecosystem-based global fishing policy scenarios* assessments all include projections on commercial fisheries given their direct relevance to humans and the availability of data. The IAASTD and the *Ecosystem-based global fishing policy scenarios* used the EcoOcean model (see Box 3.1), whereas the GEO-4 and the MA used its predecessor EcoPath with EcoSim (Alder *et al.*, 2007). The MA selected three regions

- the Gulf of Thailand (shallow coastal shelf system), Benguela Current (coastal upwelling system), and the Central North Pacific (pelagic system) - for which good modelling tools existed to investigate how the diversity of fisheries and the biomass of species might change under the four MA scenarios. The other assessments take global approaches based on data from the Sea Around Us Project.

Box 3.1 The EcoOcean MODEL (Taken from Braat & ten Brink, 2008: adapted from Alder *et al*, 2007)

The EcoOcean model was developed to quantitatively assess the future of fisheries under different scenarios. It is based on a series of 19 marine ecosystem models representing the 19 Food and Agriculture Organization of the United Nations (FAO) areas of the world's oceans and seas. The models account for the biomass of each functional group, their diet composition, consumption per unit of biomass, natural and fishing mortality, accumulation of biomass, net migration, and other causes of mortality. The model is based on the principle that future biomass can be estimated from the current biomass plus change in biomass due to growth, recruitment, predation, fisheries and so on.

The model identifies 43 functional ecological groups that are common to the world's oceans which include all major groups in the oceans, but pays special attention on exploited fish species. The most important driver for the model simulations is fishing effort. Five major fleet categories (demersal, distant water fleet, baitfish tuna (purse seine), tuna long-line and small pelagic) are used to distinguish different fishing effort based on historical information. For current purposes, the oceans should be considered as spatially-separated production systems with distinct fishing fleet activity.

The aggregated global model produces results within 10 per cent of the reported total for any given year. This gave confidence that the models are providing plausible results for different scenarios. The development of EcoOcean also provided the opportunity to look at the future of marine biodiversity using a **depletion index** (*Box 5.2*) as a proxy for changes in species composition and abundance under the different scenarios. EcoOcean is however not a full representation of the world's oceans as it contains several sources of uncertainties (see section 5.4).

The projections from the analyses are unanimous that pressures on marine fish stocks will increase over the next 40 years. In the GEO-4, all four scenarios project an increase in fishing effort, and as a consequence landings increase significantly (see Appendix 2.2). The catch projections are lowest under the *Sustainability First* scenario due to a smaller population increase and changing diets leading to lower demand. In addition, under this scenario an effort is made to fish lower in the food chain resulting in a lower marine trophic index (MTI) of the catches (see Box 3.2 for information on the MTI and other marine biodiversity indicators). In combination these two factors result in a large increase in total biomass of large demersal fish and the smallest decrease of large pelagics of all the scenarios. The *Markets First* scenario projects the biggest increases in landings and the largest decreases in biomass of large pelagics and demersals, due to an increase in technology, population and a wealthier society.

Under the *Ecosystem-based global fishing policy scenarios* modelled landings were increased by augmenting the proportion of secondary demersal fish groups and the proportion of invertebrates. As a consequence, the MTI generally decreased in all oceans. The decline in MTI confirms that as demersal effort increased, landings increased, but usually at lower trophic levels. With the exception of the Mediterranean Sea and the Caribbean region, the biomass diversity index also decreased for the three main oceans. In the Mediterranean Sea and Caribbean region, the increase appears to be a result of the predation impact of a few top predators being lowered as their biomasses decrease, allowing for an increase in dominance of species of lower trophic levels (Alder *et al.* 2007, p25-27).

The MA shows quite different responses from the different case studies. Diversity of commercial fisheries showed large differences among scenarios until 2030, but all scenarios converge into a common value by 2050. Policy changes after 2030 generally included increasing the value of the fisheries by lowering costs, focusing on high-value species, substituting technology for ecosystem services, or a combination of the three approaches. However, no approach was optimal, since the approaches used in the scenarios reduced biomass diversity to a common level in each ecosystem (MA 2005d, p377).

In the Gulf of Thailand, both global strategies, *Techno Garden* and *Global Orchestration* fared well up to 2030 when policy shifted to rebuilding the ecosystem. Regional strategies fared worse, with *Adapting Mosaic* failing to respond to efforts to rebuild the stock after 2010 and *Order from Strength* showing steady declines of the biomass diversity index. However, all scenarios showed dramatic declines in biomass diversity index after 2030 when technology had improved and the policy shifted to providing fish meal for aquaculture which had taken over primary production of food (MA 2005d, p377). In the Central North Pacific and Benguella areas regional policies fare slightly better through well informed local strategies but are hampered by lack of co-ordination at the global level and all scenarios converge by 2050. All fisheries are projected to respond well to ecosystem approaches.

Box 3.2 Indicators of Marine Biodiversity (adapted from Alder et al. 2007)

- A **biomass diversity index** can be used to provide a synthesis on the number of species or functional groups that compose the biomass of the ecosystem. The biomass diversity index assumes that more stable ecosystems will tend to have a more even distribution of biomass across the functional groups and can therefore be used to evaluate model behaviour.
- The **marine trophic index (MTI)** is calculated as the average trophic level of the catch and is used to describe how the fishery and the ecosystem may interact as a result of modelled policy measures. The index is often used to evaluate the degree of "fishing down the food web" (Pauly *et al*., 1998). The MTI is one of the core indicators being used by the Convention on Biological Diversity.
- The **depletion index** (DI) has been developed to provide a marine equivalent to the MSA, that is calculated as part of the overall assessment within EcoOcean. It attempts to evaluate the degree of depletion of fish species by accounting for differences in their intrinsic vulnerability to fishing. It was calculated from prior knowledge of the intrinsic vulnerability and the estimated changes in functional group biomasses. Intrinsic vulnerability to fishing of the 733 species of marine fishes with catch data available from the Sea Around Us Project database (www.seaaroundus.org) was included in the analysis.

Growth of aquaculture

The GEO4 assessment states that growth in aquaculture will help compensate for some of the shortfall in wild-caught fish but points out that much of the increase in aquaculture has been in high-value species that meet the needs of affluent societies and does little to meet the needs of developing countries (GEO4, 2007, p147).

The OECD baseline scenario projects that increased wealth and population will require much stronger increases in prices to limit fisheries growth to the FAO's projected 1.6 per cent given that global GDP in the Baseline is 2.8 per cent (OECD, 2008, p332). Given that the majority of capture fisheries are at or near maximum sustainable yields, it assumes no growth in capture fisheries and an average growth of aquaculture of 3.9 per cent annually to 2030. This may have implications for fishmeal as between 2 to 12 kg of fishmeal is required to produce 1 kg of farmed fish (depending on the species). However, as the price increases it is assumed that alternative feeds, such as soya-based products, will be developed for those fish that can be fed on vegetarian diets (OECD, 2008, p333).

The trophic level of species used for fish meal in aquaculture is increasing, suggesting some fish species previously destined for human consumption are being diverted to fish meal, with potential negative implications for food security in other countries. Modelling from the MA (Gulf of Thailand area) suggests that gains from taking a global ecosystem management approach could be lost if improved technology and big increases in demand for aquaculture lead to increases in catches for fishmeal.

Modelling from the IAASTD suggests that although populations of small pelagic species are robust, the behaviour of the small pelagic fish towards the end of the modelled period (2048) indicate that policies of exploiting small pelagic fisheries to support a growing aquaculture industry may not be sustainable in the long-term except in a limited part of the world's oceans. Caution needs to be taken even with this interpretation since small pelagic fish are extremely sensitive to oceanographic changes and if the predictions for changes in sea temperature come about, the species dynamics within this group will change significantly. This could potentially have knock-on impacts up through higher trophic levels since most animals, especially marine mammals and seabirds, rely on this group of fish for much of their food. Therefore, a policy of increasing landings would need to be carefully considered in the light of climate change (IAASTD, 2008, p355).

3.6.3 Impact of policy interventions

To date, there have been some initiatives to rebuild depleted stocks, but recovery efforts are quite variable. A common and appropriate policy response is to take an ecosystem approach to fisheries management but many governments are still struggling to translate guidelines and policies into effective intervention actions. Other policy options have included eliminating perverse subsidies, establishing certification, improving monitoring, control and surveillance, reducing destructive fishing practices such as bottom trawling bans, expanding marine protected areas and changing fishing access agreements. There are also policy responses to reduce effort in industrial scale fishing in many areas, while also supporting small-scale fisheries through improved access to prices and market information and increasing awareness on appropriate fishing practices and post-harvest technologies.

Ecosystem-based management

All assessments show relative improvements in scenarios where ecosystem-based conservation policies have been employed although the impact depends on the fishery. In the MA, diversity of marine biomass was quite sensitive to changes in regional policy. Scenarios with policies that focused on maintaining or increasing the value of fisheries resulted in declining biomass diversity, while the scenarios with policy that focused on maintaining the ecosystem responded with increasing biomass diversity. However, rebuilding selected stocks did not necessarily increase biomass diversity as effectively as an ecosystem-focused policy (MA 2005d, p377). The MA concluded that policies that focus on maximising profits do not necessarily maintain diversity or support employment. Similarly, policies that focus on employment do not necessarily maximise profits or maintain ecosystem structures. The diversity of the stocks exploited can be enhanced if policy favours maximising the ecosystem or rebuilding stocks. Diversity, however, is lost if the sole objective of management is to maintain or increase profits (MA 2005d, p342).

3.6.4 Gaps and limitations of the assessments

It is widely recognised that marine biodiversity is poorly understood. The MA points to a particular lack of knowledge of the deep sea, sea mounts, the mid-water column, and thermal vents (MA 2005d, p378).

The EcoOcean model does not consider climate or oceanographic conditions and as such cannot accurately model small pelagic fish groups that are heavily influenced by oceanographic conditions (IAASTD, 2008, p312). The tuna groups do not differentiate between long-lived slow-growing species such as bluefin tuna and short-lived ones such as yellow-fin. This can result in overestimation of tuna landings and optimistic assertions about the species' resilience. The lack of information on artisanal fishing, especially in Asia and several regions in Africa, results in some underestimation of landings and effort. Antarctic and Arctic models are incomplete, as catch, effort and biomass data availability is poor for these areas. Consequently they were not included in the IAASTD assessment (IAASTD, 2008 p313).

3.7 Freshwater biodiversity

Freshwater biodiversity is largely overlooked by the assessments except the MA. The MA considers freshwater ecosystems amongst the most threatened on Earth but notes that quantitative information on species richness and responses to anthropogenic pressures is still largely unknown (MA, 2005d, p379). The models consider the impacts of changing river discharge, eutrophication and acidification on the biodiversity of freshwater ecosystems.

Under all four scenarios, 70 per cent of the world's rivers, especially those at higher latitudes, are expected to experience increases in water availability due to increased precipitation caused by climate change. This may increase the potential for production of fishes adapted to higher flow habitats, which would most likely involve non indigenous species (low certainty). Under all scenarios, 30 per cent of the modelled river basins will be subject to decreases in water availability from the combined effects of climate change and water withdrawal. Based on established but incomplete scientific understanding, this is projected to result in eventual losses (at equilibrium) of 1–55 per cent (by 2050; 1–65 per cent by 2100) of fish species from these basins. According to the projections, climate change rather than water withdrawal is the major driver of species losses from most basins (80 per cent), with losses from climate change alone of about 1–30 per cent by 2050 (1–65 per cent by 2100). The differences among scenarios were minor relative to the average magnitude of projected losses of freshwater biodiversity.

Acidification and eutrophication are likely to have the most detrimental impacts under the *Global Orchestration* and *Order from Strength* scenarios. Of the three scenarios modelled (*Adapting Mosaic* was not modelled for freshwater impacts) *TechnoGarden* is the only scenario which projects regions of steady or declining nitrogen deposition and a less severe degree of acidification (MA, 2005d, p397).

It is important to note that projected losses of fish biodiversity on the basis of declining water availability alone will be underestimated. Many of the rivers and lakes in drying regions will also be vulnerable to increased temperatures, eutrophication, acidification and increased invasions by non indigenous species. These factors all increase losses of native biodiversity in rivers and lakes that are drying and cause losses of fishes and other freshwater taxa in other rivers and lakes. The MA concludes that much greater declines in freshwater biodiversity are likely to come from drivers that are more difficult to directly model such as local overfishing, construction of dams and impacts of alien invasive species (MA, 2005d, p398).

The MA also highlights that rivers that are forecast to lose fish species are concentrated in developing tropical and sub-tropical countries, where the needs for human adaptation are most likely to exceed governmental and societal capacities to cope. The current average GDP in countries with declining water availability is about 20 per cent lower than that in countries whose rivers are not drying.

3.8 Ecosystem Services

The results of the assessments are described below with respect to their implications for the provisions of ecosystem services, as set out in the MA framework (Figure 3.8). This has since become the basis from which the value of ecosystem services are commonly evaluated and assessed.

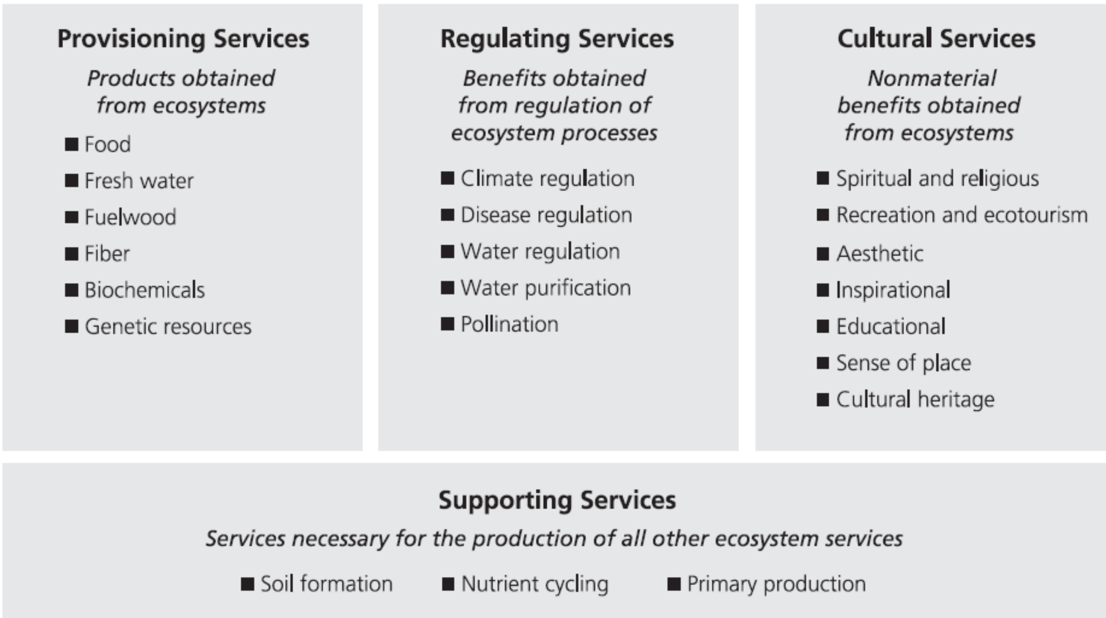

Figure 3.8 Ecosystem service framework.
Source**:** MA (2003).

However, other than the MA, the assessments considered in this review do not specifically devote attention to the impact of future pressures on ecosystem services. Indeed, the extent to which biodiversity loss will impact on ecosystems and their services is highly uncertain. For example, ecosystems may often cease to provide some services long before species extinctions are observed (see Boxes 3.3 and 3.4).

The MA distinguishes between two types of ecosystem services which it highlights as having broad policy implications. Type-I refers to the abundance of individuals and includes provisioning services such as food and fibre and regulating services such as soil erosion and cultural services such as aesthetic value. The provisioning of the service depends on individuals present (e.g. a 50 per cent decline of fruit tree abundance provides 50 per cent less fruit) and it refers to the health of populations at a local scale. Loss of Type-I ecosystem services can be reversed through conservation efforts. It is estimated by habitat loss and local extinctions. Type-II ecosystem services relate to the unique genetic combinations resident in the population rather than the number of copies of the combination. It includes the provisioning of genetic resources, which are the basis for plant breeding, biotechnology and the development of pharmaceuticals. The loss of Type-II ecosystem services is thus irreversible and is best estimated by measuring global extinctions (MA, 2005d, p403).

Box 3.3. Biodiversity and ecosystem services (taken from Braat and ten Brink, 2008. Adapted from MA, 2005c)

- **Species composition is often more important than the number of species in affecting ecosystem processes**. Conserving or restoring the composition of communities, rather than simply maximising species numbers, is critical to maintaining ecosystem services.
- **The properties of species are more important than species number in influencing climate regulation.** Climate regulation is influenced by species properties via ecosystem level effects on sequestration of carbon, fire regime, and water and energy exchange. The traits of dominant plant species, such as size and leaf area, and the spatial arrangement of landscape units are a key element in determining the success of mitigation practices such as afforestation, reforestation, slowed-down deforestation, and biofuels plantations.
- **The nominal or functional extinction of local populations can have dramatic consequences in terms of regulating and supporting ecosystem services.** Before becoming extinct, species become rare and their ranges contract. Therefore their influence on ecosystem processes decreases, even if local populations persist for a long time, well before the species becomes globally extinct.
- **Preserving interactions among species is critical for maintaining long term production of food and fibre on land and in the sea.** The production of food and fibre depends on the ability of the organisms involved to successfully complete their life cycles. For most plant species, this requires interactions with pollinators, seed disseminators, herbivores, or symbionts. Therefore, land use practices that disrupt these interactions will have a negative impact on these ecosystem services.
- **The diversity of landscape units also influences ecosystem services.** The spatial arrangement of habitat loss, in addition to its amount, determines the effects of habitat loss on ecosystem services. Fragmentation of habitat has disproportionately large effects on ecosystem services.

3.8.1 Provisioning services

Food production and reducing hunger

In 2000 the world committed itself through the Millennium Development Goals to reducing the number of structurally malnourished people by half by 2015. Key to achieving this goal is ensuring a secure, sufficient and affordable food supply. Food price increases lead to the number of people suffering from hunger. Due to the importance of maintaining a secure food supply many countries employ trade barriers and income support for farmers.

Global food production has increased by 168 per cent over the past 42 years. The production of cereals increased by about 130 per cent, but is now growing more slowly. Despite this, an estimated 852 million people were undernourished in 2000–02, up 37 million from the period 1997–99. Of this total, nearly 96 per cent live in developing countries. Sub-Saharan Africa is the region with the largest share of undernourished people (MA, 2005c; cited in Braat and ten Brink, 2008).

Neither the GEO-4 nor the IAASTD, which examine progress towards the Millennium Development Goal with respect to extreme hunger, expect it to be met. Both interpret the goal in terms of malnourished children aged between zero and five years. The IAASTD projects that in the absence of new policies the number of malnourished children will reduce from 150 million in 2000 to 130 million in 2025 and to 100 million by 2050. Malnutrition in children in Sub-Saharan Africa in particular will remain a problem, while in some other areas the goals *will* be met, The number of malnourished children is projected to roughly halve by 2050 under scenarios that implemented targeted policies, such as the GEO-4 scenarios *Policy First* and *Sustainability First* (UNEP, 2007, p429) and policy scenarios under the IAASTD (Kok *et al.*, 2008).

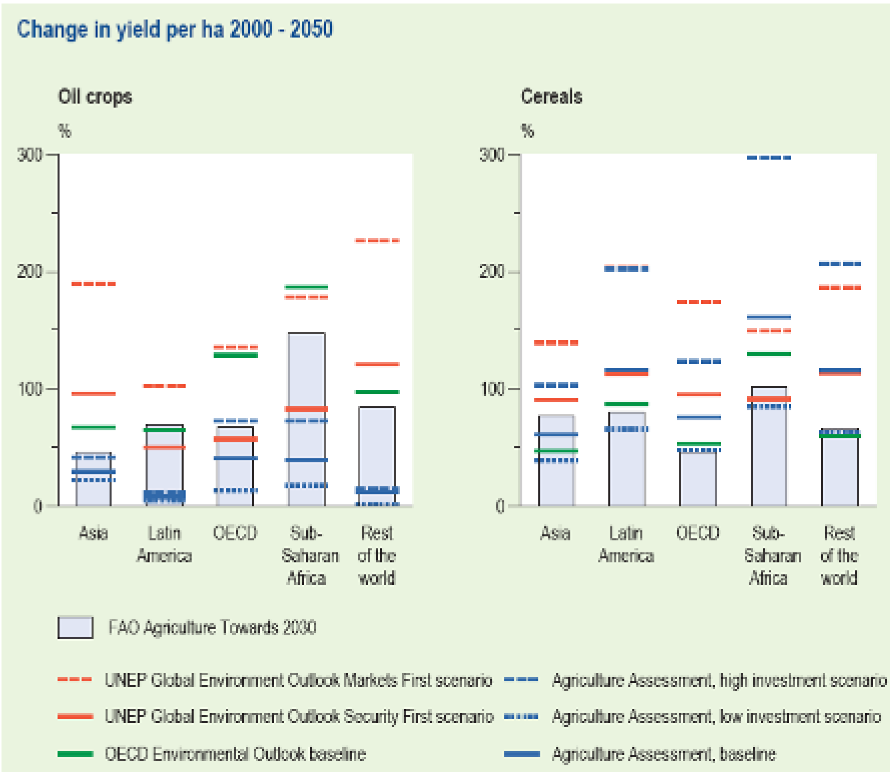

Figure 3.9 Increase in crop yields between 2000-2050, according to the FAO and three of the assessments discussed in this report. (Source: Bruinsma (ed), 2003; UNEP, 2007; IAASTD, 2008; OECD, 2008. Taken from Kok *et al.* 2008).

All scenarios expect food productivity to rise (see section 3.2.1 above; Figure 3.9; Appendix 2.2). The market scenarios see the highest overall increases in food production. Under the MA scenario *Global Orchestration* the global food output increases by 72 per cent, with a four-fold increase in Sub-Saharan Africa. This is attributed to large increases in agricultural research and supporting infrastructure as well as a rapid increase in land under irrigation. The IAASTD projects increases lower than the historic rate if no new policies are implemented. However, the high investment scenario produces significant increases, including a three-fold increase in Sub-Saharan Africa.

Despite food production rising in all scenarios, food availability does not always increase at the same rate. Regional policies appear to have a negative effect. Under the GEO-4 scenarios, modest increases due to low technology investment and knowledge transfer under *Security First* are cancelled out in Africa and West Asia by rising population growth, ultimately leading to a dip in calorie intake after 2040. In the MA, the *Adapting Mosaic* scenario results in food produced on expanded crop areas being insufficient for demand causing food price increases and an increased demand for imports.

Total fish consumption has declined somewhat in industrial countries, while it has increased by 200 per cent in the developing world since 1973. For the world as a whole, increases in the volume of fish consumed are made possible by aquaculture, which in 2002 is estimated to have contributed 27 per cent of all fish harvested and 40 per cent of the total amount of fish products consumed as food (MA, 2005c: cited in Braat and ten Brink, 2008).

Fuel

Provision of fuel can be separated into natural fuel wood and biofuels. Whilst fuel wood still comprises a large part of the total energy use in some areas, it is fuel in the context of biofuels that is more often assessed, as in the MA. Although the current usage of biofuels is fairly modest, it is projected to greatly expand in the future. Under the *Global Orchestration* scenario, expansion of biofuel production is the highest out of all four MA scenarios at 384 mega tonnes per year, a six fold increase on today's production levels. The high production is attributed to the fact that competition with food production is projected to be low since there is a high level of investment in more efficient crop growth under this scenario and also that electricity demand is high owing to strong economic growth. However, as a consequence of high biofuel production, deforestation rates are also increased. Global production of biofuels under the *TechnoGarden* scenario is projected to increase four fold from current levels, the main influence behind this being a focus on climate policy. Under the *Order from Strength* scenario, energy crops have to compete with food crops for land. This scenario projects the largest population increase of all four scenarios which coupled with low productivity of croplands (from little investment in agricultural technology) means that land and biofuels are more expensive. Despite this, biofuel production does increase from current levels by a factor of approximately two.

Water availability

The MA examined water availability, which they defined as the sum of average annual run off and groundwater recharge. This gives a figure of the total volume of water that is annually renewed by precipitation and which, in theory, is available for the requirements of both society and freshwater ecosystems. Current global water availability was estimated to be between 42,600 and 55,300 km^3 per year (MA, 2005d, p345). Global water availability projected from the four MA scenarios did not show as large differences between scenarios as there were between regions. By 2050 global water availability is projected to increase by between five and seven per cent, depending on the scenario being considered. Latin America sees the smallest increase in water availability (approximately two per cent depending on scenario). The small changes in water availability projected up to 2050 owe themselves to increasing precipitation leading to increased runoff on the one hand and warmer temperatures intensifying evaporation and transpiration leading to decreased run off on the other. By 2100 the differences in global water availability between scenarios are still not as great as the differences between regions. It should be noted that whilst an increase in water availability in this context can increase water supply for society and freshwater ecosystems, it can also lead to more instances of flooding.

Overall, the *Global Orchestration* scenario projects the largest global increase in water availability of all four scenarios by 2100 (17 per cent increase). Under this scenario, the fastest rate of climate change is projected. In contrast, the scenario where the lowest rate of climate change is projected, *TechnoGarden*, projects the smallest change in global water availability (seven per cent)..

Furthermore, although availability is projected to increase in most areas, there are important arid areas where availability is projected to decrease including the Middle East, Southern Africa and Southern Europe. These areas are projected to see a decrease in water availability of approximately 50 per cent from current levels under all four MA scenarios.

Water stress denotes reaching the limits of water quality as well as water quantity (Cosgrave and Rijsberman, 2000) and is a situation where low water supplies limit food production and economic development and affect human health. According to the OECD, 44 per cent of the world population in 2005 lived in areas of severe water stress and the situation is projected to worsen, with an additional 1 billion people (or 47 per cent of the world's population) projected to be living in areas of severe water stress by 2030 (OECD, 2008, p222). The main increase in population affected is likely to be India, followed by China, Africa and the Middle East.

Other provisioning ecosystem services

Other provisioning ecosystem services include genetic resources and biochemical discoveries. These services were not directly evaluated by the MA but preliminary judgements were made in terms of the four scenarios in the assessment. Under the *Global Orchestration* and *Order from Strength* scenarios, genetic resources may severely decline whilst under the *TechnoGarden* and *Adapting Mosaic* scenarios, they are projected to be roughly the same as current levels. All of the projections regarding these provisional services have a low certainty.

3.8.2 Regulating ecosystem services

Soil erosion control

Soil degradation can occur through chemical degradation, physical deterioration and water erosion. For the purposes of the MA, water erosion was used as the indicator of soil degradation. The MA water erosion index was calculated by combining trends in climate and land use change with the erosibility index. Whilst water erosion of soils is influenced by natural conditions, the way that soil is utilised can have significant effects. The rate of soil erosion can be driven by a number of factors including agricultural practices, land use change (especially vegetative cover) as well as precipitation changes resulting from climate change. The damaging effects of soil erosion in terms of ecosystem services is seen plainly in productivity loss of soils that are vital to world food production. Soil erosion also plays a role in climate change since it contributes to GHG emissions.

A number of the assessments model future soil water erosion risk in the context of land-use change and climate change (MA and GEO-4). All scenarios under the GEO-4 assessment predict a 50 per cent increase in the global extent of soils with high water erosion risk compared to the current situation. The risk increases after 2025 for *Sustainability First* as more biofuel crops are introduced. The increases are largest under *Policy First* due to larger food demand and increased demand for biofuels.

The scenarios in the MA project very similar levels of risk in terms of the global area of soils at risk of water erosion up to 2050. The *Order from Strength* scenario is projected to result in the highest risk of water erosion with 32 Mkm^2 of the global area of soil considered to be at high risk. The MA scenarios show greater divergence by 2100 where the global area of soil at risk from water erosion is projected to have doubled from year 2000 levels to approximately 40 Mkm^2 under the *Order from Strength* scenario. Under this scenario, the largest increase in agricultural land is projected to occur. The risk of water erosion is largest in agricultural areas, so it follows that under this scenario, soil erosion risk is projected to be highest among all four scenarios. The *TechnoGarden* scenario projects the smallest global area at risk from water erosion by 2100, with 31Mkm^2 projected to be at high risk. Under this scenario there are relatively low population levels and more ecologically proactive agricultural practices are projected to be in place.

There are regions of the world where the risk of water erosion of soils is expected to decline (OECD regions Central Europe, Australia and New Zealand), mainly as a result of a decrease in area being used for grazing.

Climate regulation

Ecosystems have an important role in climate regulation. The MA considers that under the *Global Orchestration* scenario, this role would become more important to all countries. However, the future capacity that ecosystems will have for carbon sequestration in wealthy countries is uncertain. Under the *Order from Strength* scenario, it is projected that the capacity of ecosystems to regulate climate will decline, primarily due to a lack of international coordination present under this scenario. Despite advances in engineering ecosystems present in the *TechnoGarden* scenario, it is unclear as to whether this would markedly improve ecosystem capacity to sequester carbon beyond the level achieved in *Global Orchestration*. Overall, none of the MA scenarios project clear effectiveness of land ecosystems in climate regulation on their own, without additional management (MEA, 2005d, p355).

Water purification

Water purification is defined in the MA as the process whereby freshwater ecosystems, such as wetlands, helping to deteriorate or remove substances that are hazardous to the health of humans and the ecosystems themselves. Under the *Global Orchestration* scenario, there is a divide between wealthy and poor nations in the capacity of ecosystems to purify water. In wealthy nations, break downs in water purification are fixed when they occur whereas in poorer nations a net loss in water purification by ecosystems is projected. The main drivers fuelling the break down in water purification are projected to be the speed at which ecosystems are degrading, high waste loads overloading ecosystems and the reduction in wetland area due to increases in population and agricultural land. Under the *Order from Strength* scenario, water purification declines in all countries and in the case of some poorer nations, the water purification capacity of some ecosystems decreases to lower levels than projected under the *Global Orchestration* scenario. Under the *Adapting Mosaic* scenario, localised protection of wetlands means that an increase in the water purification capacity of ecosystems is projected. Even though the *TechnoGarden* scenario projects the smallest environmental pressures out of the four scenarios, the time taken for reengineering of ecosystems is slow resulting in little net change in projected water regulation by 2050. There are, however, improvements made in poorer countries owing to the time lag present in ecosystem engineering and in some countries, avoiding mistakes made in wealthier countries (MEA, 2005, pp358-359).

Coastal protection

The level of coastal protection provided by ecosystems was considered by the MA with respect to the adaptive capacity of nature (e.g. existence of coral reefs and mangroves) and society as well as the extent of sea level rise. The MA projects with medium certainty that there will be a higher storm risk to all coastal populations under all scenarios due to sea level rise, the risk being relatively higher in poorer countries. Among the scenarios of the MA, coastal protection is projected to remain around the same as current levels under the *Global Orchestration* scenario owing largely to the reactive approach to environmental protection taken. A similar picture emerges from the projections for coastal protection under the *Order from Strength* scenario, but degradation of coastal ecosystems in some poorer nations leads to a large loss of coastal protection. Owing to the regional approach taken under the *Adapting Mosaic* scenario, it is likely that storm protection would feature as a priority and hence it is projected that improvements to coastal protection will be made under this scenario.

3.8.3 Supporting services

Supporting ecosystem services are those that are necessary for the production of all other ecosystem services. Their impacts on people are indirect or occur over a long time frame and include nutrient cycling, soil formation, primary production and provisioning of habitat. In general, the scenarios in which people handle environmental problems in a reactive manner more often than not—*Global Orchestration* and *Order from Strength*—do not focus on maintaining supporting services. The short-term approach to fixing the most immediate problems does not allow for full consideration of long-term services such as the ones in this category. Thus supporting services are projected to undergo a slight, gradual decline in these two scenarios. This decline is likely to go unnoticed until it causes significant changes. On the other hand, the two scenarios in which some environmental actions are proactive, *Adapting Mosaic* and *TechnoGarden*, may give some consideration to the management of certain supporting services, causing them to remain steady throughout these scenarios.

3.8.4 Gaps or limitations in the models

Certain ecosystem services, such as cultural and supporting services, pose particular challenges in relation to modelling and have not been modelled in the assessments. Assessments under the MA made for these services are qualitative based on expert opinion (2005d, p360). In addition, other services are referred to but not modelled directly, such as pollination and biological pest control.

Non-linearity in the flow of services could be a major issue because there are likely to be thresholds of biodiversity required beyond which the ecosystem services decline rapidly (see Box 3.4). As a result significant loss of ecosystem services may occur long before key species become globally extinct (MA, 2005d p377). However, such thresholds are not addressed in any of the models.

Box 3.4. Critical thresholds/tipping points

A ‘critical threshold’ can be defined as a point between alternate regimes in natural systems. When a threshold in a certain variable in a system is passed, the system shifts in character and the provision of certain ecosystem services may be lost. Once crossed, it may be difficult (or impossible) and costly to return an ecosystem to its original state. Thresholds may include a minimum habitat size to support viable populations of species or a minimum number or density of a species to remain stable (ten Brink *et al.* 2008).

3.9 Costs of biodiversity and ecosystem service loss

Access to knowledge about the economic impact and costs of the various policy options regarding biodiversity is essential to making informed policy decisions. This area is not extensively covered in the global assessments, which do not systematically attempt to estimate the cost of losing ecosystem services or the costs of preventing such loss. As such, no new modelling exercises were carried out in the global assessments. This following section contains a summary of the references made to the issue in the global assessments and includes a summary of the *The Cost of Policy Inaction* (COPI) study carried out as a support document for TEEB (Braat and ten Brink, 2008).

3.9.1 Cost of policy inaction

The debate around the cost of ecosystem loss has become increasingly topical since Costanza *et al.* (1997) attempted to provide an estimate of the total economic value of Nature's services. Their result – USD $33 trillion per year for the value of ecosystem services compared to $18 trillion of the global economy – has been criticised on the one hand for extrapolating marginal valuations to entire global ecosystems and on the other for being a "significant under-estimate of infinity" (Toman, 1999; cited in Braat and ten Brink, 2008).

The OECD (2008, Chapter 13) reviews literature on the cost of policy inaction in three areas of environmental policy: i) health impacts from air and water pollution; ii) fisheries management; and iii) climate change. With regards to fisheries, it quotes evidence from Bjorndal and Brasao (2005) that the net present value of retaining the existing ineffective fishery management regime for East Atlantic bluefin tuna is only one third of what would be achieved from an optimal regime of restrictions on gear selection. A separate study found that the lost net present value of continuing the existing excessive fishing regime of 13 "overfished" fish stocks in US waters was USD $373 million compared to implementing stock "rebuilding" plans developed by Regional Fishery Management Councils (Sumaila and Suatoni, 2006; cited in OECD, 2008). This made the current excessive fishing practices almost 3 times as expensive as the recovery plans. The OECD points out that although the cost of ecosystem service loss is often borne by those who exploit the resource, others may bear some of the costs. For example, after the collapse of the Canadian cod stock, an estimated CAD$3.5 billion was spent on income support and government assisted programmes for fishers, placing the burden on tax payers (OECD, 2006; cited in OECD, 2008).

In 2008, Braat and ten Brink carried out an assessment of the cost of current and projected losses of ecosystem services in the study of COPI, which considered a mixture of cost types: actual costs, income foregone (e.g. lost food production) and stated welfare costs (e.g. building on willingness to pay estimation approaches). Some costs can be directly translated into monetary terms that would feed directly into GDP; some would have an effect indirectly, and others would not be picked up by GDP statistics. This study used the GLOBIO model to estimate changes in natural areas and biomes, and attached monetary values associated with the ecosystem services of the biomes, using a significant literature review at each stage to determine these values. To compensate for gaps in the literature, assumptions were made about the relationship between ecosystem service provision and landuse type within a biome (also see Figure 4.1 below). The study found that the loss of welfare from the reduction in land based ecosystem services amounted to around 50 billion EUR per year starting in 2000, increasing every year that biodiversity loss continues. By 2050, under a business as usual scenario, expected cumulative losses between 2000 and 2050 would amount to $14 trillion per year from the loss of land based ecosystems alone, constituting 7 per cent of GDP by 2050.

These figures are estimated to be conservative as: i) they do not consider all ecosystem services (losses from coral reefs, fisheries, invasive alien species and wetlands are omitted); ii) the projected rate of loss is calculated from a "middle of the road" economic and demographic scenario; and iii) values do not consider non-linearities and threshold effects.

3.9.2 Cost of policy action

Costing policy actions provides an opportunity to compare policy options against the cost of a business as usual scenario. The GBO-2 considers six policy options and estimates if the impacts of policy scenarios on the economy will be positive or negative. The policies are:

i) liberalisation of the agricultural market;
ii) alleviation of extreme poverty and hunger in Sub-Saharan Africa,
iii) limiting climate change;
iv) sustainable meat production and consumption;
v) increasing the area of plantation forestry; and
vi) extending the protected areas to 20 per cent of each biome.

It concludes that policy options for sustainable meat production, increased plantation forestry and protected areas do not have a major impact on the broader economy given that meat and forestry sectors only form a small part of national economies (in the order of 1 per cent; FAO, 2004; cited in sCBD and MNP, 2007). Both sustainable meat consumption and production policies and extending effectively protected areas had an immediate effect on reducing the rate of biodiversity loss, suggesting these were good value-for-money policies. Trade liberalisation and poverty reduction results in a loss of biodiversity in the short to medium-term while having a positive impact on GDP. Climate change mitigation is considered to have negative impacts on both biodiversity and GDP in the short- to medium-term due to expansion of land required for biofuels, although it is expected this is partially because 2050 is too short a time period to experience the positive impacts of climate change mitigation. The distribution of benefits varies from region to region, with Sub-Saharan Africa expected to benefit economically from liberalisation, poverty alleviation and climate change mitigation, but suffering significant losses to biodiversity (sCBD and MNP, 2007; p37). The report does not provide a cost-benefit analysis assessing the overall welfare impact of losing biodiversity but gaining increased economic growth.

The GBO-2 quoted evidence that establishing and running a global reserve system (15 per cent land, 30 per cent sea coverage) would cost approximately $30 billion per year (see Balmford *et al*., 2003; Balmford. and Whitten, 2003; James *et al*., 1999a; cited in sCBD and MNP, 2007). Increasing forestry plantations would involve government subsidies or tax exemptions of approximately $10 billion (Ernst and Durst, 2004; cited in sCBD and MNP, 2007, p28). Other models have looked at the cost of reducing deforestation rates through REDD programmes (see Section 3.5.3).

The other assessments do not attempt to reflect the cost of policy actions in monetary or GDP terms.

3.10 Policy options

Ecosystem degradation can rarely be reversed without actions that address the negative effects or enhance the positive effects of one or more of the five drivers of change: population change (including growth and migration), change in economic activity (including economic growth, disparities in wealth, and trade patterns), sociopolitical factors (including factors ranging from the presence of conflict to public participation in decision-making), cultural factors, and technological change (MA 2005a, p19).

3.10.1 Improving governance for agricultural technology transfer

The IAASTD highlights the need for innovative governance and finance models to ensure the adoption of ecologically and socially sustainable agricultural systems. It states that sustainable agricultural practices are more likely when the institutional arrangements provide secure access to credit, markets, land and water for individuals and communities with limited resources. The assessment acknowledges the positive impacts of international trade but warns that without the appropriate national institutions and infrastructure in place it can impact negatively on poverty alleviation, food security and the environment. The future direction of agricultural knowledge science and technology (AKST) could be improved by internalising the environmental externalities and rewarding activities for environmental services. It suggests that this could help tackle problems such as exportation of soil nutrients and water, and unsustainable soil or water management. Likewise, targeted AKST investment that recognises the multifunctionality of agriculture, of commodity output and non-commodity/public good outputs could assist progress towards development and sustainability goals (IAASTD Summary for policy makers, p6).

3.10.2 Biotechnology and biodiversity

In spite of the limited growth in the development of transgenics, it is possible that these technologies will re-emerge as a major contributor to agricultural growth and productivity.

This may be particularly required in response to climate change related challenges such as prolonged drought and warmer temperatures. The IAASTD states that genetic engineering could have a key role in meeting these challenges, reducing vulnerability of crops to climatic and other shocks and reducing natural resource scarcity. Transgenic crops could increase crop yields and thus reduce expansion into natural and uncultivated areas.

One of the main risks to biodiversity is the out-crossing of genes to wild relatives, although the risk of crops persisting in the wild is considered relatively low. Out-crossing could be prevented by the use of genetic restriction of its reproductive capacities, but this is controversial as it prevents farmers from saving seed from one season to the next (IAASTD 2008).

3.10.3 Ecosystem-based approach to fisheries management

The assessments concur that strong international coordination and an ecosystem approach will be required to manage the multiple pressures on capture fisheries. The OECD contends that the negative trends in capture fisheries can be reversed by further measures to limit total catch levels, designate fishing seasons and zones, regulate fishing methods and eliminate subsidies for fishing capacity (OECD, 2008, p32).

3.11 Conclusions

All the assessments agree that substantial biodiversity loss will continue under all the considered policy scenarios. These scenarios include protecting 20 per cent of ecosystems in all regions of the world (which is an ambitious target) and reducing meat consumption; but both measures only result in minor biodiversity conservation benefits according to the projections and the MSA indicator. As noted above, this conclusion is surprising and may be due to the sensitivity properties of the MSA indicator, and/or models. Furthermore, the majority of the assessments used the MSA as the principal indicator of all projected biodiversity impacts. Thus most of the conclusions in this report are based on this one indicator, which highlights the need to ensure that it is as robust and sensitive as possible. This issue is addressed further in Task 3.

Although the minimal projected impact of protected areas is questionable, it is clear that, ultimately it is the drivers such as increasing population growth and prosperity,that have an overwhelming influence on biodiversity outcomes. Their impacts vastly outweigh specific measures that attempt to protect biodiversity. For example, our increasing demand for energy continues to exacerbate climate change which becomes a significant pressure on biodiversity. Scenarios which attempt to deal effectively with climate change assume a greater use of biofuels which increases demand for land and water resources and has adverse effects on soil erosion.

In addition, most assessments make optimistic assumptions about the increased productivity of agriculture, which could significantly reduce the need for expansion of agricultural land into natural areas. Therefore, according to these assessments, the productivity increases are key to ensuring that biodiversity losses are not even greater than those forecast in the models. Investment in agricultural knowledge and research will be vital to ensuring this happens.

The consequences of biodiversity loss on ecosystem services is unclear. There is evidence to suggest that ecosystems may require a minimum quality (e.g. abundance and diversity of species) to maintain many important ecosystem services. Below such critical thresholds, ecosystems reach a tipping point, and may suddenly switch their character, no longer providing the ecosystem service. Furthermore, the restoration of such ecosystems, if possible at all, is likely to be very difficult and costly.

The GEO-4 assessment contends that biodiversity loss continues because current policies and economic systems do not incorporate the values of biodiversity effectively in either the political or the market systems and many policies that are in place are not implemented fully (UNEP, 2007, p159).

Given the projected expansion of the global economy to 2030, failure to act on environmental challenges will undoubtedly result in greater impacts on biodiversity and ecosystem services in the future. Natural resource sectors will find demand increasing for their output as large economies (e.g. Brazil, the Russian Federation, India and China) continue to experience rapid growth. Sectors such as agriculture, energy, fisheries, forestry and minerals will need to have strong policies in place to reduce the environmental impacts of this rapid growth (OECD, 2008, p75).

4 ASSESSMENT OF IMPACT OF KEY ASSUMPTIONS

4.1 Description of Task 3 from the ToR

With respect to the aim of Task 3 the ToR states (with our emphasis added of key points):

A) *"The assessment should examine* ***how changes in key assumptions affect the results of different models*** *with a* ***focus on either the impact on ecosystem services or on the economy more generally****".*

B) *"The assessment should have a consideration of*

1. ***the extent to which the scenario-model studies could be used for making large-scale assessments*** *of the impacts of the loss of biodiversity and ecosystem services worldwide, and*
2. *also of* ***how such models could be adapted to better assess policies*** *(including coupling of biophysical models with economic models to assess the wider effects on the economy)."*

With respect to the methods to be employed, the ToR states:

A) *"This should be done through*

1. *the* ***identification of a number of key assumptions (or drivers) with the Commission*** *and then*
2. *an* ***examination of how these influence the models*** *(generally involving identification of a baseline and then of an alternative scenario)".*

B) *"Amongst the assumptions to be examined should be:*

1. ***a selection of exogenous factors*** *(like population growth, demand for natural resources and energy, etc) and*
2. ***a selection of policies*** *affecting biodiversity and ecosystems, such as agricultural or fisheries management decisions, timber logging/deforestation, or strict conservation".*

C) *" The choice of the key assumptions and models to be examined should be*

1. ***determined during the carrying out of the previous tasks****, and*
2. ***agreed with the Commission****."*

4.2 Methods

4.2.1 Assessment of key assumptions

It was recognised from the very beginning in this project (Inception meeting, January 2009) that it will not be possible to carry out an analysis of the sensitivity of models to policy impacts and other parameters by running models and comparing results. This recognition was based on the realisation that to run models the study team would need full access to the models, meaning (1) having operational, running versions of the models on computers capable to do so, (2) manuals to operate the models or aid from the original model builders and computer-code programmers, (3) the source code with explanations, (4) full documentation of the technical format of the model (mathematical equations, input data files, parameter settings, initial condition settings) and (5) access to a help-desk. To be able to compare results (of model runs), the study team would need full access to the output of model runs, with full documentation of the runs, including scenario-input files. The time and financial budget available for the assessment, made this approach impossible.

However, it was expected to be possible to identify potential weaknesses and key assumptions by an examination of the descriptions of model structure and applications of models in scenario-driven assessments. To test this expectation information was gathered and examined with respect to descriptions of the models and of applications of the models. The major sources have been the descriptions as produced through Task 1 of this project, summarised in tables (see Appendix 1), and the literature obtained from a literature search also provided through Task 1 (see list of references). Adequate documentation for Task 3 was only available in "bits and pieces". The description of models and applications does not provide enough detail for a reliable comparative assessment across the collected set of models. The published descriptions of models and results of applications present the output in relation to the general structure of the models and to the general features of the scenarios used to produce the model output, but only a few incomplete cases is detailed documentation available that the desired assessment could be made.

The study team therefore decided to (1) work with the material available, and (2) go through a phase of selection of models which would reflect the relevance and quality of the models at a general level, to be able to spend the available budget on an assessment of those models which were deemed most promising. The results of this limited assessment are presented in section 4.3.

4.2.2 Selection of models

In the ToR it is mentioned that the "task will consider in detail a subset of the models included in Tasks 1 and 2". It was clearly necessary from the results of Task 1, the inventory of models, scenarios and assessments, to restrict the coverage of models to enable an examination of their structure and assumptions in sufficient detail to draw useful results. The first analytical steps in Task 3 were therefore a systematic screening and evaluation of the collected models, based on an explicit set of criteria, reflecting the ToR. The criteria were discussed within the project team and agreed upon by the project leader.

As it was required that the work under Task 3 should look into to the usability of the scenarios and models in a TEEB context, this was part of the screening and evaluation criteria. Furthermore, in the selection process, the potential of individual models with respect to their degree of adaptability to key factors and to help with selection of appropriate policies was addressed. The issue of how to introduce "additional" policies to the models should also be examined, and following the Workshop (see Task 4 chapter) some views are presented in section 4.4.

The starting point of the selection process, and thus of the definition of the selection criteria is that the selected models will be those that include policy assumptions that are of most importance and relevance to TEEB and will be able to address a number of points:

- Address a variety of themes and policies
- Allow for new types of approaches and thus be a bit creative
- Be able to be adaptable, thus in the future allow expansion/adds-on or modifications.

The following selection criteria were applied to the set of models provided through Task 1.

1. Suitability for TEEB scenario-studies:

a) Quantity and quality of ecosystems services (in relation to land and marine ecosystem use); *e.g. give output in terms of provisioning services (crops, meat, fish, timber, water etc.), regulating services (carbon sequestration, water purification, flood mitigation, local pest control, natural pollination), cultural services (biodiversity measures appreciated by tourists, information content), supporting services.*
b) Economic value as output parameters or the possibility to link ecosystem (goods and) services directly to economic parameters *(services specified in terms of physical units per unit area per unit time, localised and linked to specific economies)*
c) Global – regionalised output *(preferred above specific case regions which may contribute adaptive modelling efforts).*

2. Earlier application within assessments: The assessments may be global , sectoral or regional

3. Availability to assessments within TEEB

   This criterion is secondary, as it indicates rather a practical aspect of TEEB process than a quality of the model or assessment study. (*The team realises that some models have been developed with great effort and great cost, sometimes by public funds and sometimes by private enterprise. Also, models as simplifications of reality tend to be most effective in policy analysis when the original modellers who implemented the simplifications are involved in the analysis. The availability in the "public domain", published or on internet (e.g. software products available and free to use) may however be of interest to TEEB in the long run*).

The scoring method used to rank the models of the inventory (see Task 1) is very basic. The number of criteria for which the model delivered some kind of relevant contribution was counted. Several models did not incorporate features which made output in terms of ecosystems services, biodiversity indicators, or economic values possible. In these cases a blank was left in the spreadsheets (see *Annex to Chapter 4*). Spatial resolution was also scored and global models without any spatial specification by region or grid-cell produced a zero score on this criterion. If some kind of regionalisation was available, a grey spreadsheet-cell was indicated.

4.2.3 Technical evaluation of the selected models

The selected models have subsequently been evaluated for the following five aspects:

1. General quality; this includes aspects on the extent of parameterisation, calibration and validation of the model, and whether the models have been peer reviewed and if available the results of such reviews.
   a) Parameterisation - to what extent has the model been parameterised using data?
   b) Calibration - to what extent has the model been calibrated to generate sensible output?
   c) Validation - to what extent have the model results been validated?
   d) Peer-review of model – is the model peer reviewed or not?
   e) Peer review results – what is the result of that peer review?
2. Assumptions; what are the main assumptions about dynamics (*drivers, feedbacks, distributional; trade flows, spatial physical processes; human behaviour, behaviour of economic agents, governance*) in the models and scenarios affecting the outcomes for

ecosystem services and economic aspects. How robust are the results? Drivers & assumptions – description of the main drivers and assumptions in the model.
   a) Feedbacks - Description of feedbacks in the model
   b) Sensitivity – sensitivity of the model output for changes in input or assumptions.
   c) Robustness of results.
3. Uncertainty; How certain are we about the input and output of the models.
   a) Main uncertainties – description of the main uncertainties in the models.
   b) Uncertainty analysis – (how) has an uncertainty analysis been carried out for the model?
4. Transparency; refers to how well documented the models and assumptions are.
   a) Manual/model description availability - is a manual and model description available covering al main relationships and interactions?
   b) Documentation of assumptions and uncertainties - are main assumptions and sensitivity explicitly reported?

In addition, the ToR requirements include an assessment of the adaptability of the models to accommodate other types of (policy) analysis than in previous applications. A special section in this chapter reviews the adaptability and potential of extension of the selected models with "special features" models (see Section 4.3.4).

4.2.4 Types of assumptions

With respect to scenarios, seven types of assumptions are distinguished, six of which are in the so-called "human" domain, and the last one, climate, in the natural environment domain.

- The human domain includes demographic aspects, with parameters such as total population growth rates, or various breakdowns into age classes (cohorts), regions, or sex.
- The second type, economic aspects, is often represented by a Gross Domestic Product indicator, but may also include consumption parameters, or income distribution aspects.
- The third type is sometimes incorporated as an explicit assumption of technological development, but is also in some cases built into the model-dynamics as an ever increasing efficiency parameter in energy use or production functions.
- The fourth type is split for this analysis in (1) general policy measures (part of the Response loop in the DPSIR diagram) or sectoral measures, basically enhancing the production processes, and (2) environmental, resource or biodiversity policies, basically modifying the economic production and consumption processes to achieve environmental goals.
- The fifth type is less specific, but is very much present in the story-lines of the exploratory scenario studies. It refers to different arrangements of political influence, e.g. top-down versus network versus bottom up.
- The sixth type is governance, e.g. relating to government performance and legal implementation.
- Finally, climate change, in various forms is becoming an exogenous driver in many models, following the climate change pathways resulting from e.g. the IPCC studies.

With respect to models, the different types of assumptions embedded in the model equations are assumptions for the land-use changes, for the change in other environmental factors (pressures), for the biodiversity dynamics and the equations describing the various ecosystem service processes, related to land use and other pressures, biodiversity and the drivers.

Thirdly we have addressed the assumptions behind the calculation of biodiversity indicators and ecosystem service indicators, as representations of the relevant output of the studies discussed in this Task 3. Of course, these may be part of the modelled dynamics and as such the relevant assumption may be discussed under that heading as well.

4.2.5 Indicators

Although not explicitly part of the ToR, a short discussion of the indicators for biodiversity and ecosystem services changes is included, based on a review of the most recent literature, and focusing on the indicators used most prominently in the models and assessments in the Task 1 inventory.

4.3 Results

4.3.1 Introduction

The results of the screening and selection of the models are presented in 4.3.2. The results of the evaluation on the technical criteria are presented in section 4.3.3. The adaptability is discussed in section 4.3.4. From the ambitions of TEEB project it was derived that the first filter would be the extent to which models are of a global scale, have been used in global Assessment studies and present results that would directly or indirectly be useful to TEEB objectives (see TEEB 2008). As to the types of scenarios distinguished in the Task 1 report, all types were considered useful at this stage of analysis. Terrestrial and Marine models were considered separately because the Task 1 inventory indicated that currently no models exist that combine the two, using similar approaches. Indicators for assessment of changes in biodiversity and in ecosystem services are discussed in section 4.3.5.

4.3.2 Integrated assessment models: the selection

First a preliminary selection of models that would best fit within the ambitions of TEEB was made using the criteria related to the extent the models consider the four different types of ecosystem goods and services (provisioning, supporting, regulating or cultural services) and biodiversity, if economic value is included in the output, the spatial scale of the output (whether global, regional or both, spatially explicit or not), and earlier application in global, sectoral or regional assessments.

Terrestrial models

Table 4.1 presents the top 4 terrestrial models from this evaluation step and Table 4.2 the top 3 marine models (see for full tables with features and score Annex 4.1 and Annex 4.2.

In the category of terrestrial integrated assessment models the IMAGE model, the AIM model, MIMES and the related GUMBO models received the best scores. The GUMBO and MIMES model are from the same modeling group, MIMES still under development to provide a spatially explicit version of GUMBO. The AIM model has a track record in the IPCC assessments, but it has proven to be very hard to assess the actual capabilities of the model, as there are many different “sub-models” with different degrees of documentation. The analysis in Task 1 indicates already the difficulty to pinpoint the qualities of this model. The IMAGE model has the most extensive track record in global assessments and has also been used as a basis for GUMBO/ MIMES. It is also a complex set of “sub-models” but there was documentation available for evaluation.

Table 4.1 Best scoring terrestrial integrated assessment models

Model name	Ecosystem Service Provision				Bio-diversity	Economic Value of Output	Scale of Output	Application in assessment
	Provisioning services	**Supporting services**	**Cultural services**	**Regulating services**				
IMAGE	Agricultural production, including grass/ fodder production & livestock/ milk production, demand for wood products, timber, fuelwood	Soil fertility		Carbon flux, carbon plantations, ocean carbon, water-erosion sensitivity, air pollution, soil moisture	MSA through link with GLOBIO		Global (details for 24 world regions or 0.5° x 0.5° grid (land cover, land use)	SRES, MA, GEO, OECD, IAASTD, EURURALIS
GUMBO	Harvested organic matter, water supply, mined ores, and extracted fossil fuel	Soil formation (decomposition), nutrient (N) cycling	recreation, cultural (pos.related to total biomass & density of social network, neg.related to human population size)	gas regualtion (C flux), climate regulation (temp.), waste assimilation, disturbance regulation (variation in total biomass)		valuation: marginal product of ecosystem services in both the model's production and welfare functions	***global, 11 biomes globally aggregated, not spatially explicit***	
MIMES	Food production, production of raw materials	Soil formation, nutrient cycling	recreation, cultural	climate regulation, waste assimilation , disturbance regulation		valuation: marginal product of ecosystem services in both the model's production and welfare functions	global, 1° by 1° resolution	
AIM	Water supply, food and timber production			greenhouse gas emissions, air pollution, carbon sequestration ,human health (malaria distribution), flood damage	Vegetation distribution		Focused on Asian-Pacific region, but linked to a global model representing 9 regions; 5° x 5°	SRES

In the category of terrestrial integrated assessment models the IMAGE model, the AIM model, MIMES and the related GUMBO models received the best scores. The GUMBO and MIMES model are from the same modeling group, MIMES still under development to provide a spatially explicit version of GUMBO. The AIM model has a track record in the IPCC assessments, but it has proven to be very hard to assess the actual capabilities of the model, as there are many different "sub-models" with different degrees of documentation. The analysis in Task 1 indicates already the difficulty to pinpoint the qualities of this model. The IMAGE model has the most extensive track record in global assessments and has also been used as a basis for GUMBO/ MIMES. It is also a complex set of "sub-models" but there was documentation available for evaluation.

The models that did not get included in Table 4.1 were not selected for a variety of reasons as can be seen in the Appendix 3.1. Currently there is no comprehensive terrestrial model that fullfills all TEEB ambitions of a full-scale (social and economic) assessment of the costs and benefits of biodiversity policy action scenarios, across all biomes, ecosystem services and economic values. For example, cultural services of ecosystems are only included in a limited number of models. In the MIMES and GUMBO models recreation is included as a cultural service. To be able to cover most ecosystem services and to allow analysis through all spatial scales that are relevant for impact assessment of policies, it seems necessary to combine an integrated assessment model with one or more sectoral models. Therefore a review is presented in 4.3.4. of models which are promising in "providing" additional capability to produce the desired TEEB assessments

a. IMAGE (Integrated Model to Assess the Global Environment)

The model covers a wide range of themes: demography, world economy, agriculture, energy supply and demand, emissions, land allocation, carbon, nitrogen and water cycle, climate change, land degradation. IMAGE uses input from Phoenix (demography) and has been linked to several other socio-economic models in global assessments, e.g. GTAP, Env-Linkages, WaterGAP, IMPACT. GLOBIO uses IMAGE output for the calculation of a biodiversity index. IMAGE is a global model with details for 24 world regions (energy, trade emissions) and/or 0.5º x 0.5º grid (land cover, land use). Drivers are population projections (from UN, IIASA, or from the PHOENIX model), economic drivers (from POLE Star), technological development, policy options and climate change.

b. AIM (Asian Pacific Integrated Model)

AIM covers energy consumption, land use change affecting water supply, vegetation changes (agriculture, forestry production), human health (malaria spread). It was selected as reference model in the Special Report on Emission Scenarios (SRES) and in Third Assessment Report (TAR) both of Intergovernmental Panel on Climate Change (IPCC) and also in the Global Environment Outlook (GEO) of United Nations Environmental Program (UNEP). AIM simulation results were used by many other international organizations including OECD, ESCAP, ADB, UNU, and WWF. The AIM can also be applied to other issues, such as local air pollution issues, acid rain problems, forest management policies and other energy, agricultural and water resource management problems. AIM was also used in the GEO assessments. AIM is a global model with 9 regions : USA, Western Europe OECD and Canada, Pacific OECD, Eastern Europe and Former Soviet Union, China and Central Planned Asia, South and East Asia, Middle East, Africa, Middle and South America (focussed on Asian-Pacific region, but linked to a global model), spatial resolution: 5º by 5º.

c. GUMBO (global unified metamodel of the biosphere)

GUMBO is a complex simulation model, with dynamic interlinkages between social, economic and biophysical systems on a global scale, focusing on ecosystem goods and services and their contribution to sustaining human welfare. The main objective in creating the GUMBO model was not to accurately predict the future, but to provide simulation capabilities and a knowledge base to facilitate integrated participation in modeling. There are many (>100) international collaborators. Drivers in the model are human population, knowledge and social institutions (rules and norms). They drive the rate of the material and energy flux. Both ecological and socioeconomic changes are endogenous to the model, with a pronounced emphasis on interactions and feedbacks between the two. Dynamic feedbacks are included between human technology, economic production, welfare and ecosystem services. There are modules to simulate carbon, water, and nutrient fluxes through the Atmosphere, Lithosphere, Hydrosphere, and Biosphere of the global system. Social and economic dynamics are simulated within the Anthroposphere. GUMBO links these five spheres across eleven biomes, which together encompass the entire surface of the planet. Limited degree of substitutability between natural and social, human and built capital. The 11 biomes are globally aggregated (open ocean, coastal ocean, forests, grasslands, wetlands, lakes/rivers, deserts, tundra, ice/rock, croplands, urban): areal land use, but is not spatially explicit. It is constructed in STELLA (a graphically supported simulation language) as a dynamic systems model, but in fact uses as a meta-model relationships based on outputs of more complex and computational intense models, a.o. IMAGE.

d. MIMES (Multiscale integrated model of ecosystem services)

MIMES builds on the GUMBO model to allow for spatial explicit modelling at various scales, MIMES is a metamodel that used output from several global models (IFs, IMAGE, CLUE, Phoenix, AIM, CLIMBER, EcoSim, IMPACT, WaterGAP, CENTURY, BIOME) to derive relationships between variables.

Marine models

Currently there is no comprehensive marine model that fulfills TEEB's ambition of a full-scale (social and economic) assessment of the costs and benefits of biodiversity policy action scenarios, across all biomes, ecosystem services and economic values. From a review of currently available marine models it was concluded that the marine model that best fulfils the needs of TEEB is the Ecopath with Ecosim (EwE) model developed by the Fisheries Centre at the University of British Columbia. Two other models which should also be considered by TEEB are the Cumulative Threat Model, developed by Ben Halpern and colleagues at the University of California, Santa Barbara (Halpern *et al*. 2008), and the Reefs at Risk approach, developed by the World Resources Institute (WRI), the International Center for Aquatic Living Resources Management (ICLARM), the UNEP World Conservation Monitoring Centre (WCMC), and the United Nations Environment Programme (UNEP). These last two models provide a contrast to EwE in their approach as they are based on combining spatial data layers as opposed to the mathematical approach of EwE where the outputs are derived from differential equations to quantify the ecosystem.

Table 4.2 Best scoring Marine Integrated Assessment models

Model name	Ecosystem Service Provision				Bio-diversity	Economic Value of Output	Scale of Output	Application in assessment
	Provisioning services	Regulating services	Cultural services	Supporting services				
EwE, EcoSpace & EcoVal	Fisheries (inc. their ecosystem effects).	Biomass and fluxes	Economic valuation of resources (Ecoval).	Population dynamics (Top-down vs. Bottom-up controls)	x	EV under different management scenarios;	Multi-scale, ecosystem models. Ecospace: spatial representation & user-defined grid cells.	Millennium Ecosystem Assessment scenarios and the GEO-3 and -4 projections.
Cumulative Threat Model for the global ocean	Impacts on fisheries/aquaculture; abiility of ecosystems to provide non-living resources.	Impact ability of ecosystem to provide regulating services generally.	Impacts on recreation, aesthetic values and experience, spiritual enrichment etc.	Reduction in nutrient cycling ability (e.g. through dead zones/pollution); Impacts on habitats and their services.	x	benefits of highly impacted areas vs less impacted areas.	Global but can be applied at the local- and regional-scale; 1km^2 resolution grid.	x
Reefs at Risk	fisheries; medicines; seaweed and algae for agar; Curio and jewellry; Live fish and coral for aquarium trade.	Nitrogen fixation; CO2/Ca budget control; Waste assimilation.	Recreational Value; ecotourism; sustaining livelihoods of local communities; aesthetic value; support of cultural, religious and spiritual values.	Mantainence of habitats, biodiversity and genetic library; resilience; exchange between ecosystems; protection of shorelines; generation of coral sand; build up of land.	x	benefits of coral reefs; vulnerability of coastal habitats to natural hazards; human health; livelihood	Global coral reefs; 4km resolution	x

(1) Ecopath with Ecosim (EwE)

The EwE model was deemed most suitable for inclusion in TEEB process. Although primarily applied to the fisheries sector, it is an ecosystem model and assesses the ecosystem status through the quantification of biomass at each trophic level. EwE covers a broad range of ecosystem services including provisioning, supporting and cultural services, and as such is relevant to the economic valuation of ecosystem goods and services under different management scenarios, linking to food security issues and economic impacts of bioaccumulation, among others. EwE is a multi-scale model which can be applied to any ecosystem scale as defined by the user, and has previously been applied as a component of integrated assessments, namely the Millennium Ecosystem Assessment and the GEO-3 and GEO-4. As part of the integrated assessments, EwE was linked with other models proving it can be adapted to a range of assessment applications. The model, including its sensitivities and uncertainties, is well documented in the literature. Model outputs are based on actual data from stock assessments, ecological studies, and the literature, and model outputs are validated by time series fitting and uncertainties assessed using the 'Ecoranger' application. Although this leads to the assumption that the results are fairly robust, outputs from EwE are senstive to the input data used meaning the user is required to carefully select input data depending on the outcome required.

(2) Cumulative Threat Model

Halpern *et al.*'s (2008) Cumulative Threat Model assesses the impact of anthropogenic threats on the global ocean through an additive analysis of spatial data layers. As a global model which examines a wide variety of marine ecosystems, the outputs can be related to a broad range of ecosystem goods and services provided by marine habitats. As such, it is relevant to economic models via the implication that areas of the ocean that are more highly impacted will not be able to provide the quality and range of ecosystem goods and services when compared to less impacted areas, and subsequently loss of ecosystem goods and services will negatively impact the economic value of these habitats and may have implications for human health. The Cumulative Threat Model is a global model which can also be applied at local and regional scales. However, it has not yet been included as a component in broader integrated assessments or been soft-linked to other models, indicating that its adaptability is still unknown. The model, including its sensitivities, uncertainties and validation, is well documented in the online Supplementary Materials which accompany the peer-reviewed paper. Model outputs are based on statistics from governments and international organisations, observational data, remote sensing data, and secondary model outputs which are manipulated statistically and normalised prior to being combined to produce the final output. Although there are discrepancies in the data in terms of temporal variation and gaps, the extent of statistical treatment and documentation of this process is indicative of the ouputs being fairly robust.

(3) Reefs at Risk

The Reefs at Risk model illustrates a similar approach as the Cumulative Threat Model, through the addition of spatial data layers, and in some instances model outputs, to produce an output describing the degree of anthropogenic threat to coral reefs. In terms of ecosystem goods and services, the model applies to a broad range of ecosystem goods and services provided by coral reefs, including provisioning, regulating, supporting, and cultural services. Economic valuation of negative impacts on these services relate directly to food security and livelihood viability issues, the increased vulnerability of coastal communities and habitats to natural hazards, and the tourist trade. The original Reefs at Risk provides a global analysis, however later applications have been carried out at the regional scale demonstrating the multi-scale nature of the model. Reefs at Risk has not yet been included as a component in broader integrated assessments or been linked to other models, indicating that its adaptability is still unknown. The model is documented briefly in the main publication's technical notes. Datasets used and their spatial and temporal variability are described, however, there is no in-depth description of data manipulation undertaken (if any) in order to process the data layers for the final output. There is also no discussion of sensitivity or uncertainty analysis. It may be that the lead authors need to be contacted for this information, however, it is recommended that the robustness of the final outputs be approached with some caution.

General Conclusions on Integrated Assessment Models

The best model for TEEB assessment of terrestrial ecosystems at this point in time is the IMAGE model. It has the most extensive track record in global assessments (especially compared to GUMBO/MIMES), it covers a wide range of TEEB relevant themes (but not as wide as GUMBO/MIMES), and is spatially explicit, readily available (compared to e.g. AIM) and has already been used as the basis for the Cost of Policy Inaction analysis included in TEEB phase I. It is, however not complete, perfect and easy to use. It does require actual involvement of the IMAGE team at the Netherlands Environmental Assessment Agency, and needs various extensions to allow for a full coverage of the MA range of ecosystem services. GUMBO/MIMES do have a wider set of services but not complete yet either, and MIMES is still under development as the spatially explicit (and improved in other respects) version of GUMBO. The dynamic feedback of changes in ecosystem services to economic indicators is very interesting to TEEB and a definite improvement on the IMAGE-GLOBIO-COPI-toolbox used in TEEB phase I, but it has not been reviewed (as we have been able to establish) by economists for its "meaning" in economic policy.

Overall, the marine model that meets TEEB selection criteria best is the Ecopath with Ecosim (EwE), mainly due to its high level of documentation and its inclusion in previous integrated assessments. This model does, however, provide only one approach based upon the quantification of biomass within an ecosystem. It may be that the additive methodology undertaken by the other two models described, the Cumulative Threat Model and Reefs at Risk, provide a more suitable approach in some cases depending upon the required outputs and the types of data available. The adaptability of these latter two models have not yet been tested (the Cumulative Threat Model was only published in 2008) and so an approach may be developed in order to integrate this type of model, through soft-linking or other means, with others in order to comprehensively inform TEEB process.

So far models of the marine and terrestrial "domains" have been developed in isolation. However, marine and terrestrial models need to be integrated to explore and highlight the important interlinkages, interdependencies and trade-offs among marine and terrestrial ecosystems. For example, marine systems provide regulating services which are relevant at global scales. These include the regulation of climate through the fixation of atmospheric carbon by oceanic algae and its eventual deposition in deep water, and the role that coastal wetlands play in water quality regulation by capturing and filtering sediments and organic wastes in transit from inland regions to the ocean. In terms of provisioning services, marine environments provide food, water, timber, and fibre (UNEP, 2006). More than a billion people worldwide rely on fish as their main source of protein (Halpern *et al*. 2008), a trade-off which is necessary to understand. Other provisioning services from marine ecosystems relevant to humans and terrestrial systems include building materials from mangrove and coral reef areas, and pharmaceutical compounds derived from marine algae and invertebrates. Finally, the marine environment provides supporting services for many terrestrial processes, including soil formation, photosynthesis, and nutrient cycling by healthy ecosystems, which support goods and services used by humans. Only by integrating models of marine and terrestrial domains can these connectivities be explored and the full impacts of policies on both the marine and terrestrial biomes be assessed.

4.3.3 Integrated assessment models: technical evaluation

The Technical assessment has concentrated on the preferred model (set of models). This technical evaluation deals with the following domains: quality, assumptions, uncertainty and transparency.

IMAGE

As a global Integrated Assessment Model, the focus of IMAGE is on large-scale, mostly first-order drivers of global environmental change. Most of the relationships in IMAGE can be characterised as “established but incomplete knowledge”. This obviously introduces some important limitations, particularly on how to interpret the accuracy and uncertainty.

IMAGE is calibrated against historical data from 1765-2000 (carbon and climate), data from 1970-2000 for energy and agriculture. These data were derived from large international databases (e.g. FAO). The sub-models have been validated. To date, no comprehensive and systematic exploration has been performed of key uncertainties and how they are propagated throughout the entire IMAGE model to influence the final results. What has been done in many instances is to look at uncertainties in underlying data and model formulations in sub-systems of the overall framework, thus providing partial sensitivity analyses for IMAGE 2.4 framework. For a discussion of the sensitivity analysis of IMAGE 1 see Rotmans (1990). IMAGE has been reviewed by an expert advisory board: http://www.rivm.nl/bibliotheek/rapporten/500110003.pdf

A large number of uncertain relationships and model drivers that depend on human decisions can be varied. Uncertainties in model parameters have been assessed using sensitivity analysis:
For the energy sub-model (TIMER; de Vries *et al*., 2001), an elaborate uncertainty assessment pointed out that assumptions for technological improvement in the energy system and translation of human activities (such as human lifestyles, economic sector change, and energy efficiency) into energy demand were highly relevant for the model outcomes. The carbon cycle model has also been used in a sensitivity analysis (Leemans *et al*., 2002). Central to climate change modelling are the responses to increased greenhouse gas concentrations. In the IMAGE model this concerns the responses in global temperature increase and local climate shifts. Another model element relevant to the biodiversity issue is the implementation of specific land-use allocation rules determining conversion of natural biomes (see preference rules in Alcamo *et al*., 1998). These rules are most relevant for the calculated biodiversity value. Only a limited set of land-use change is implemented, that is obviously a simplification of actual land-use changes. This limits the assessment of careful land-use planning, for instance, bio-energy production and forest plantations on available, already impacted, areas instead of natural biomes.

EwE
The core routine of Ecopath is calibrated from the Ecopath program of Polovina (1984a; 1984b) modified to render superfluous its original assumption of steady state. Ecopath no longer assumes steady state but instead bases the parameterization on an assumption of mass balance over an arbitrary period, usually a year. Ecosim and Ecospace are both calibrated to the outputs of Ecopath. Ecopath is in turn recalibrated based upon the outputs of Ecosim and Ecospace. Models are fitted to time series reference data with a long a reference period, with as many different disturbance patterns, as it is possible to assemble. Developers recommend an iterative, stepwise procedure for model fitting.

The modelling approach is thoroughly documented in peer-reviewed scientific literature. Key papers include: Ecopath - 1992, Ecological modelling 61: 169-185; Ecosim - 1997, Fish Biol. Fisheries 7: 139-172; Ecosim II - 2000, Ecosystems 3: 70-83; Ecospace - 1999, Ecosystems, 2: 539-554; EwE overview - 2000, ICES J. Of Marine Science; EwE - 2000, 'EwE: A User's Guide'; among others. The software has more than 2000 registered users representing 120 countries, more than a hundred ecosystem models applying the software have been published, see www.ecopath.org.

Key assumptions through the EwE models relate to incorrect biomass interpretations, misinterpretation of trend data (e.g. hyperstability of catch per effort data), and failure to account for persistent effects such as environmental regime changes or confounding of these effects with the effects of fishing. EwE can produce misleading predictions about even the direction of impacts of policy proposals. However, erroneous predictions usually result from bad estimates or errors of omission for a few key parameters, rather than 'diffuse' effects of uncertainties in all input information. Particular problems have been recorded with: 1) Incorrect assessments of predation impacts for prey that are rare in predator diets; 2) Trophic mediation effects (indirect trophic effects); 3) Underestimates of predation vulnerabilities; 4) Non-additivity in predation rates due to shared foraging areas; and 5) Temporal variation in species-specific habitat factors. Overall, dealing with sensitivity seems to be based upon the user re-running the model several times using different parameters to test the level of sensitivity.

When EwE is used for policy comparisons, incorrect comparisons (EwE leading the user to favor a wrong policy option) are due to errors in the specific input data to which a particular policy comparison is sensitive. Therefore, EwE can give correct answers for some policy comparisons but some wildly incorrect ones for others based upon the inputs used. Lack of historical data and difficulty in measuring some ecosystem components and processes (these are general uncertainties, not just with this model). Semi-Bayesian sampling routine is employed to explicitly consider the numerical uncertainty associated with the inputs. Ecopath has a number of routines that encourage users to explore the effects of uncertainty in input information on the mass balance estimates. In particular, the 'Ecoranger' routine allows users to calculate probability distributions for the estimates when they specify probability distributions for the input data components. Similarly, Ecosim has a graphical interface that encourages policy 'gaming' and sensitivity testing. Confidence intervals can be assigned to all input parameters and can be estimated for output parameters using Ecoranger. Overall, dealing with uncertainty seems to be based upon the user re-running the model several times using different parameters to test the level of uncertainty.

The models in this series are linked in a hierarchical manner (i.e. outputs of Ecopath provide the parameters for Ecosim, whilst the outputs of Ecosim are used to validate Ecopath. Outputs of EwE feed into Ecospace, and these outputs feed into Ecoval. In Ecosim, the 'formal estimation' produced by the ecosystem model feeds into a 'judgmental evaluation' by the user leading to adjustment of inputs and parameters, which subsequently feeds back into the 'formal estimation'. This is an integral part of the process of dealing with uncertainties and sensitivities of the model.

All methods are fully and transparently published and discussed in the scientific literature. All data sets, user guide, and the model are freely available to download online at: http://www.ecopath.org. All assumptions and uncertainties are well documented in the scientific literature and information documents available from http://www.ecopath.org, particularly well described in the user guide which can be found at: http://www.ecopath.org/modules/Support/Helpfile/EweUserGuide51.pdf

EwE has also been soft linked with a number of other models to develop the Millennium Ecosystem Assessment scenarios and the GEO-3 and -4 projections. In the MEA, these models were IMPACT, WaterGAP, IMAGE, a Freshwater Biodiversity Model, a Terrestrial Biodiversity Model, and AIM, and in the GEO analyses the models were International Futures, IMAGE, IMPACT, WaterGAP, GLOBIO, LandSHIFT, CLUE-S, and AIM.

The EcoOcean model is an ecosystem model (based on the Ecopath with Ecosim approach) that was used to explore the GEO-4 scenarios. The model simulates changes in ecosystem and fisheries based on fishing effort levels estimated by a 'policy optimization' routine. This routine varies fishing effort to maximize overall utilities (ecology, economic and employment) based on weighting factors developed under the GEO-4 scenarios.

4.3.4 Adaptability

Continuing on the evaluation of the integrated assessment models as summarised in Section 3.3, and the conclusions that none of these models discussed is complete or perfect to the demands derived from TEEB objectives, the other models in the inventory of Task 1 have been looked at to find out whether they can contribute to the development of a toolbox for TEEB. Indicators for this could be the range of the themes covered by the sectoral, thematic or regional models. First, the models with Biodiversity as their core variable are discussed.

Biodiversity

Given the importance of Biodiversity in the project, special attention has been given to models addressing biodiversity. Table 4.3 shows the scores of the three biodiversity models that were reviewed.

Table 4.3 Biodiversity models

Model name	**Ecosystem Service Provision**				**Biodiversity**	**Economic Value of Output**	**Scale of Output**	**application in assessment**
	Provisioning services	**Supporting services**	**Cultural services**	**Regulating services**				
GLOBIO	***FROM link with IMAGE:***	***FROM link with IMAGE:***		***FROM link with IMAGE:***	mean species abundance (MSA)		global, (0.5º by 0.5º for climatic data, 1km by 1km for land use data)	OECD, GBO
BII					biodiversity intactness index		global, scale of aggregation: 104 to 106 km2	
SAR					number of species; Vegetation composition/ species distribution		global, for biomes, ecoregions, not spatially explicit	

GLOBIO (full documentation in Alkemade *et al*, 2009)

The heart of the GLOBIO3 model is a set of dose-response relationships between the mean abundance of original species (the MSA indicator) and five pressure factors. The relationships are based on model exercises (climate change effects), on data from extensive literature reviews for pressure factors (for land-use change, nitrogen deposition and infrastructure), and on review studies on fragmentation. The data found in the literature was interpreted and figures were recalculated to fit into comparable relationships and indicators. This procedure is sensitive to errors and, to some extent, misinterpretation, but allows comparison among effects of different pressure factors. The unavoidable differences in the quality of datasets used create uncertainty in the estimated dose response relationships. The overall result of GLOBIO3 shows similar patterns as earlier global studies (Sala *et al*., 2000; Wackernagel *et al*., 2002; MA, 2005).

The study used 130, 50 and 300 studies for land-use, nitrogen and infrastructure effects, respectively. The majority of the land-use studies are from tropical biomes, while the studies on nitrogen and infrastructure mostly build on temperate and boreal data. Especially low impact pressures, like grazing in grassland ecosystems, selective logging or nitrogen deposition close to critical load values have high uncertainty. For secondary vegetation a mean value is used, but a time dependent component (reflecting natural recovery) needs to be incorporated. The climate dose-response relationship cannot be based on data that measure the climate effects directly, as most effects will show up in future. Therefore, the relationships are based on model exercises that estimate climate envelopes for species (Bakkenes *et al*., 2002) or vegetation types (Leemans & Eickhout, 2003). Meta analyses (Parmesan & Yohe, 2003; Walther *et al*.2002) and other model studies (Thomas *et al*., 2004) confirm the main tendencies of the GLOBIO3 exercises, but the modelled effects are relatively low. Thus the effect of climate change might be underestimated in this study. For fragmentation, we used five review studies on minimum area requirement (MAR) of animal species (data on 156 mammal and 76 bird species).

BII (Biodiversity Intactness Index; from Scholes & Biggs, 2005)
The BII is an indicator of the "average abundance of a large and diverse set of organisms in a given geographical area, relative to their reference populations". In this way it is very similar to the approach used in the Mean Species Abundance Indicator in GLOBIO (see also 4.3.5). Scholes and Biggs (2005) recommend calculating the BII across all species within the broad taxonomic groups that are reasonably well described, which includes plants and vertebrates, and excludes invertebrates and microbes, which are diverse but poorly documented. They exclude alien species.

The recommended reference population for large parts of the world is the landscape before alteration by modern industrial society. The BII can in principle be calculated exactly by 'bottom-up' aggregation of population data for individual species. However, this will not be a practical option for the next several decades. The proposed strategy is therefore to initially calculate the BII 'topdown'. Scholes and Biggs estimate the impacts of a set of land use activities on the population sizes of groups of ecologically similar species ('functional types'). The chosen land use activities range from complete protection to extreme transformation, such as urbanization. All activities are expressed on the basis of the area affected. The index is aggregated by weighting by the area subject to each activity and the number of species occurring in the particular area. The BII is an aggregate index, intended to provide an intuitive, high-level synthetic overview for the public and policy makers. It can be disaggregated in several ways to meet the information needs of particular users: by ecosystem or political units, taxonomic group, functional type, or land use activity (Scholes & Biggs, 2005)

SAR (Species Area Relationship; from Van Vuuren, Sala & Pereira, 2006)

The SAR is an empirical relationship describing how the number of species relates to area (Rosenzweig, 1995) and is defined as $S = c A^z$, where S is the number of species, A the habitat area, c is the species density and z the slope of the relationship. The SAR has been used earlier to estimate biodiversity loss when native habitat is reduced by deforestation (e.g., May *et al*. 1995, Pimm *et al*. 1995, Brook, *et al*. 2003) or climate change (Thomas *et al*. 2004).

In contrast to the loss of biodiversity at the global scale, local changes in species abundance and local extinctions are directly proportional to losses in habitat. Species and the ecosystem services that those species provided often disappear immediately after a piece of native habitat is converted into an agricultural or urban patch. Moreover, another important difference between local and global losses of biodiversity is the reversibility of the phenomenon. Local losses could be reversed as a result of abandonment or active conservation practices. Populations can invade from adjacent patches naturally or assisted by human intervention. Ecosystem services derived from local diversity can therefore increase or decrease as a result of gains and losses of habitat.

4.3.5 Conclusions

The GLOBIO model has a track record in global assessments (GBO2, GEO4, OECD2030, COPI). It includes a well developed link to the IMAGE output data which act as drivers of biodiversity loss. The biodiversity indicator is the mean species abundance, which is similar to the Biodiversity Inatctness Index. It is relatively simple in mathematical structure, based on peer reviewed literature and can be adapted easily to include other stress factors or reflect the effect of new environmental policies. The GLOBIO model includes many different anthropogenic pressure factors affecting biodiversity. Additionally a strong advantage of the GLOBIO model is that it can be directly linked to the IMAGE model that provides information on ecosystem services. The BII and SAR models (used in the MA) could contribute as well in TEEB context.

Biogeochemical and hydrological models

Next to extension of the Integrated Assessment Models with Biodiversity models, there are a number of extensions possible to improve the biogeochemistry aspects (Tables 4.4). The category of biogeochemical models in the Task 1 inventory mainly contains sectoral (or some multi-sectoral) models. In this category, IBIS, LPJmL and SAVANNA scored best. The SAVANNA model is a model that can only be applied for the savannah biome. For this biome it will be possible to get very detailed results, but for other processes and biomes the results will probably be less accurate than the more general vegetation models like IBIS and LPJmL. Although it only includes provisioning services (agricultural food productions), IMPACT-WATER is the only biogeochemical model that includes a feedback from ecosystem services to socio-economic development, through including effect on water availability/ water scarcity..

IBIS

The model is restricted to terrestrial ecosystems. It includes vegetation with energy, water and carbon exchange and nutrient cycling.

LPJmL

The LPJmL model is a general dynamic global vegetation model that also includes agricultural land and managed forests. Output of the model is vegetation cover (as fraction of different plant functional types per grid cell), CO2 exchange, seasonal water balance, NPP and crop production. The plant functional types can be classified based on the needs of the user. However, if a user wants to use or introduce new functional types, the model needs to be parameterised or calibrated for these new groups. It will probably take a long time to do this right. Currently the LPJmL model is being integrated into the IMAGE modelling framework to provide improved modelling of vegetation in IMAGE. The model is expected to be available in the second half of 2009, further adding to the applicability of IMAGE. No links to other models are known, but output of LPJmL could probably relatively easily be included in the meta-modelling approaches like MIMES/GUMBO and the assessment tools like ATEAM and InVEST.

Table 4.4 Biogeochemical and hydrological models

Model name	Ecosystem Service Provision				Biodiversity	Economic Value of Output	Scale of Output	Application in assessment
	Provisioning services	Supporting services	Cultural services	Regulating services				
IBIS	water runoff	NPP, SOC, N balance		carbon balance, water regulation	Vegetation composition (functional types)		0.5 - 4º	
LPJmL	runoff volumes, crop production	annual NPP		CO2 exchange, water balance	vegetation cover (fraction of different plant functional types per grid cell); Vegetation composition		global, 0.5º grid cells	
SAVANA	livestock production, grass and timber production, water supply (runoff, deep drainage)	NPP, nutrient cycling		water balance	Species distribution and abundance (plants + animals); community composition		***regional, resolution depending on input data and studied ecosystem***	
WaterGAP	water supply						global, country, river basin, grid cells 0.5° by 0.5°	OECD, GEO, MA, in combination with IMAGE, IMPACT, EcoSim and AIM

Of the hydrological models, only the WaterGAP model has enough promising features to be relevant for TEEB. It has been widely used in other assessments.

4.3.6 Regional models / assessment tools

The ATEAM and InVEST modelling tools score best in the category of regional models/assessment tools (Table 4.5). They include all four ecosystem services and biodiversity and are available for external researchers. The ATEAM tool uses as input the output from some of the models considered before, like the LPJ and IMAGE models. The CLUE model is a specialised land use dynamic model with its major application in Europe but with a great number of country level applications around the world

Table 4.5 Regional models

Model name	Ecosystem Service Provision				Bio-diversity	Economic Value of Output	Scale of Output	application in assessment
	Provisioning services	Supporting services	Cultural services	Regulating services				
ATEAM	food production, wood production, energy production, water supply	soil fertility maintenance (soil organic carbon), pollination	recreation, sense of place, beauty	carbon storage (LPJ model), drought and flood prevention, water quality	statistical niche modelling		Europe 15 + Norway and Switzerland , 10' by 10' grid	
InVEST	drinking water, irrigation water, food production, timber production, non-timber forest products	pollination (contribution to yield)	recreation and tourism, cultural and aethetic values, real estate prices as indicator of valuation of nature	flood mitigation, carbon sequestratio n, erosion control, water quality	species richness (habitat requiremen ts of 37 terrestrial vertebrate species, dispersal ability)		regional, resolution flexible; case study: Willamette Basin, Oregon, USA (30 m x 30 m grid, for results: 500 ha units)	
CLUE	None (but land used for agriculture, grazing, forestry)				Land cover diversity explicit		Europe (EU-27), also case studies between 30m and 32km	EU-RURALIS

Also the ATEAM and InVEST assessment tools include cultural services, mainly related to recreation and aesthetic and cultural values of landscapes. The regional assessment tools that were evaluated, i.e. ATEAM and InVEST, follow an interesting approach that could provide the necessary framework to combine model outputs and assess impacts on value of ecosystem goods and services. These models build on existing models and use their output, while increasing feedbacks and interlinkages between components. Disadvantage is that they are relatively data demanding.

4.3.7 Economics in the assessment models

TEEB ambitions point at a need for a strong economic perspective connected to Global assessment models. In the models reviewed, economic variables act as drivers of land use and other environmental changes. Except for GUMBO/MIMES none of the models has developed a link between the physical changes and economic values. This is currently a huge gap in most of the models and consequently in the global assessments, which the COPI I exercise has addressed in an exploratory fashion. Some participants of the Workshop (see Task 4) were in favour of assessing economic implications which go beyond GDP, for instance employment and tax revenues, in order to assess the full social impact of the global loss of biodiversity. None of the models reviewed address these economic aspects. The Global Ocean Economics Project was mentioned to take value chains following from fish landings into account, while more limited work has also been done on trade impacts of biofuels. It was also remarked that the idea of (economic) multipliers can be questioned in the context of global assessments, as there are still too many uncertainties which need to be overcome first.

4.3.8 Indicators of change in biodiversity and ecosystem services

Biodiversity indicators

Biodiversity as defined by the Convention on Biological Diversity encompasses the diversity of genes, species and ecosystems. Given this complexity, biodiversity dynamics can only be described by a set of complementary indices. Several focal areas and indicators have been identified and accepted for measuring the progress towards the 2010 CBD target 'to achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national level as a contribution to poverty alleviation and to the benefit of all life on Earth'.

Well known indicators for the status and trends in terrestrial biodiversity are the Red List Index (IUCN), the Living planet index (WWF and UNEP-WCMC), the coverage of Protected Areas (UNEP-WCMC) and the Ecological Footprint (Global Footprint Network and WWF). Each of the indicators has strengths and weaknesses. In decision VII/30 the Conference of the Parties of the CBD in 2004 adopted a framework to assess and communicate progress towards the 2010 target at the global scale. The framework includes seven focal areas, each of which encompasses a number of indicators for assessing progress towards, and communicating, the 2010 target at the global level. In total, 27 indicators were indentified by the Conference of the Parties. These indicators are in the process of being developed at the global scale by a wide range of organizations, including UN agencies, research institutes and universities, and non-governmental organisations, brought together by the 2010 Biodiversity Indicators Partnership project. The EEA is developing a set of indicators derived from the CBD set, to monitor progress in Europe (EEA, 2007).

In selecting biodiversity indicators a multitude of methodological questions need to be addressed. The process of Streamlining European Biodiversity Indicators (SEBI2010) led by the European Environment Agency illustrates this well. This refers to question such as: how to define 'undisturbed', how to deal with biological, ecological and environmental differences in the 'dose-response curves' for different species, whether to exclude or include cases where the populations do well in disturbed habitats, how to deal with both biological variance and error variance, as well as with the fact that non-linear responses may be both common and significant. Trivial but essential is of course whether there are data to quantify the indicators selected on theoretical arguments. Again the European situation is illustrative: many countries have some sort of monitoring program, but there is no consistency in selection of taxa, methodologies etc. (Dominique Richard of ETC-Biodiversity at the Workshop).

The Mean Species Abundance (MSA) indicator

In the Cost Of Policy Inaction (COPI) study (Braat & Ten Brink, 2008), a model framework and biodiversity indicator were used to assess terrestrial biodiversity dynamics which together are able to reflect the impacts of the most important direct and indirect drivers and create a quantitative link between changes in these drivers and associated pressures, biodiversity and ecosystem services and economic value. The process of biodiversity loss is characterised in the COPI study by the decrease in abundance of many original species and the increase in abundance of a few other -opportunistic- species, as a result of human activities. Until recently, it was difficult to measure the process of biodiversity loss. "Species richness" appeared to be an insufficient indicator. It is hard to monitor the number of species in an area, but more important it may sometimes increase as original species are gradually replaced by new human-favoured species. Consequently the Convention on Biological Diversity (VII/30) has chosen a limited set of indicators to track this degradation process, including the "change in abundance of selected species".

As any indicator, the MSA indicator has strong and weak points depending on the requirements of the user and the real world processes to be represented. MSA has the advantage that it measures the key process of homogenisation, is universally applicable, and can be modelled with relative ease. MSA is also applicable at different scales from national to global. Biodiversity loss is calculated in terms of the mean species abundance of the original species compared to the natural or low-impacted state. This natural or low-impacted state baseline is used here as a means of comparing different model outputs, rather than as an absolute measure of biodiversity (Box 4.1). If the indicator is 100%, the biodiversity is similar to the natural or low-impacted state. If the indicator is 50%, the average abundance of the original species is 50% of the natural or low-impacted state and so on. A strength of the MSA indicator is that it is possible to link scenarios on economic developments, climate and land-use change (indirect and direct drivers) to dose-response relationships between environmental pressures and mean species abundance. Thus, scenarios and option effects can be assessed in an integrated way for all global terrestrial biomes.

Because it is a measure of the average population response, the same MSA value can result from very different situations. For example, if the MSA indicator is 50%, half of the original species might be extinct, with the remaining half at original abundance levels. The MSA cannot distinguish between abundance and extinction. The mean species abundance at global and regional levels is the weighted average of the underlying biome values, in which each square kilometre of every biome is equally weighted (B. ten Brink, 2000).).

In this review it is useful to identify what indicators can or cannot produce in terms of biodiversity information. For extensive reviews of a wide array of biodiversity indicators see EEA (2007). For the MSA it can be summarised as:

- It cannot distinguish different levels of species richness – either before or after 'disturbance'.
- It cannot deal with changing species composition (extinction, invasion etc.).
- It does not differentiate between different levels of biomass.
- It seems to be largely a measure of driver intensity.

A disputable choice was made to apply equal weights for the different biomes (non-weighted MSA), from polar to tropical forests. Equal weights put the burden of mitigating biodiversity loss also equally over biomes. So, in aggregate MSA values, every square kilometre of each biome contributes equally to the regional or global MSA. If the biomes were weighted on their species richness (weighted MSA), converting a tropical rain forest would probably have more impact than converting grasslands in the same region. This indicates that human impact on species richness is higher in species-rich tropical and temperate zones than in species-poor boreal and polar regions.

The MSA shows the value of the original species abundance that can occur under a natural condition/baseline (climate and soil) as 100%. The consequence of this choice is that all change due to human interference, except restoration and mitigation, leads to lower indicator values. Not all indicators behave this way. For instance, species richness can increase due to human interference in specific situations (e.g. invasive alien species introductions). This only holds for local situation, at biome level species richness will only exceptionally increase and on global level never!

BOX 4.1 The need for a baseline (from sCBD & MNP, 2007)
Baselines are starting points for measuring change from a certain state or date. They are common practice for such items as medical care, economic development and climate change. The MSA indicator uses undisturbed, natural or original ecosystems as baseline. Since there is no unambiguous natural baseline point in history, and all ecosystems are also transitory by nature, a baseline must be established at an arbitrary but practical point in time. Because it makes the most sense to show the biodiversity change when human influence was accelerating rapidly, the *first CBD Liaison Group on Biodiversity Indicators* recommends “a postulated baseline, set in pre-industrial times” or a “low-impact baseline” as being the most appropriate. The baseline allows aggregation to a high level, makes figures within and between countries comparable, is a fair and common denominator for all countries, being in different stages of economic development, and is relevant for all habitat types. It has to be stressed that the baseline is not the targeted state. Policy-makers choose their ecological targets somewhere on the axis between 0 and 100%, depending on the political balance between social, economic and ecological interests.

Other biodiversity indicators

An often used biodiversity indicator is “species richness”. This indicator would probably be less sensitive to the homogenisation process. It can be expected that in some regions species richness on local levels will be stable or will increase during the coming decades, as a result of the introduction of many new species due to human activities. New species will become more and more abundant, partly replacing original species without necessarily leading to complete extinction. Consequently the species richness will increase at the local, national and regional level. The homogenization process was observed in 100 years of industrialization and demographic growth in the Netherlands (van Veen *et al*., 2008.). However, one could use “original species richness”, like MSA does! Another often used indicator is the “number of threatened and extinct species”. As the status of threatened species depends on both the threat and sensitivity of species, the pattern of change cannot easily be predicted. In general, an indicator based on threatened species will show declines when pressures on ecosystems increase due to the limited distribution areas. We expect similar changes as mean species abundance (MSA) but less profound (lags behind). This is basically the IUCN Red List Index, and there are more than one time point for several taxonomic groups. The difficulty is that trends in different groups are measured over different time spans. Change in the “number and abundance of endemic species” is expected to behave similar as change in threatened species. Both species groups have generally small distribution areas (by definition), making them more vulnerable to habitat loss and the process of homogenisation. Biomass density is sometimes mentioned because of its role in delivering very important services, especially carbon storage and water provisioning. Population Viability, which refers to physical dispersion, mean range size and separation, and its resulting species risk, hence economic risk and costs, is also a candidate. IUCN has mean species range size globally for a number of groups, but not trends.

Indicators for ecosystem services

Braat & Ten Brink (2008) have introduced a simplified set of relationships between the levels of ecosystem services and the degree of loss of biodiversity compared to a (theoretical) 100% reference situation. (see figure 4.1). The X-axis shows a series of land use types with corresponding MSA values, decreasing from left to right. The following reasoning underlies the shape of the curves.

Provisioning (P): By definition, there is no provisioning service in a pristine ecosystem. With increasing intensity of use and conversion of the structure, species composition and thus functioning of the original natural area, the Mean Species Abundance (a measure of biodiversity and ecosystem functioning) decreases (from 1 to 0) and the benefit flow (EV; ecosystem service value) increases. Adding labor, fertilizer, irrigation, pest control etc. will raise the gross benefits, and to some limit the net benefits. At some point along the X-axis, e.g. intensive agriculture, the remaining ecosystem will be reduced to a substrate for production of biomass only. The final state is defined as approaching zero value, having been built on and covered by concrete or asphalt.

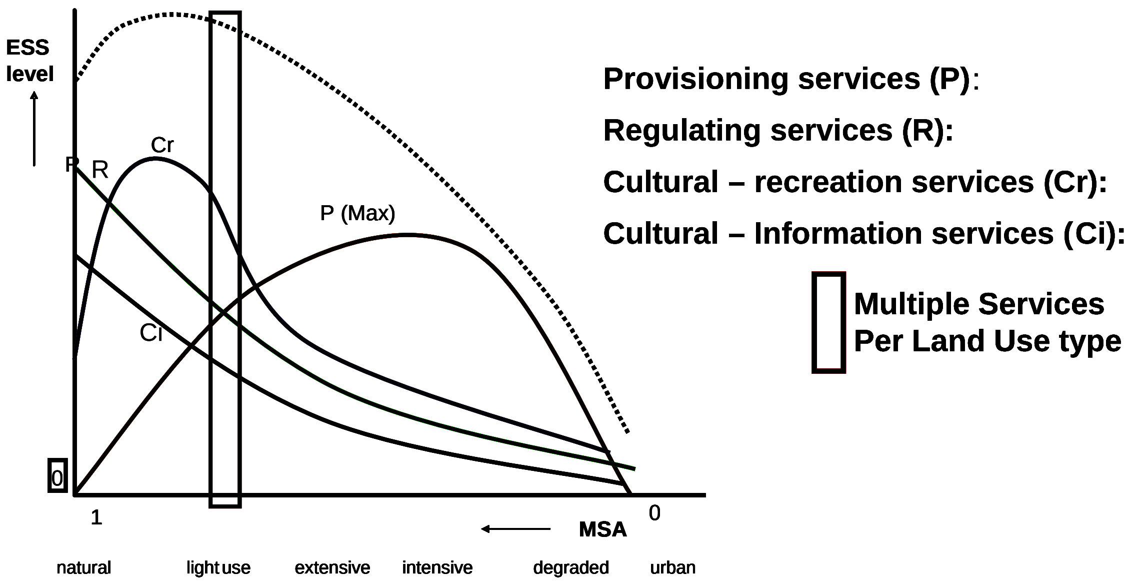

Figure 4.1 Generalised functional relationships between ecosystem service level (Y-axis) and degree of land use intensity (corresponding to decreasing MSA values; X-axis)

Regulating (R): Most of the information from case studies on regulating services (climate change buffering by carbon sequestration, flood regulation) points at a complex relationship between the "intact" ecosystem and the service levels. As systems are converted, they lose structure, functions and their regulating potential, so their actual performance drops more or less proportionally with the decrease of MSA along the range of land use types on the X-axis.
Cultural – recreation (Cr): Recreational benefits are classified as part of the Cultural services in the MA. A crucial feature in the valuation of the recreational services of ecosystems is accessibility. The graph therefore displays an increase from low value at inaccessible pristine systems to high values in accessible light use systems, with still a relatively high appreciated complexity and biodiversity, and a subsequent drop in value towards the more degraded systems. There are of course other forms of recreational values, based on for example the openness of landscapes, the cultural-historical value of buildings, or artificial amenities, which are not addressed in this approach.
Cultural – Information (Ci): Most of the other cultural ecosystem services and their values are a function of the information content which is considered to decrease with the degree of conversion.

A vertical summation of the ecosystem service levels, and implicitly their economic and social values, per land use type points at the trade-offs included in land use conversions.

The challenge in future ecosystem services studies could well be to specify the types of services and quantify the X- and Y-axes of Figure 4.1, as illustrated in Figure 4.2, and thus give substance to the generalised conceptual model. In Figure 4.2 for the cluster of Provisioning services a few possible different graphs have been drawn, and it is suggested that such graphs may result from specifying the relationships for different services, different crops and in different biomes. Obviously, in figure 4.2 the curves are still generalised curves with an illustrative purpose only.

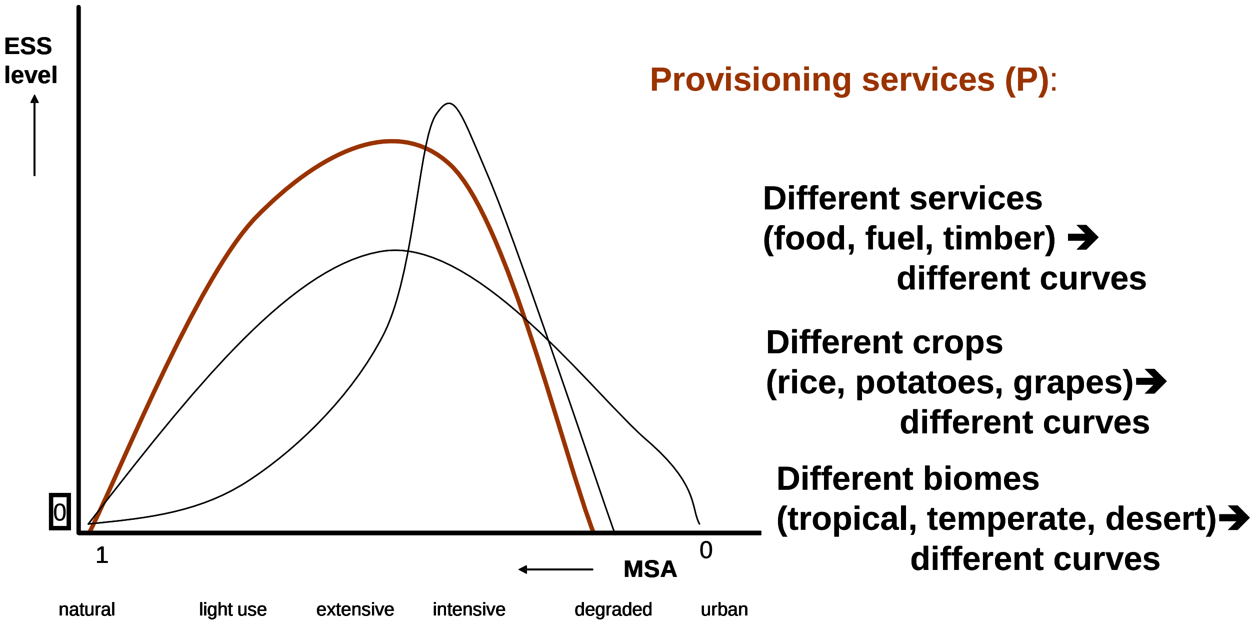

Figure 4.2 Generalised functional relationships between ecosystem service level (Y-axis) and degree of land use intensity (corresponding to decreasing MSA values; X-axis). The graph shows that the exact curves might differ for different groups of provisioning services (different services, crops, and biomes).

An ongoing effort to develop a systematic set of indicators for ecosystem services is the work at the World Resources Institute (C. Layke, 2009, in prep.: Measuring Nature's Benefits: a status report and action agenda for improving Ecosystem Service Indicators). In this project the Millennium Ecosystem Assessment is systematically screened for the use of indicators of services, which are then screened and evaluated for the "ability to convey information" and "data availability". Other efforts which show similar struggles for pinpointing the most appropriate indicators are the UK Countryside Survey (CEH, 2007), Van Veen *et al* (2008) reporting on the efforts of the Netherlands in halting the loss of biodiversity (and ecosystem services) and Dumortier *et al*. (2008), doing the same for the Belgian region Flanders.

4.4 Conclusions

The conclusions have been grouped to form a check against the Task 3 objectives:

Determine how: changes in key assumptions affect the results of different models with a focus on either the impact on ecosystem services or on the economy more generally

Although the study has not empirically tested the effect of changes in key assumptions, there are a few findings from the survey of the models, assessments and background literature, which shed some light on this:

- Changes in the numerical values of drivers (development of population, economy, land use or energy use) applied as different scenarios in the assessments have crucial influences on biodiversity and features of land use such as agricultural production, carbon sequestration and water availability, which can be seen as indicators of ecosystem services. In addition, the framing and design of assessments as a whole are at least as important factors in terms of their influence on the uncertainty and potential bias of results.

- Effects on the economy are not modelled, except by the GUMBO/MIMES models, but they have not been applied or tested in global assessments.

- The documentation of most of the models in the inventory was not of sufficient detail to determine to what extent changes in assumptions about internal model dynamics would quantitatively affect outcomes. Such an analysis is currently being done for the translation of land use and biodiversity changes produced with the IMAGE-GLOBIO model to economic values in the so called COPI – 2 study (P. ten Brink *et al*., 2009; in prep.).

Determine the extent to which the scenario-model studies could be used for making large-scale assessments of the impacts of the loss of biodiversity and ecosystem services worldwide

- The various global scenario-model studies present different futures of biodiversity, in relation to different scenarios (packages of driver developments and policies). A considerable share of the scenario-studies in the Task 1 inventory, e.g. MA, IPCC, GEO4 and OECD2030, have used the IMAGE model as major land use and environmental change model, in some cases extende with the GLOBIO model (in the MA with the SAR model) to produce assessments of biodiversity change.

- In the evaluation, the features of the models have been the focus; the application of the models in assessments has been used as selection and evaluation criterion. A comparative analysis of the features of the published scenarios is available in Kok *et al*., 2009. The conclusion is: The exploratory scenarios (e.g. GEO4) are relevant to "create and illustrate the virtual future space in which conflicts between population and economic growth versus ecosystems and sustainable use will take place". The baseline-scenario approach (e.g. OECD EO-2030) is more useful for developing insight in economic consequences of alternative policy options to deal with the looming conflicts. Very few are available which deal with biodiversity and ecosystems explicitly. The analysis done with the IMAGE-GLOBIO toolbox for GBO2 (2006) is a rare example, at least at the global scale (see sCBD & MNP, 2007).

- Changes in terms of ecosystem services have been described under a great variety of indicators and mechanisms. They are as variable across the studies as the definitions of ecosystem services. A systematic classification of ecosystem service indicators is being developed now (by WRI) but as for the definition and selection of biodiversity indicators, a broad discussion about appropriateness, representativeness and make-ability with respect to data, is looming.

Determine how such models could be adapted to better assess policies (including coupling of biophysical models with economic models to assess the wider effects on the economy)."

- The inventory of models, scenarios and assessments reported in the Task 1 report contains a wealth of structured information on the features of the models. When a closer look is taken, and a strict reference is chosen of short term, direct usability in TEEB project, e.g. for TEEB deliverables D0 and D1, none of the individual tools is sufficient, but many offer useful elements.

- The integrated assessment models reviewed and selected as most promising for TEEB ambitions (IMAGE for Terrestrial and EwE for Marine) are developed in such a way that they can relatively easily be adapted and include submodels or extensions to accommodate TEEB specific questions regarding ecosystems, ecosystem services and economic indicators. A number of theme, sector or region specific models exist which can be used to achieve this.

- The dynamic feedback from changes in the physical domain (ecosystems, biodiversity and services) to the economic and social domain have been proposed by the GUMBO modellers. This needs to be explored further.

- Although not explicit part of the ToR, the MSA indicator has been discussed at some length in this report, specifically on request of the project leader, in view of the debate in TEEB project. Overall, it was agreed in the Workshop discussion that the best means of modelling global biodiversity impacts at the moment is probably through the GLOBIO model and MSA indicator, despite their limitations. Thus the MSA indicator can be regarded as a suitable metric for use in TEEB. Nevertheless, its use in the COPI biodiversity study to refine per hectare values of ecosystems services is a critical issue and needs to be re-examined. The approach needs to be validated and if appropriate the MSA / ecosystem functional relationships adjusted accordingly. It was also pointed out that some ecosystem services may be better modelled directly, as they are not affected by biodiversity as measured through the MSA. It was suggested that consideration should be given to assessing biodiversity impacts according to the Human Appropriation of Net Primary Production (HANPP) indicator. HANPP measures to what extent land conversion and biomass harvest alter the availability of Net Primary Production (biomass) in ecosystems. This is considered by some to closely reflect pressures on biodiversity. If linked to GLOBIO, it could be used to compare results obtained from the MSA indicator.

5 WORKSHOP

5.1 Description of Task 4 from the ToR

"The contractor should hold a small on-day expert workshop, expected to be attended by up to 30 participants, to discuss further:

- *the modelling approaches currently available*
- *how these can be used to model policies*
- *how models and their respective scenarios could be further developed.*

It is expected that the interim report comprising the results of Task 1 and work related to Tasks 2 and 3 completed at this time will be addressed and discussed during the workshop."

5.2 Background and aims of the workshop

Recent studies such as The Cost of Policy Inaction on Biodiversity (COPI) and the wider review on The Economics of Ecosystems and Biodiversity (TEEB) have revealed that biodiversity loss has widespread and substantial economic costs and impacts on human wellbeing. Such studies have taken into account a number of recent global and regional assessments that project future changes in drivers of ecosystem change and biodiversity loss. In order to support the second phase of TEEB, the European Commission (DG Environment) has initiated a study to examine the use of scenarios, models, and other quantitative tools for exploring future trends in biodiversity and their impacts on ecosystem services.

The workshop aimed to discuss the interim results of Task 1 and Task 3 of the project report. While Task 1 focuses on identification and overview of available models of biodiversity and ecosystem services and key assumptions, the objective of Task 3 is to assess how changes in key assumptions affect the results of different models and how such models could be adapted to better assess policies.

In particular, the workshop participants were invited to discuss:
1. the modelling approaches currently available;
2. how these can be used to assess policies; and
3. how current models and scenarios could be further developed.

5.3 Proceedings

5.3.1 Opening and introduction: What this study aims to do?

Robin Miège (DG Environment) opened the workshop and welcomed the participants. He explained that the current project takes place in the context of the wider study on "The Economics of Ecosystems and Biodiversity" (TEEB) and that its purpose is to pick up the recommendations and suggestions from the TEEB expert workshop, which took place in March 2008 in Brussels. The central recommendations from that workshop were:

- to run scenarios on sustainable ecosystem use;
- to work more on the absence of feedback loops between loss of biodiversity / ecosystems and economic growth to enhance the credibility of results;

- to pay attention to quantifying the trade-offs between provisioning and regulating services in models;
- to produce an inventory of model runs for all major ecosystems and to illustrate the loss of ecosystem services expected under different scenarios; and
- to develop maps of best conservation opportunities available.

Robin Miège outlined that the **aim of this workshop** was to discuss the interim project report, which was produced by the project team, to review the assessed models, and to discuss a set of suitable models and scenarios for TEEB, but also to set the future research agenda. Eventually, the results shall feed into the TEEB phase II reports and facilitate the discussions on the post-2010 biodiversity target.

5.3.2 The role of the scenarios and models project in the TEEB context

Patrick ten Brink (IEEP) summarised the political background that led to the TEEB project and outlined how the current project will feed into TEEB. With regard to the timeframe, he mentioned **three important milestones** that should be taken into account in the discussion:

- September 2009, when the results from the projects "Further Developing Assumptions on Monetary Valuation of Biodiversity Cost Of Policy Inaction (COPI)" and "Scenarios and models for exploring future trends of biodiversity and ecosystem services changes" should feed into the TEEB report for policy-makers;
- October 2010, by which some further runs of models and scenarios should be completed and fed into a TEEB update to be presented at the CBD COP-10 in Nagoya; and
- 2015, which is the target date for achieving the Millennium Development Goals (MDG), and by when further modelling could be used to support discussions on future MDGs.

Patrick concluded his presentation by outlining the following main questions for consideration during the afternoon session

- What do you think can and should be done in terms of modelling and scenarios for TEEB?
- Which models would be useful to TEEB and what improvements could be made to existing models?
- What scenarios/sensitivities (covering what issues?)
- What biomes/ecosystems/geographic scales?
- What is feasible in the timescale?
- What costs/inputs would be required?
- Ideal vision vs. Pragmatic reality – what can be done for Nagoya and what to 2015 (MDGs) and what beyond?

Discussion

The subsequent discussion focussed on the questions which models will be used in the wider TEEB project to assess the loss of biodiversity, and whether these models will continue to be land-based. Patrick stated that in the COPI I project, the Image-GLOBIO model was used, as it produces the Mean Species Abundance (MSA) indicator. Limitations of the analysis were that the exercise did not take into account marine ecosystems and did not make use of a range of scenarios or sensitivities. He emphasised that, in the TEEB phase II, there is a need for a **more developed approach**, which also adequately includes marine ecosystems. Ideally, a range of scenarios shall be run to take into account various assumptions and predictions.

After the first introductory presentations, the following two sessions discussed the main results of **Task 1** (**Review of available models and scenarios)** and **Task 3** (**Assessment of key assumptions in the available quantitative tools)**.

5.3.3 Session 1: Review of available models and scenarios: "State of the Art"

Tom Kram (Netherlands Environmental Assessment Agency) presented the key findings from Task 1 of the project, which aims to provide an overview of existing models and scenarios that have been built and applied to model biodiversity and ecosystem services, often is the context of comprehensive assessment studies. He summarised that quite a lot of material is available that could be used for a qualitative assessment. While provisioning and regulating services were to a reasonable extent covered by the reviewed models, **regulating and cultural services were covered to a lesser extent**. It appeared that, in most models, **land use is the central link** between drivers of biodiversity loss and the decline in associated ecosystem services. As no model was identified which covers all aspects of biodiversity loss, Tom recommended **the use of a combination of models** for TEEB phase II.

Discussion
The subsequent discussion focussed on several issues regarding the capabilities of the models reviewed. It was remarked that **most existing models focus on provisioning ecosystem services**, whereas all other ecosystem services categories are barely covered (with the exception of carbon sequestration n). The fact that the impact of **invasive alien species** on the provision of ecosystem services has so far not been taken into account was also raised. The participants agreed, however, that a global assessment of biodiversity loss will always be subject to compromise, as the whole range of available ecosystem services (especially at the local level) **cannot be covered by a single model**.

The issue of **how to avoid double counting** of ecosystem benefits from integrated assessment models was discussed and it was acknowledged that this is a complex and difficult task. An assessment of the problem cannot be made without detailed knowledge about the respective models. Within the scope of the TEEB project, such a task was regarded as not feasible. Instead, it was suggested that the **focus should be on assessing the most important ecosystem services**. It was also noted that integrated assessment models tend to incorporate uncertainties in their complex structure and multitude of variables, thus users should be aware of their possible limitations. One way of dealing with this could be to use minimally realistic models, and considering the purpose of the model. Another way could be the use of expert opinions on the impact on biomes under certain local conditions.

One alternative option would be to **identify different groups of models**, of which several could be used for the modelling exercise within TEEB phase II. In this way, the results of different modelling approaches could be compared to each other. An alternative option is to join together simpler and more specialised models in which the limitations and assumptions of each model are better known and there is greater scope to take account of local differences. This was largely discounted as an option in the short term, as coupling models of biodiversity is difficult given the different parameters, priorities, timescales and geographical scales used. However, this approach may be an option in the medium to long-term.

When reporting results, note should be taken of the **IPCC approach** of reflecting their uncertainty.

Part of the challenge for biodiversity models is that fewer data exist than, for example, on climate change, and thus the models are heavily reliant on assumptions. This makes it difficult to make reliable projections of biodiversity change in response to future scenarios, in particular if the diversity of impacts is taken into account. This requires combining the expertise of different research communities and working with often disparate bodies of knowledge. Another problem is that the relationships between biodiversity and the provision of various ecosystems services are often not well understood.

As a practical recommendation, it was suggested to first **establish an inventory of existing ecosystem services** and, in a following step, see which economic benefits these services provide and for which services economic assessments are available. Appearing gaps could be used to show policy-makers and researchers the needs for new primary research (to some extent, this work is available through the COPI I exercise). New primary research is also needed on the **relationships between biodiversity loss and ecosystem service provision**, as explored in the 'Scoping the Science' study conducted in parallel with COPI I during TEEB phase 1. Moreover, when **aggregating the values of different ecosystem services**, attention should be paid to the fact that some of them might originate from the same ecosystem function. In such cases, there is a clear **risk of double counting**, which needs to be avoided by careful, case-specific assessment.

In conclusion, it was agreed that the appropriate choice of models and scenarios depends on the **sort of policy questions** that are supposed to be answered by the exercise. In general, the setup of global assessments should focus on the target audience. Moreover, the assumptions made in terms of scenarios need to be clear. However, it was agreed that too explicit assumptions would, on a global level, confine the number of interested parties, which would weaken the messages from such a global assessment. As, within the scope of TEEB, not all dimensions can be covered, the aim should be to **identify what can be done with the help of existing models in the available time**.

5.3.4 Session 2: Assessment of key assumptions in the available quantitative tools

Leon Braat (Alterra) presented the key findings from Task 3 of the project, which aims to assess how changes in key assumptions affect the results of different models, to evaluate large-scale assessments of the impacts of the loss of biodiversity, and to assess how such models could be adapted to better assess policies. He found that a **limited number of models and scenarios** have so far been be used for large-scale assessments and policy impact assessments; **no single model comprehensively assesses all aspects of biodiversity and ecosystem services and links to the economy**. Leon considered that, while modelling approaches are quite different in the terrestrial and marine domains**, no model was identified that could compete with GLOBIO on a global scale as far as terrestrial ecosystems are concerned.**

However, there are new promising models which could not be evaluated as they have not been subject to a peer review process nor been applied within large assessments.

It is **difficult to assess the reliability** of many of the various models, because **independent reviews** of them are **not** generally **available** and only a very limited number out of the 40 models in the survey is being used more frequently. Moreover, detailed examinations of the models are not possible within the scope of this current study. Similarly, it is not possible to assess the models' sensitivity to changes in assumptions because these are not normally documented. An assessment of driver-assumption sensitivity could only be found for the IMAGE model. The sensitivity of other models to changes in assumptions can only be made by comparing outputs according to different scenarios, but it is difficult to draw conclusions from such comparisons, because many parameters vary among the scenarios.

Discussion

In the subsequent discussion, several modelling approaches were suggested to be considered in the evaluation. The **Atlantis model,** which deals with fisheries was mentioned to be currently at the same state of development as MIMES, was regarded as a useful tool that **could potentially cover the marine dimension within TEEB**. (Unfortunately there is no documentation available in the web for the Atlantis model). It has been applied in two or three places so far and progress has been made to include the economic aspects of biodiversity loss. The **FAO review on marine models** was suggested as a reference. With regard to GUMBO, which is not spatially explicit, it was noted that this is a dynamic model with a long-time projection, while the **focus within TEEB should rather be on evolutionary models** with a timeframe of max. 20 years.

There was some detailed discussion of the **Mean Species Abundance (MSA)** metric and its use in the GLOBIO model as well on the use of indicators in general. It was recognised that the **MSA has some significant limitations** (being based on averaged species responses to a number of key drivers of biodiversity loss) and can be misunderstood and misapplied (partly due to its name and lack of easily accessible documentation). Although the MSA indicator has been verified in a study of biodiversity change in the Netherlands, it needs to be tested more widely. However, this is difficult, because the MSA cannot be directly measured in the field.

Overall, it was generally agreed that the best means of modelling global biodiversity impacts at the moment is probably through the GLOBIO model and MSA despite their limitations. Thus the **MSA indicator can be regarded as a potential metric for use in TEEB**, but not necessarily the only one to be used. Its use in the COPI I biodiversity study to refine per hectare values of ecosystems services is a critical issue and needs to be re-examined. The approach needs to be validated and if appropriate the MSA / ecosystem functional relationships adjusted accordingly. It was also pointed out that some ecosystem services may be better modelled in other ways, as they may not be strongly correlated with MSA or biodiversity more broadly.

It was suggested that consideration should be given to assessing biodiversity impacts according to the **Human Appropriation of Net Primary Production (HANPP) indicator**. HANPP measures to what extent land conversion and biomass harvest alter the availability of Net Primary Production (biomass) in ecosystems as compared to the potential natural vegetation as the baseline. This has been shown in some studies to closely reflect pressures on biodiversity, but generalisation would probably be premature. If linked to GLOBIO, it could be used to **compare results obtained from the MSA indicator**, although they are based on the same data inputs (e.g. FAO statistics).

It was acknowledged that there needs to be a **strong economic perspective connected to the modelling exercise**. Leon Braat explained that this is currently a huge gap in most of the models, which the COPI I exercise attempted to address. Some participants were in favour of **assessing economic implications which go beyond GDP**, for instance employment and tax revenues, in order to assess the full social impact of the global loss of biodiversity. This **multiplier effect** has partly been taken into account in studies on the impacts of agrienvironmental schemes on the Dutch agricultural sector. **The Global Ocean Economics Project** takes value chains into account, while more limited work has also been done on trade impacts of biofuels. It was remarked that the idea of multipliers can be questioned in the context of global assessments, as there are still too many uncertainties which need to be overcome first.

5.3.5 Session 3: Policy recommendations: How to use the quantitative tools for policy development within TEEB

Rob Alkemade (Netherlands Environmental Protection Agency) acknowledged that the interim project report gives a good overview of the existing models. He pointed out that most of them are still missing the crucial point of **how the loss of biodiversity feeds back into the economy.** Although the MSA indicator seems to be the only available biodiversity indicator so far, he saw a need to **go beyond this indicator,** as it does not say anything about species functions, species richness, red-list species, or the community level – aspects which are of major relevance for the provision of ecosystem services. The same goes for biodiversity in aquatic environments. The aim should therefore be to **develop a set of new biodiversity indicators that link to ecosystem services**.

Rob preferred the **use of parallel model suits** in order to ensure that modelling results can be compared to each other. As a positive example the competitive use of different models within the IPPC has been mentioned. Furthermore, he stated that there is a need for the **formulation of scenarios that focus on biodiversity** (instead of climate change) in order to **derive a set of relevant policy options**. A problem with the scenarios that have been analysed in the project so far is that they differ little in their biodiversity outcomes.

It was noted in the discussion afterwards that, when coupling models together, it is important to include appropriate feedback between the models.

Heather Tallis (Stanford University) suggested that the project team should consider the **creation of new, more policy relevant scenarios,** which differ from the usually applied scenarios. Policy-makers often find it difficult to engage with complex scenarios that have little to do with the real world and are based on multiple assumptions (e.g. the impact of talking about TechnoGarden, one of the four scenarios in the Millennium Ecosystem Assessment, to most people is limited). She recommended **considering only a few types of policies** (e.g. payments for ecosystem services, mitigation and offsetting, subsidies, caps). For example, it is important to develop scenarios that are relevant to REDD now, so that the impacts of possible policy options can be examined. The results could have implications for a range of ecosystem services, beyond carbon storage, including biodiversity and water benefits. The use of models for such purposes would help politicians and other decision-makers understand their value. She also stressed the use of competing models similar to IPCC, considering rigour and political sensitivity.

Heather stressed that the **link between biodiversity loss and poverty** should be a central aspect of the assessment. In this context, she noted that the Millennium Development Goals (MDG) rely on ecosystem services. Ecosystem services are so far not covered in most models, because those can often not take informal markets into account. Rather than covering the whole range of ecosystem services, she suggested that it would be better to **focus on only a few important services** such as clean water and flood control. The latter one could probably be assessed more easily in the context of institutional settings. In addition, for ecosystem services models, it is important to not only consider the supply of a service (for example, water availability), but also the demand, as this will change significantly in the future with implications for the availability of the service.

Furthermore, she promoted the idea of using **simple models** such as InVEST. The exercise should be focussed on what is appropriate for different policy contexts, rather than being aligned with the models' requirements. It was noted in the discussion that InVEST would be useful to try out in the TEEB setting to test how well it performs.

Villy Christensen (University of British Columbia) acknowledged that the interim project report covers all of the important issues. He stressed that the relevance of the project results depends to a high degree on the **policy questions to be answered**. Such a set of policy questions should be developed within TEEB. Furthermore, a **common set of drivers and indicators** to be used in all assessments should be developed, as well as **guidelines for how to translate scenario policies into changes in model drivers or objectives.**

He stated that most models require a vast amount of data and that these data are often missing in the area of biodiversity. Therefore, modelling approaches should build upon available data. He stressed that **the informal sector and value chains should be taken into account** [producer-processor-distributor-seller-consumer] in the modelling exercise, as these aspects will make a huge difference with regard to the social dimension of biodiversity loss (as the work of Hernando de Soto could demonstrate). He mentioned the example of the **Global Ocean Economics Project**, which takes account of these issues. The underlying model will be finished in time to be of relevance for the TEEB project. The model showed the importance of taking the whole value chain into consideration, as this has changed the outcome of the model significantly. Only looking at the entire value chain could explain why current overfishing has its roots in economic pressures although revenues for the fishery sector are decreasing.

With regard to priority options to be incorporated into the models, Villy suggested to **couple reliable, specialised models** set-by-set to avoid one big model that could become unmanageable (the so called 'Frankenstein' model). This could facilitate the integration of terrestrial and marine domain models. However, in this context, scale issues and data-exchange formats are important factors to consider.

Villy noted that model calibration with existing data is important, however, this is limited by data availability. He therefore suggested that a **global database** is needed of data resources, their use and status. Consideration also needs to be given to data exchange formats so that database can feed models directly.

On the use of the project results for policy and decision-makers, he commented that one should think about tools such as decision-support systems, policy toolkits, and end-user interfaces. Policy-makers are usually less interested in the assumptions and specifications made in the assessment process, but demand **simple communication tools.** Villy demonstrated the output of the EcoOcean model linked to gaming software, which visually illustrated the impacts of specific policies on the marine environment, demonstrating a potentially powerful tool for communicating to policy- makers. Visual outputs had been used before, but not linked to gaming software, which enable dynamic visual feedback that reflects the impacts of chosen policies.

Henrique Pereira (University of Lisbon) stated that not all of the most important drivers of biodiversity change are being addressed in the scenarios. We lack models that project biodiversity changes from the expansion of natural vegetation in developed countries. He regards the **MSA indicator as an adequate tool** for modelling, but noted that the **GLOBIO methodology used to calculate it has not been validated,** which is a widespread problem with many scenarios and models but causes problem with the acceptance of MSA as an indicator. There are more models to project the impacts of climate change, since this is – in contrast to projecting changes in biodiversity from other drivers – a relatively easy exercise.

Henrique noted that particularly **invasive species and biotic exchange** are not covered by the majority of the models, although these are important drivers for the global loss of biodiversity (for instance on islands). In freshwater systems, dam construction is one of the biggest drivers of biodiversity loss, but no scenarios account for it. Moreover, issues such as **overexploitation of resources** (other than fisheries) **and pollution of ecosystems** are not yet in the focus of modellers. Neither are models able to deal with issues such as intensification and extensification of land-use management, or the recovery and expansion of natural vegetation (which are important issues in many regions, e.g. Europe).

Another limitation of current models is that they do not address **flows of ecosystem services** (where do people benefit from services produced elsewhere?) and the **scale of ecosystem service delivery**. Furthermore, we lack understanding of the direct links between ecosystem services and biodiversity.

Henrique suggested that it would be worth doing some '**reality checks'** on important issues using simple robust models of the key ecosystem services. Moreover, one needs to be more open with regard to models, e.g. make them available as open source.

Regarding a possible communication strategy, Henrique Pereira proposed **the use of storylines** or even the use of 'scary' scenarios, since people tend to pay more attention to them than to the bare figures. The project team should also develop storylines that are based on partial, simpler models that accompany the big integrated approach. He also suggested the development of scenarios by cross-cutting experts to incorporate the threats that have not to date been considered.

Discussion
Graham Tucker pointed out that positive visioning stories often have a greater impact than negative scare stories (because many people chose not to believe them). Henrique Pereira agreed about the need to communicate positive scenarios side-by-side with negative ones and responded that in GBO-3, a number of experts will also be writing about the biodiversity restoration opportunities arising on apparently negative scenarios for biodiversity conservation.

There was also a discussion regarding the appropriate scale/spatial resolution and accuracy of the modelling exercises. It was mentioned that for many issues, like the assessment of impacts of agricultural practices on riparian vegetation local/smaller scale models/assessments are necessary as the global one lack in a scientific basis for this small scale interdependencies.

Joachim Spangenberg (Sustainable Europe Research Institute) stressed that, in order to be relevant to policy-makers, a model needs to be able to **show the impacts of certain policy decisions** as it has been attempted in the ALARM project**.** Scenarios are useful for pointing to the general direction, but cannot provide the detail of the implications of policy decisions. Policy-makers should focus biodiversity policies on the major pressures (such as land use patterns including transport, invasive alien species and climate change) and aim to minimise these pressures (for example through agricultural policy, EU TEN, or structural funds).

Within TEEB, it should be emphasised that if there is no apparent economic value for a certain ecosystem function, this does not mean that it is worthless. In this respect, it is important to emphasise that "**there is no useless biodiversity**" and **TEEB must clarify what can and what cannot be monetised**. Joachim pointed out that the models do not currently take account of shocks, such as the recent economic crisis, or non-linear changes in biodiversity and ecosystem services. He suggested **priming models with shocks** to gauge how they respond. For example, the International Energy Agency predicts a recovery from the current crisis followed by another crash due to oil shortage. These shocks should be examined in future projections of models. He also noted a problem with IMAGE, namely that it does not allow for the feed back of economic parameters into the model.

Joachim concluded by emphasising that the figures produced within TEEB must not necessarily be precise, but that **they must be robust** enough to provide the basis for directionally secure policy decisions. The project team needs to consider what the requirements of decision-makers are and design tools to fit around them.

Finally, he strongly suggested **including recent FP6 projects** on biodiversity modelling in the evaluation.

5.3.6 Summary of the expert feedback

Alexandra Vakrou (DG Environment) and Patrick ten Brink summarised the session by stating that it was likely that the GLOBIO and EcoOcean models would be used between now and Nagoya, but that it should be supplemented with simpler models as a reality check. The overall move should be towards a more specialised suite of models in the medium term. GLOBIO could also be run with a different set of scenarios.

Ecosystem services values are currently not adequately addressed in models, making it an area for future development. There needs to be a greater focus on the local scale, which can be provided by the specialised models, which should accompany the bigger picture.

It was concluded that there is an urgent need to add fisheries and the marine environment to the used global models.

Alexandra Vakrou observed that issues surrounding joining models together, such as the differences in scales and units (data availability), will have to be addressed before it becomes a viable option, if at all.

Irrespective of which models are used in the future there is a need to address current knowledge gaps such as the influence of IAS or technical infrastructure on freshwater biodiversity and the relationship between biodiversity and ecosystem services . There is no perfect indicator available so far. Work on indicators has to be intensified and in respect to the MSA it is crucial that the MSA link to ecosystem services is tested.

From the policy maker side it would be beneficial to run scenarios that reflect “real” policy options. An interesting example would be the discussion on REED or biofuels. To increase the communicative power of global models they should be supported by local/small scale models and narrative stories e.g. on specific ecosystem functions or tipping points.

Finally it would be useful to have a set of competing models in the medium term as for example promoted by the IPCC.

Closing of the workshop

Alexandra Vakrou (DG Environment) thanked the participants for their fruitful contributions to the discussion and closed the workshop.

6 INTEGRATION OF THE STUDY FINDINGS INTO THE SECOND PHASE OF TEEB

6.1 Description of Task 5 from the ToR

"Based on the outcome of the workshop, the contractor will propose a possible modelling framework that could be used for the second phase of TEEB, including the time and the resources needed."

This task aims to make explicit recommendations on what model runs could be valuable to help meeting the wider TEEB objectives of assessing the costs and benefits of biodiversity/ecosystem losses and the relative assessment of the cost of action relative to the benefits of action. This builds on the analysis described in Chapters 2-4 and the discussions at the May 13th workshop described in Chapter 5 and subsequent reflections by the team.

The recommendations initially focus on providing input to TEEB, specifically relating to opportunities to contribute to the TEEB reports to be circulated at CoP 10 in Nagoya in October/November 2010. More generic recommendations are then provided that aim to be of relevance to longer-term initiatives, including EEA's work on the Eureca project[7] and the new Millennium Ecosystem Assessment planned for 2015.

In preparing these recommendations, it is firstly important to consider what would constitute an "ideal" modelling framework, so that requirements for pragmatic choices can be explicitly identified and their implications clarified in the wider policy context. Already in TEEB Phase 1 the choice of the GLOBIO-IMAGE model, linked to the OECD 2030 baseline-scenario, and the use of the MSA indicator sparked considerable discussion amongst biodiversity experts. Some have taken the choice of MSA by the TEEB team as an indication that the team feels this indicator is better than others. In reality, the selection was simply one of pragmatism, as the MSA was the indicator used in the main model that was available and possible to build on (see Braat & ten Brink, 2008 (eds.)).

6.2 Context: The ideal global assessment of the economics of ecosystems and biodiversity and the TEEB Phase 1 first step

Ideally, an analysis of economic consequences of changes in biodiversity, ecosystems and ecosystem services at the global scale would include a comprehensive upgrade of the current modeling approaches. This would include an integrated terrestrial and marine model and an improved set of indicators that can represent the range of biodiversity. Table 6.1 summarises the list of elements for an ideal modeling framework.

[7] http://eureca.ew.eea.europa.eu/index_html

Table 6.1 A description of the "ideal" elements of a biodiversity or ecosystems analysis

Ideal action	**Description**
A global analysis across all biomes and ecosystems	This may be via one model or range of models, determined by model coverage and quality which would include terrestrial, marine, wetlands and coastal biomes, including mountains, islands and man-made ecosystems.
An analysis across the full set of ecosystem services	This could, for instance, be based on the MA list (MA, 2005a) or on an updated list that is more "benefits" focused (as recommended in Balmford *et al* (2008) and under ongoing investigation in TEEB Ecological and Economic Foundations. This may require complementary analysis using different ecosystem service models, if details are not sufficiently well covered in a global general coverage model.
Regional specifics and particularities are taken into account	This could eventually require regional modeling where global models cannot give sufficient detail to make analysis relevant. It could also require some local modeling where details of ecosystem service inter-linkages are critical.
Indicators that best represent the biodiversity and ecosystem services	This requires a move beyond the MSA, which has been a pragmatic choice to date and would need to ensure that data exist in appropriate detail.
Looking at costs and benefits over time	This should include financial, broader economic, social/human and environmental implications of policy inaction and action. This needs appropriate treatment of not just costs captured in general economics (and hence in GDP) but also externalities as well as opportunity costs.
A "suite" of models that allow comparison and cross-checking.	This would mirror the IPCC approach of complementary or competing models. It is important to note that reality may lie outside the envelope created by the model set, so a link to monitoring is particularly important.
A range of scenarios of drivers and responses.	This will need to include various baselines and a set of regionally specific policy actions, consistent at the global level.
Complementing global level answers with regional estimates	This will allow cross-checking of the answers as part of quality control. It should include national and even lower level estimates to ensure that results are most relevant to the audiences and reflect practical realities.
Use of policy relevant scenarios that can describe policy options	This enables policymakers to directly view the impacts of particular policy options. For example, in relation to protected area coverage; investment in natural capital such as forests or coral reefs; or subsidy reform.
A spatially explicit analysis	This would consider the spatial dimension where services produced in one place are "enjoyed" in another into account.
Adequate and achievable within the timescales	This includes model runs and analysis time, access to models and engagement by model holders. Engagement of model holders is important not just to TEEB but will be very valuable for other ongoing and post-TEEB work.

The TEEB Phase 1 analysis was significantly more limited than this ideal. It comprised a global analysis for land-based biomes based on a single baseline scenario with no-new-policies and quantitative modelling (marine, coral and invasive alien species were only treated by literature review and "back-of-the-envelope" calculations) incorporating:

- A subset of the biomes - results were more forest focused (data were not available for all biomes);
- A subset of ecosystem services - (again economic data not available for all services; extensive use of benefit transfers);
- A single indicator used in the quantitative model based analysis– MSA - (this being "hard-wired" in the GLOBIO model);
- Cost of policy inaction, but not costs of action or benefits, or opportunity costs; and
- Very limited sensitivity analysis with some ranges for the economics, but not for different drivers.

Scope and ambitions of TEEB II
In short, the first estimate was "a first estimate", acceptable in its limitations given the timescale of the first exercise. The expectations for a TEEB report to the CBD CoP 10 in Nagoya are significantly higher; there is an expectation[8] of the results being one level better than the first estimates. However, there is also realism by experts[9] that the task is very complex, data are not always there (and will not all be there in the next 12 months), nor indeed do global models exist for everything. Hence the community does not expect a perfect comprehensive answer. In practice, there is an expectation that the TEEB report in September 2009 be a step forward from the May 2008 Bonn report, and that the Nagoya October 2010 answers are a full "level up", but that further work and improvements will be needed beyond that to move towards "the ideal"[10]. It is recognized that the full suite of models, using better biodiversity indicators to model changes across ecosystems, ecosystem services and covering costs of action (including opportunity costs) and cost of inaction, will not be fully possible by Nagoya (given that the delivery date will be several months in advance of the CBD meeting).

6.3 Recommendations

This section presents recommendations on different aspects of the models, scenarios and assessments in light of the ambitions for using models and scenarios for TEEB and beyond based on the analysis of currently available models and scenarios.

Which models to use

6.3.1 Modelled effects on nature

There are many models that effectively forecast changes in the biophysical domain. They differ in focus, timeline, assumptions, spatial resolution, sensitivities and in choice of indicators of biodiversity and ecosystem services (see below). This is covered in Chapters 2 and 4.

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[8] Based on discussions with interested parties at the Athens Beyond 2010 conference.

[9] Ibid as point 1.

[10] Discussions at the scenarios and models workshop, Brussels.

The conclusions on the "best" available models at the current time are:

- Land-use: the IMAGE model, and some of the other integrated models, are arguably the most useful at this stage, given IMAGE has a finer grid and greater track record than the other models.
- Marine: The EwE family of models is the best in both a technical sense and usability for TEEB as it has global coverage (i.e. all oceans) in a regionalised format. There is a reasonably data rich base, although the economics is still being developed.
- Coral reefs: There is a coral reef model that has some promise - REEFS at RISK.
- Coastal (mangroves/wetlands): There are no global models, but some regional/local models exist, for Louisiana, New Jersey and South East Asia (for example, on mangroves). The challenge is one of upscaling or aggregating to the global scale.

Meeting the requirements of TEEB II will require the upgrade, integration and extension of existing work. As noted above, this needs to cover all ecosystems and ecosystem services, be global and build in a diverse set of indicators for biodiversity.

There also needs to be developed a fully functional link of biodiversity or natural capital to economic values and social impacts. This is not currently available in any existing model, except for a design in the GUMBO model which has yet to be tested in a global assessment. This suggests that in the short term an approach of "adding on" an "economics or valuation" module to the outputs of the physical models remains an important part of the practical solution.

Given the timescale, it will be necessary to work with current material and extend it to develop a new fuller TEEB toolkit (see also Chapter 2). This toolkit should include:

- Use existing models and add new indicators including:
  - IMAGE-GLOBIO and COPI upgrade and scenarios;
  - marine (EwE set and MSA indicator to match GLOBIO land assessment);
  - global models for coral reefs; and
  - make use of the results from the InVEST global assessment (which is forthcoming).
- Promote efforts to validate GLOBIO and other models through observation and experiment.
- Incorporate a wider range of drivers into models (see later discussion).

It will also be important to work with models at a regional or local level to offer additional insights on the ecology-economic-society links, for example for mangroves, water purification and flood control or natural hazards.

Suitable modelling of ecology-economic-society links of mangrove development in a spatially explicit manner will be critical to help understand the economics in more detail in order to assess social costs, distributional impacts and also risk issues (for example, as related to flood risks).

On water purification-provision, there is a need to apply suitable spatial planning tools to be able to show the interrelation between natural capital and associated activities providing the service, and the benefits and help tools offer to support the wider use (if and where appropriate) of payments for environmental services as well as strategies to protect or invest in natural capital. This will also be important to link to the development of natural capital accounts.

On flood control it will be important to apply suitable spatially planning tools to develop risk maps, links to event frequency and also socio-economic-demographic issues to help communicate risk and cost.

6.3.2 Empirically test the effect of changes in key assumptions

Testing the sensitivity of modelling results to key assumptions is a very time consuming and costly activity. The only "good" way to do this is together with the original model-developers; which would require contracts with "supervision" (see conclusions in Chapter 4).

6.3.3 Model effects on the economy

Very few models actually address within them the economic impacts of changes in biodiversity and ecosystem services. The main exceptions are the GUMBO/MIMES models. For other models, an "economic impact module" needs to be added (as with the COPI work); the output of the GLOBIO-IMAGE model was changes in land-use and degradation up to 2050, and an "economic module" was added, outside of the model.

There are therefore a number of ways forward:

- Discussion with the GUMBO/MIMES modelling team (Costanza et al.,) about their approach to investigate the possibilities of using a model that combines both environmental and economic aspects, arguably in parallel;
- Consider the addition of meta-models, such as InVEST and MIMES for rapid mapping of alternatives and first indications of economic feedback on sectors;
- Further develop the "COPI spreadsheet model" with COPI 2 results (more case study values, better view of sensitivities of benefit transfer, effects of substitutability) and the wider TEEB Ecological and Economic foundations work on the "matrix of ecosystem service values" (see Chapter 7 of the report);
- Substantiate ecosystem service – land-use type (MSA) relationships with empirical data; and
- Test model(s) scenario context (for example, OECD baseline for comparison with COPI 1).

Some parts of the 2nd and 3rd points have been carried out in the COPI II contract [ENV, 07.0307/2008/514422/ETU/G1], but while a step forward, this does not go as far as addressing all the gaps.

Scenarios

6.3.4 Baseline scenarios

There has already been extensive work done on baseline scenarios of different types within the range of global assessments. It is arguably not cost-effective to focus efforts on creating a new suite of baseline scenarios. However, for the proposed modelling of the economics of ecosystems and biodiversity, a combination of models will need to be used and these risk having different assumptions within the baseline scenarios and hence creating potential incompatibilities. There is the possibility, therefore, to follow the example of the IPCC to coordinate the assumptions within a baseline scenario, thus removing these potential compatibilities between model comparisons. The critical new work will be on the policy action scenarios.

6.3.5 Policy action scenarios for biodiversity and ecosystem services management

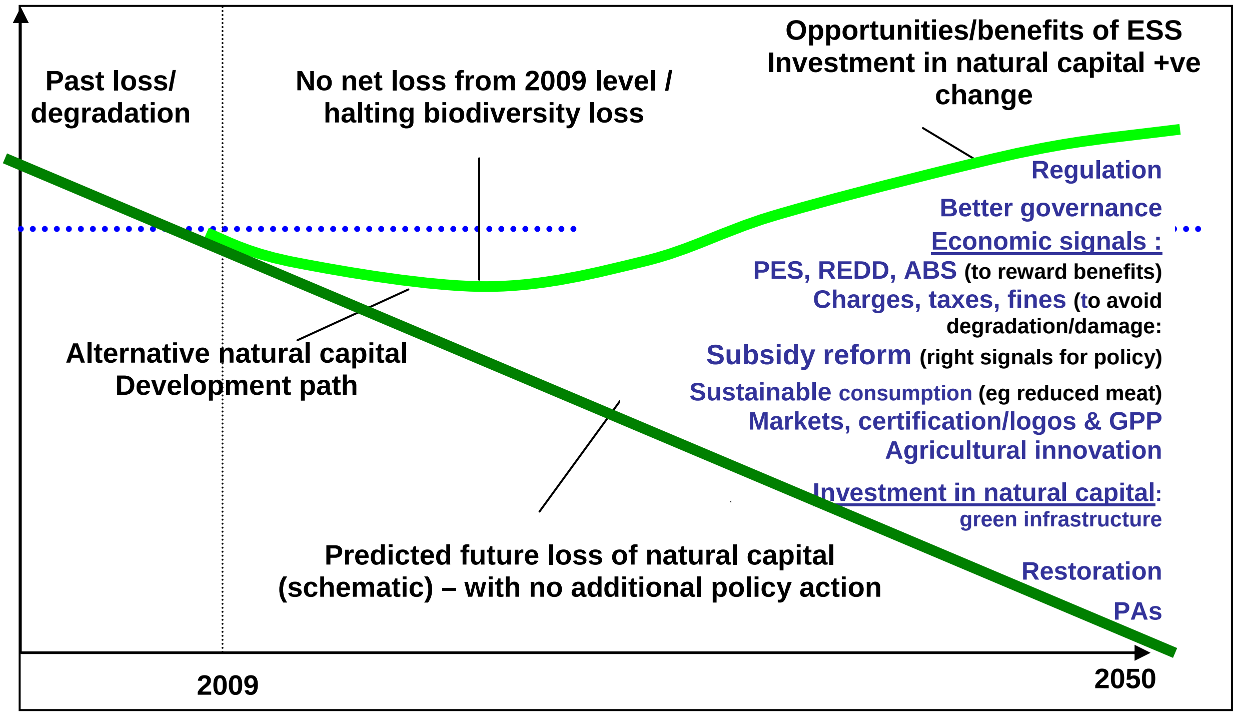
Very few of the global assessments studies have scenarios which deal with biodiversity and ecosystems services explicitly. The analysis carried out by the IMAGE-GLOBIO toolbox for GBO2 is a rare example, at least at the global scale (see sCBD and MNP, 2007). The GBO2 scenarios should be further developed, with integrated packages and regional specific sets of policy measures. Additional work would ideally also build on TEEB D1 for applying the toolkit of policy measures/instruments and take into account the expected targets for post 2010, although this may not be possible in the timescale. A policy dialogue should be set up to develop Policy Action Scenarios which have a broad support across stakeholders and world regions (an example is available in the GBO2 analysis (sCBD, 2006)). The scenarios need to build in the key drivers behind ecosystem and biodiversity loss (population growth, economic growth, consumption patterns (notably calorie intake and dietary preferences), productivity gains (notably for food production), trade and transport growth etc. There still may also be a need for policy measures, both in business-as-usual scenarios and for different policy action scenarios. This can therefore usefully build in results from the *Underlying Causes* project (ENV.G.1/FRA/2006/0073).

It will be useful to ensure different milestones are integrated, notably, by 2015 (to reflect the MDGs), as well as analysis to 2020/2030/2050 to be sufficiently short term for policy makers, but sufficiently long term to allow major trends to be integrated.

Attention should be paid to the construction of meaningful alternative scenarios, which should focus on the main drivers of land-use change and biodiversity loss and make use of the full potential of the existing models when implementing those scenarios.

The scenarios need to be able to explore critical issues such as deforestation and REDD approaches, biofuels policies, agriculture, productivity and consumer demand. The figure below gives a simplified schematic graphic of contributions that some policy tools could hypothetically make to an alternative natural capital development path.

Figure 6.1: Natural Capital loss under no new policies baseline, alternative development path and contribution of instruments - a simplified schematic.



Source: ten Brink (2009). Presentation: *Measuring Natural Capital TEEB approach and Working insights*. Presentation to Chinese Delegation Defra, UK 6th July 2009

Indicators

6.3.6 Systematic classification of ecosystem service indicators

Changes in terms of ecosystem services have been described under a great variety of indicators and mechanisms. They are as variable across the studies as the definitions of ecosystem services. A systematic classification of ecosystem service indicators is being developed now (by the World Research Institute -WRI) but as for the definition and selection of biodiversity indicators, a broad discussion about how appropriate and representative the data are, needs to be initiated and "given a sense of urgency". There is a short-term tension between indicators that are available in the models and hence available for analysis, and those that would be "better" as they reflect ecosystems and biodiversity better. It is important therefore that a phased approach be taken, distinguishing between what can be used now (and present results with due caveats), and what can be developed in parallel, so that different approaches are available in the future, building on different indicators. It should be ensured that supply and demand of ecosystem services are covered to be able to estimate actual service provisioning and help valuation.

6.3.7 Re-examination of the use of the MSA indicator

The use-ability of other biodiversity indicators than MSA (see Chapter 4) must be further developed by examining the relationships between different indicators of biodiversity, land use and ecosystem services. Some ecosystem services may be better modelled directly, as they appear not to be affected by biodiversity/ecosystem intactness as measured through the MSA. The use of biodiversity as an indicator of ecosystem services, such as pollination, pest control, genetic resources and spiritual services (as in the global study by Gallai *et al*. 2009) could cover gaps in current models. It was also suggested during the workshop that consideration should be given to assessing biodiversity impacts according to the Human Appropriation of Net Primary Production (HANPP) indicator. HANPP measures to what extent land conversion and biomass harvest alter the availability of Net Primary Production (biomass) in ecosystems. This could be part of the indicator development effort.

6.4 Research needs

The need for more research into linkages and relationships has to be highlighted, including how biodiversity loss influences ecosystem services, and how drivers affect both biodiversity and ecosystem services, both independently and inter-relatedly. Understanding these relationships (the core of any models) will help to identify the best metrics/indicators.

6.4.1 Models

A wider range of drivers should be incorporated into models. Further development should focus on enhancing economic feedback and sectoral impacts, broaden the set of biodiversity indicators to strengthen their relevance for ecosystem service provisioning and integrate ocean models with socio-economic and terrestrial models.

Current models are less apt at dealing with “non-linearities” – such as issues of crisis or modelling tipping points that might cause local or global disasters. In principle this could be addressed within “disaster” scenarios but modelling development will need to be done to ensure that these work. It will be useful to carry out selective “what if” analyses, such as simulating a resources crisis, effects of major plant pest outbreaks (e.g. potato blight), ocean acidification cases, and so on. The aim of this would be to explore future extremes to see whether policies or trajectories are “future proof” or “crisis proof”.

There is a need for models to address trade-offs of decisions that reflect wider spatial and intergenerational relationships. For example, actions that have a positive impact in one area to one group of people may have adverse impacts on those in other areas. Similarly, actions that have short term gains may be followed by low term costs, affecting other generations.

6.4.2 Indicators

As indicated above, it is necessary to evaluate the extent to which the MSA indicator (and changes to it) correlate with actual changes in biodiversity and ecosystem services. The aim of this should be to validate and calibrate key functional relationships.

Realistic time deadlines need to be set to achieve this (i.e. 2-5 years minimum) with sufficient funding allocated for both the basic research needs and the model development and application.

6.5 General recommendations

As this review of the available models has shown, none of the existing models can fulfil all the needs for TEEB. No one model covers all aspects of biodiversity and ecosystem services, and none integrate marine and terrestrial realms.

Combinations of multiple tools are required to cover the entire chain from ultimate drivers to impacts on ecosystem services and biodiversity; to link across scales as needed to capture key processes at a finer scale; and to enhance assessment of feedbacks from changes in ecosystem services. It is also important to accept that one metric cannot be used to model biodiversity in its entirety, nor the full suite of ecosystem services – a range of models focusing on different elements will be required, and at different scales, so as to build up a more comprehensive picture of change. Compare the results from multiple models rather than relying on one alone; i.e. an ensemble approach (currently suggested in climate modelling). These should include models centred around land-use/cover change (like IMAGE) and those that are not. Consider the use of meta-models like InVEST and MIMES for rapid mapping of alternatives and first indications of economic feedback on sectors.

It is essential to consider the potential contributions of teams and consortia, not separate models alone to assess potential for contributions to TEEB: besides methodological soundness, scientific rigour and technical capabilities of the models, the teams' track-record in contributing to large scale international assessment studies is an important criterion. This has been the experience in the IPCC process. Availability of the toolbox to external users, and communication about the modelling approach and assumptions is considered essential to build policy support. The team should ideally work across models, and in coordination with the modelling teams related to the models. This is important as the elements of the analysis of different models have to fit together and relate to common scenarios to be able to create a global composite picture.

In addition, it could be useful to consider inviting a range of different modelling groups to undertake model runs using the same policy-relevant scenarios as competition breeds innovation.

To be pragmatic it will be important to explore ways of combining quantitative and qualitative approaches and not rely purely on quantitative models to inform policy (as they may give a false sense of greater accuracy over 'expert-led' qualitative options).

6.6 Recommendations for TEEB II (up to October 2010)

On the basis of the analysis and workshop discussions, the following recommendations are made for the analysis.

6.6.1 Developing new approaches

1. **Expansion of a global model suite.** A small but growing suite of global models is needed. Small initially because there are not many models available that can answer the questions, and growing as there is a need for different approaches to allow cross-checking and comparison. Below are a number of considerations.
    a. To address terrestrial ecosystems, the study and discussions suggest that an updated and extended use of IMAGE, GLOBIO, LPJmL and WaterGAP model be run covering land-use, biodiversity and a selection of ecosystem services.
    b. For fisheries and the marine environment, the best current global marine models are: EwE family, cumulative Threats Model and Reefs at Risk model covering limited biodiversity and the relevant ecosystem services.
    c. Reality check or complement: apply simple model(s) for key ecosystem services as the above models will not cover everything.
    d. It is important not to try to bundle everything together as this risks creating a "Frankenstein model."
    e. Aim for a suite of models to be available and operational (for the question of biodiversity/ecosystem loss) in the medium term.
    f. Use species area richness (SAR) for additional biodiversity estimates.

g. Upgrade COPI for economic valuation of gains and losses due to biodiversity policy action and inaction.
h. The GUMBO/MIMES model suite can provide indications about ecosystem services dynamics and includes feedbacks to economic values. The suite is being further developed and its progress should be closely tracked.
i. Use ATEAM/InVEST for regional specific analysis, which in itself it adds species richness estimates and several ecosystem services.

2. **Develop global models run with different scenarios.** Include a wider range of policy actions that include more specific approaches to tackle biodiversity loss including direct impacts of biofuels, REDD options, subsidy reform, investment in protected areas and other natural capital, and market based instruments.

3. **Complement the above with regional or local models as well as ecosystem specific models and sector models.** InVEST could be useful to bring in the spatial angle, for example by demonstrating links to flooding, as well as developing case studies focusing on ecosystem functions. For sector, ecosystem or policy specific modeling it could be useful to do REDD modeling, use agricultural models, and also carry out modeling of biofuels to address critical questions. In many cases significant work of others can be built on, so care needs to be taken to avoid duplicating existing work.

6.6.2 Implementation and resources required

Below are suggestions as to practical needs for analysis to support TEEB to Nagoya. This includes some order of magnitude estimates of costs to help clarify what is possible within the timescale and budget. The outline is constrained by the timeline for TEEB II and the assumed review and CBD procedure requirements.

Upgrade of the global toolbox

- Completion of current extensions and improvements of IMAGE and EwE families (unknown projects and timelines).
- New version of GLOBIO, including several other biodiversity measures (based on species-response models), link to EwE marine models with a MSA-like biodiversity indicator, and some ecosystem service indicators (based on empirical relationships). This would allow GLOBIO to do more than the current version and address some its current weaknesses as regards biodiversity/ecosystem impact modelling.

Development of broadly supported Policy Action Scenarios

- Policy dialogue - using key policy makers, scenario developers, links to beyond 2010 policy groups, and work on quantifying the policy recommendations present in TEEB D1 and parallel activities (e.g. TEEB France, CBD, etc.).
- Based on GBO2 and regional specifics, and building on the September product and experience.

Scenario-runs (including sensitivities)

- Embed the results of the policy dialogue in policy scenarios and run these scenarios, assess results in biodiversity, ecosystem services, and social and economic terms, including risks and opportunities.

Synthesis

- Produce a synthesis report and prepare presentations for Nagoya.
- Start communication of results.

6.7 The medium and long term: up to the MDG timescale 2015 and beyond

In the longer term it would be useful to facilitate development of and competition amongst a variety of models; following the IPCC approach. Indeed this could be particularly relevant to the establishment of an *Intergovernmental Panel on Biodiversity an Ecosystem Services (IPBES).*

Such work needs to be supported over the period to Nagoya, but the fruits of competition are most likely to come only after Nagoya. To see how much the models and the assumptions in the scenarios influence the results, different scenarios and model combinations should be tested. This will help allow one to see the answers in context. It will also help avoid answers being too anchored to one model, one perhaps too small set of indicators and assumptions, and subset of the experts working in the field. It would, for example, be useful to run GUMBO/MIMES with the same assumptions. The value of encouraging competition amongst models also holds true for marine/fisheries models.

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