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 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 a 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.*"

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[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 landuse 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 landuse 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).

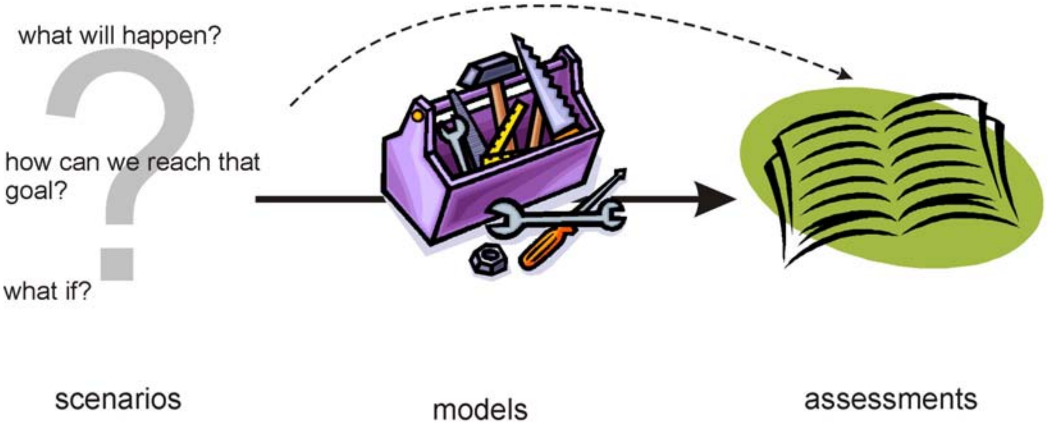


Figure 2.1 The link between assessments, models and tools: Assessments summarize the answers provided by modelling exercises on questions posed by scenarios. But not all questions can be answered by models.

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).

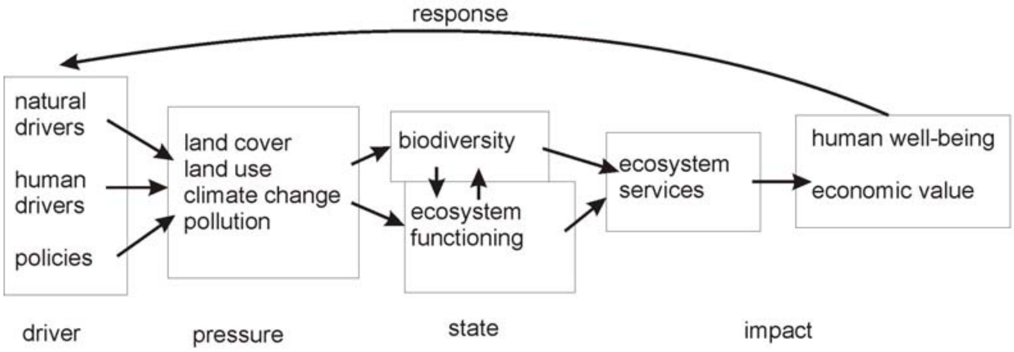


Figure 2.2: Driver-pressure-state-impact-response framework for ecosystem services and biodiversity change

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).

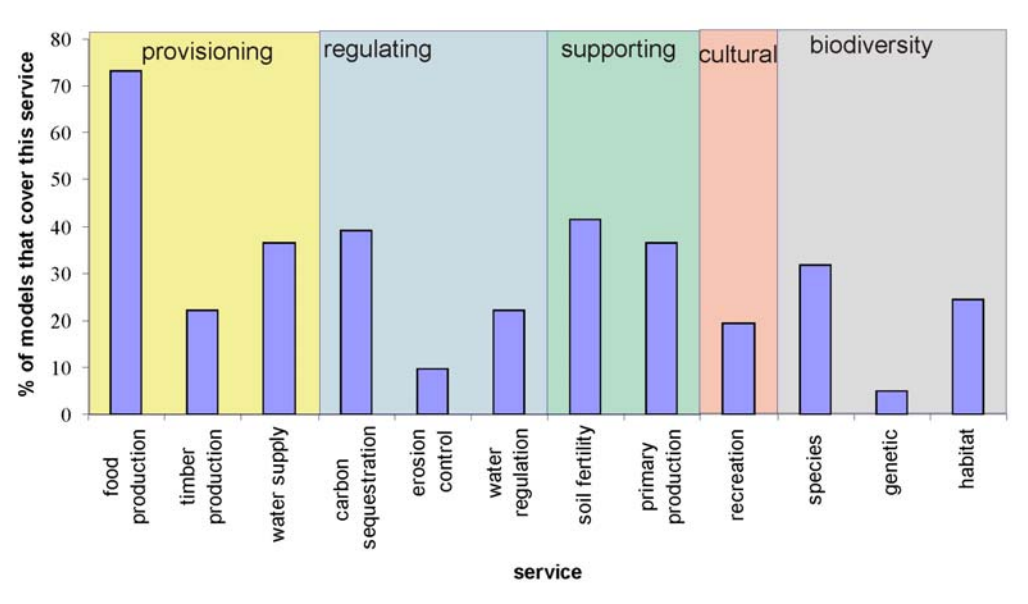


Figure 2.3: Coverage of the different (groups) of ecosystem services and biodiversity measures by the models reviewed. While food production is covered by most models all other services are only included in a small number of models.

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.ecosystemservicesproject.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)

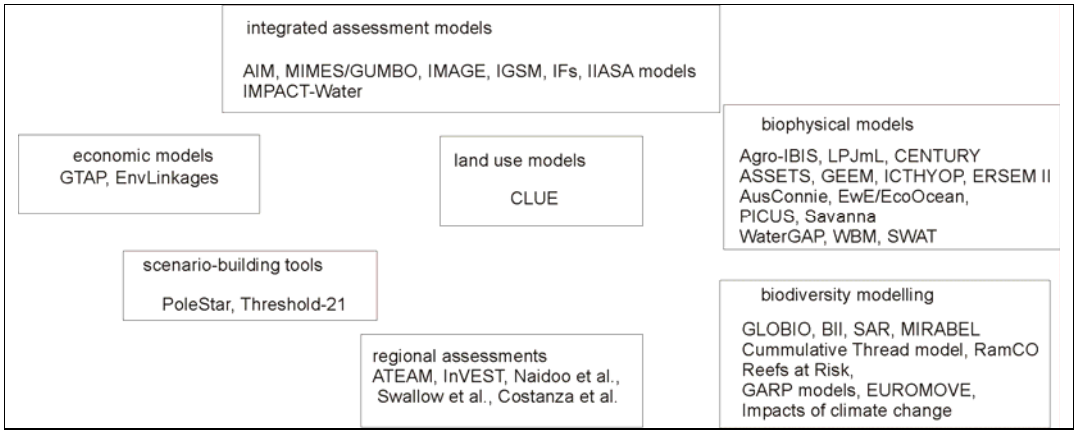


Figure 2.4: Grouping of models covered by this review.

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).

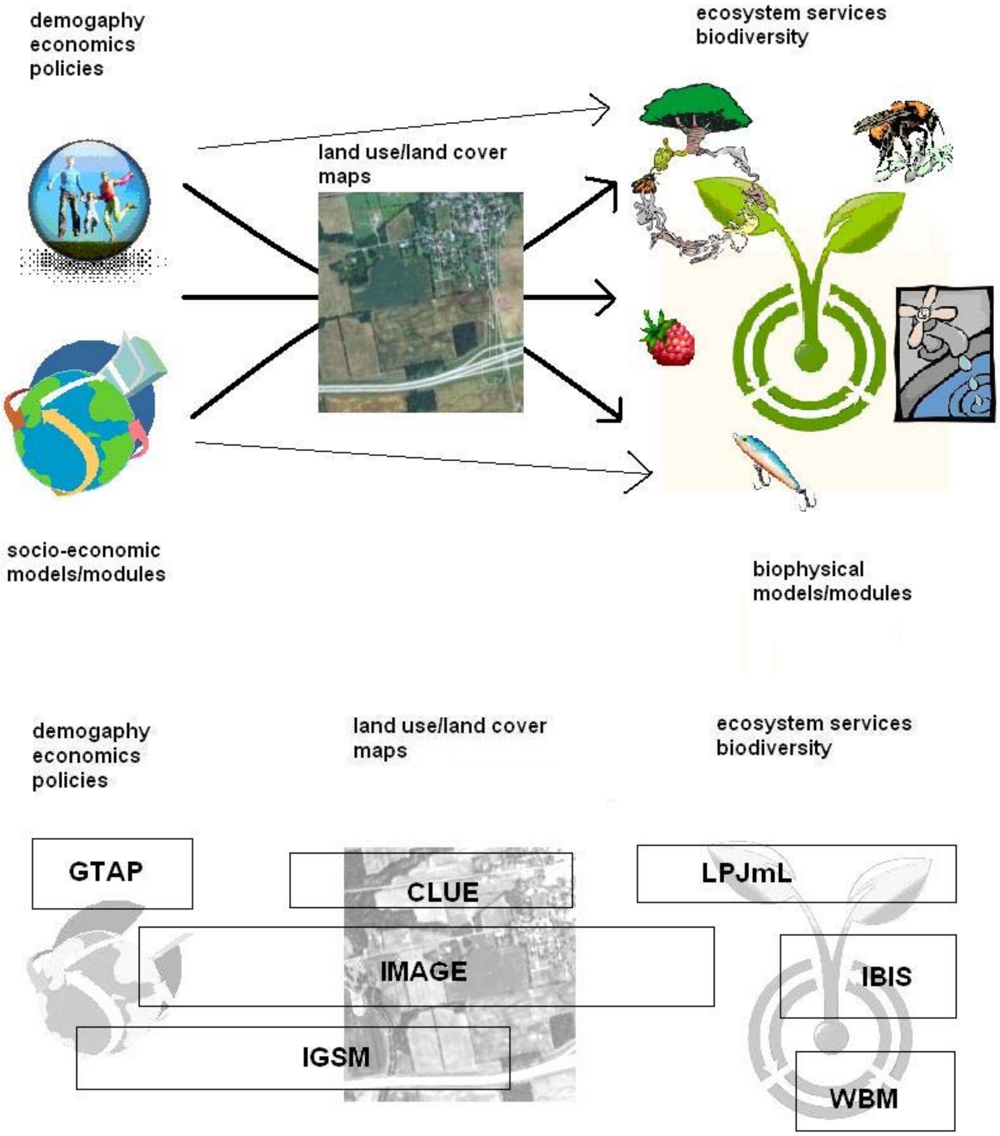


Figure 2.5: (a) Socio-economic and biophysical models can be linked via land use. (b) coverage of the different areas (socio-economics, land use, biophysical cycles) by different models (example).

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.

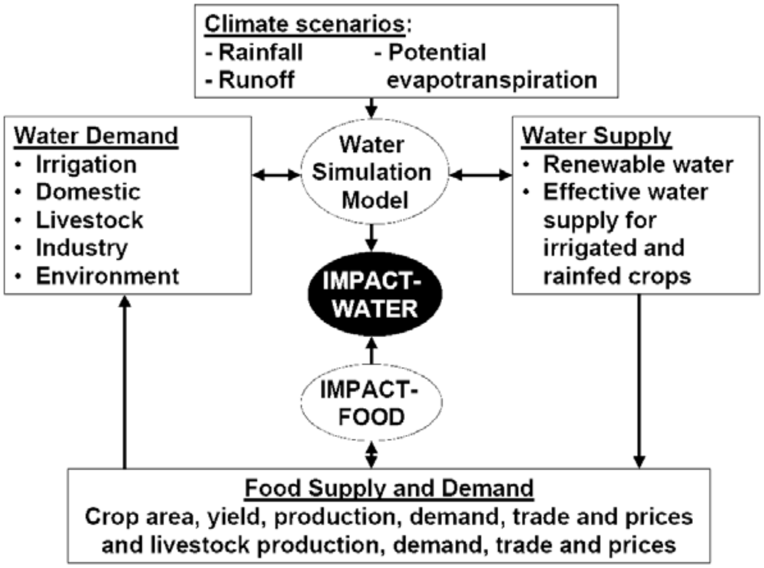
Key input and key output variables give information on how different models might be linked, for example biodiversity or biochemical models for which land use change is the key driver might be linked via land use models (key output: land use change) to socio-economic models that predict the effects of 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

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[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.

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[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.

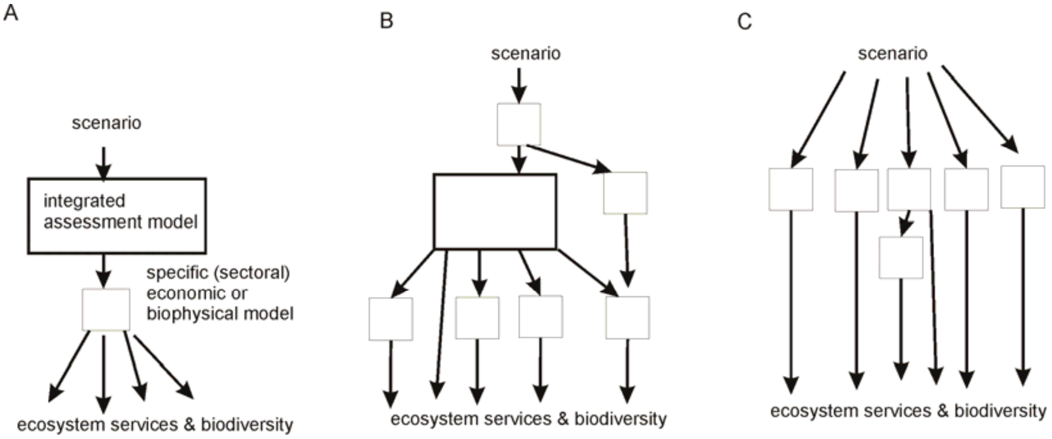

Figure 2.6: Different modelling options: (a) represents the COPI-approach of linking all ecosystem services to biodiversity derived from a combination of two models. (b) represents a combination of different sectoral models linked via an integrated assessment model to ensure the consistency of the scenario-input.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

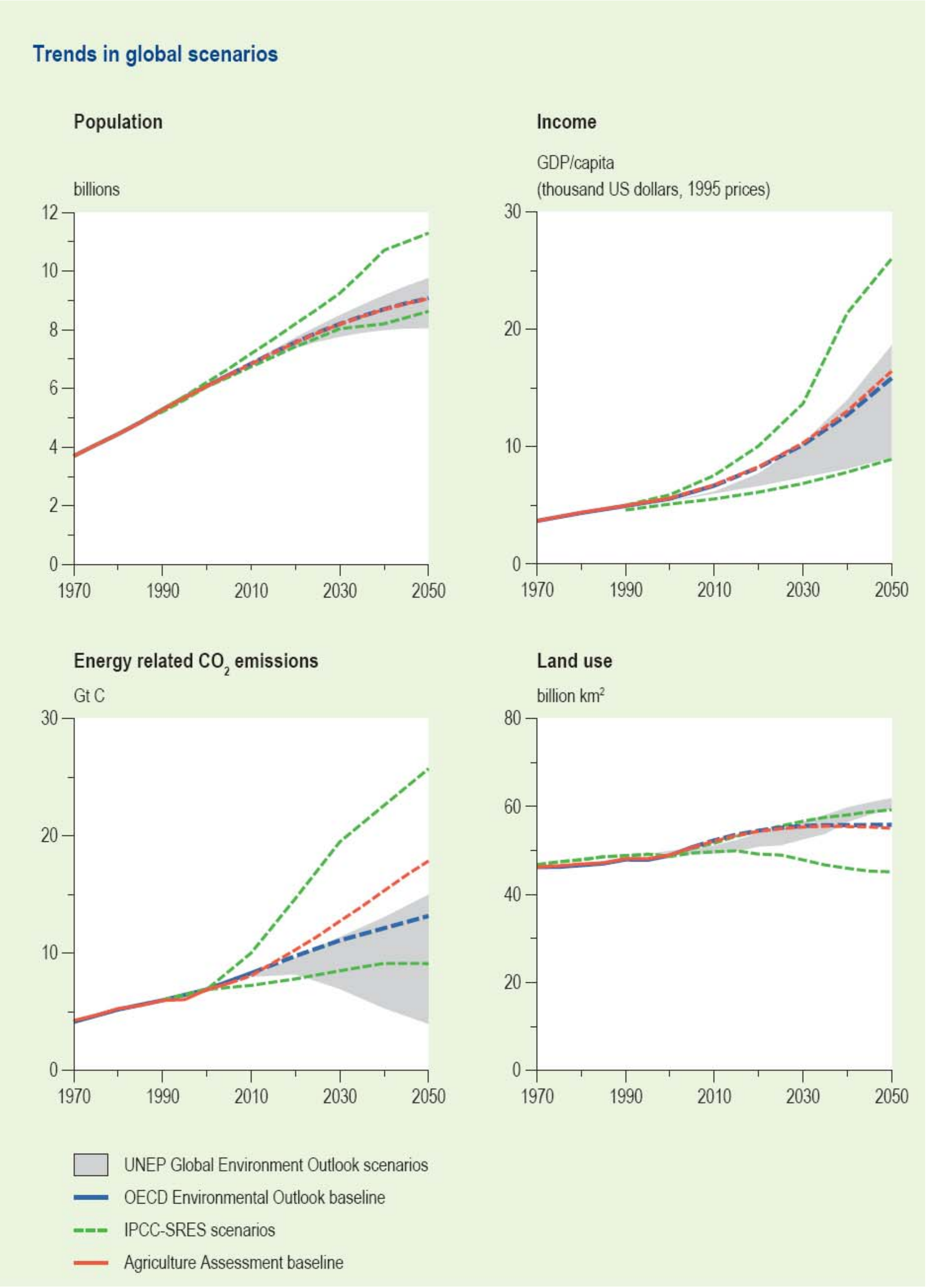

Figure 3.1 Projected trends in some key drivers of biodiversity and ecosystem change according to four recent global assessments. Source: Kok *et al.* (2008).

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.

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[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).

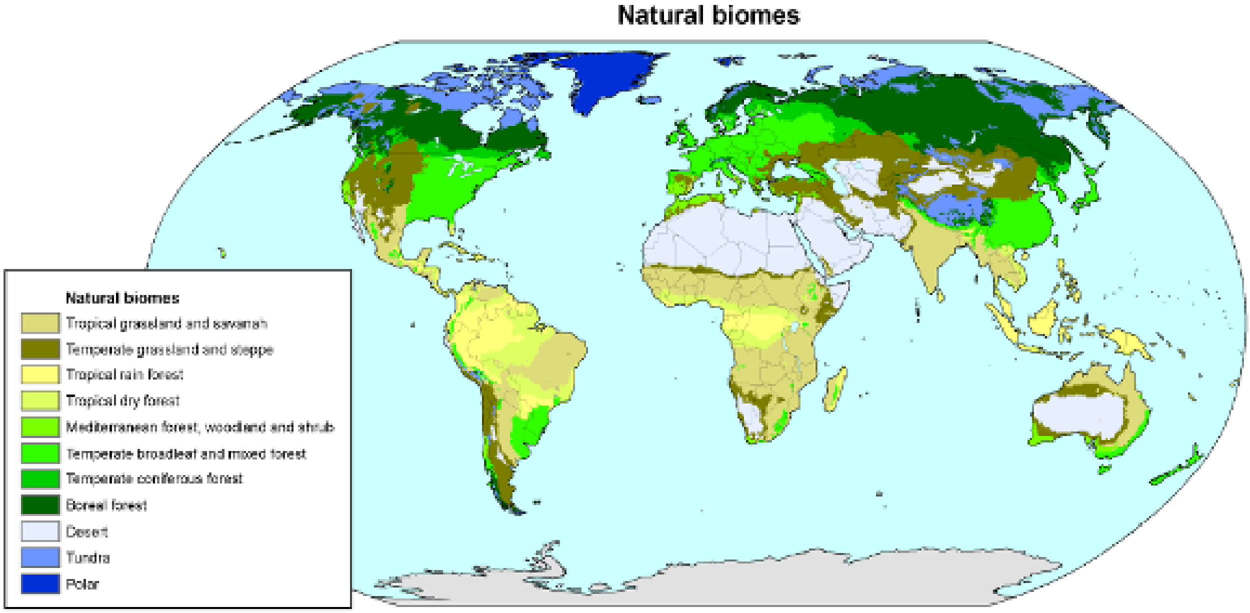

Figure 3.2. Geography of the world's major biomes, as used in the IMAGE and GLOBIO framework
Source: Bakkes & Bosch (2008)

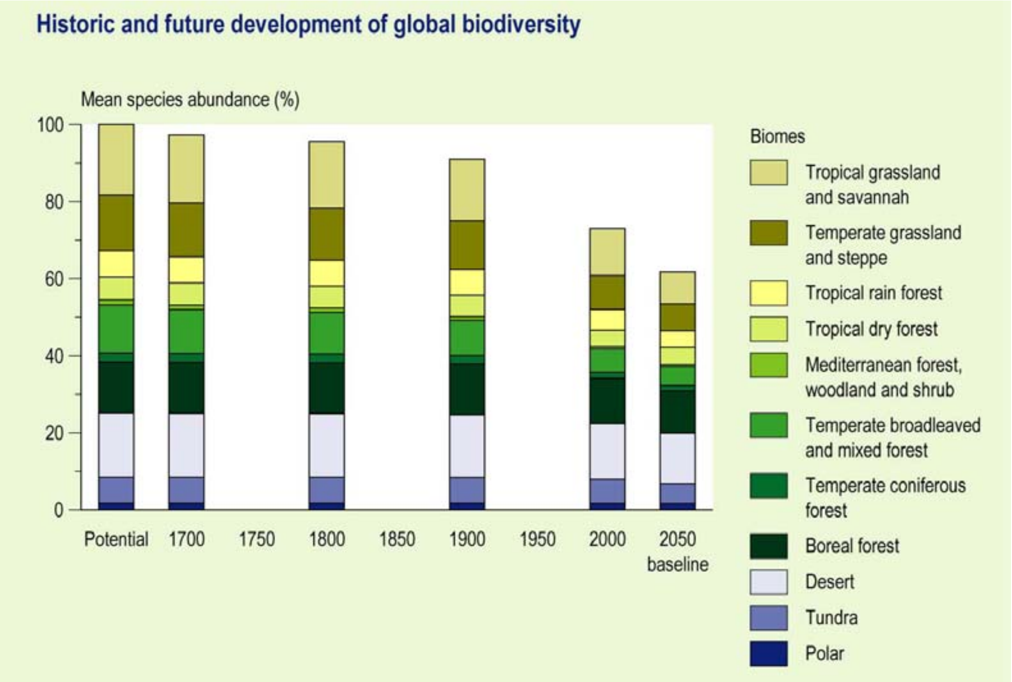

Figure 3.3. Global biodiversity from 1700 to 2050, OECD baseline.
OECD Environmental Outlook modelling suite, final output from IMAGE cluster
Source: Bakkes & Bosch (2008)

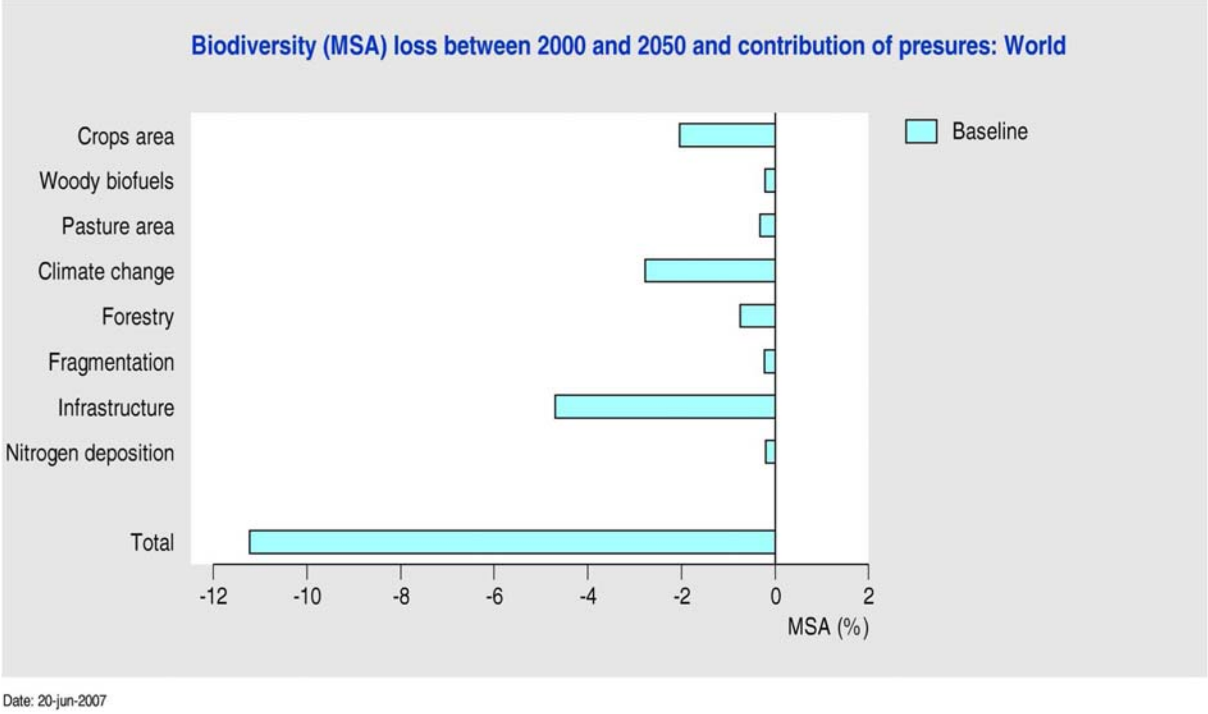

Figure 3.4. Contribution of different pressures to the global biodiversity loss between 2000 and 2050 in the OECD baseline.
Source: Bakkes & Bosch (2008)**.**

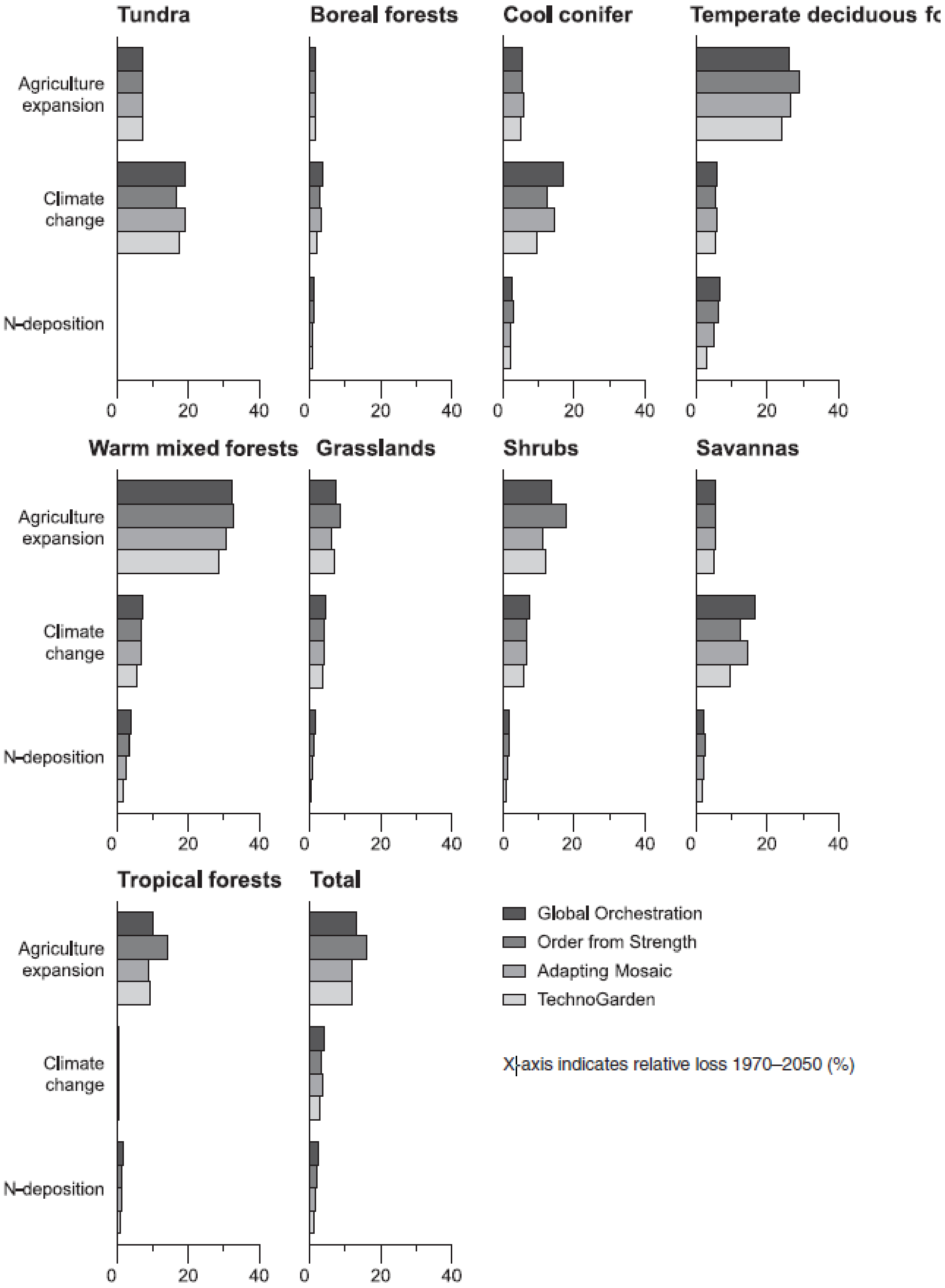

Figure 3.5. Comparison of effects of agriculture expansion, climate change and nitrogen deposition between 1970 and 2050 under four scenarios for different biomes and the World. Source: MA (2005d)

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.

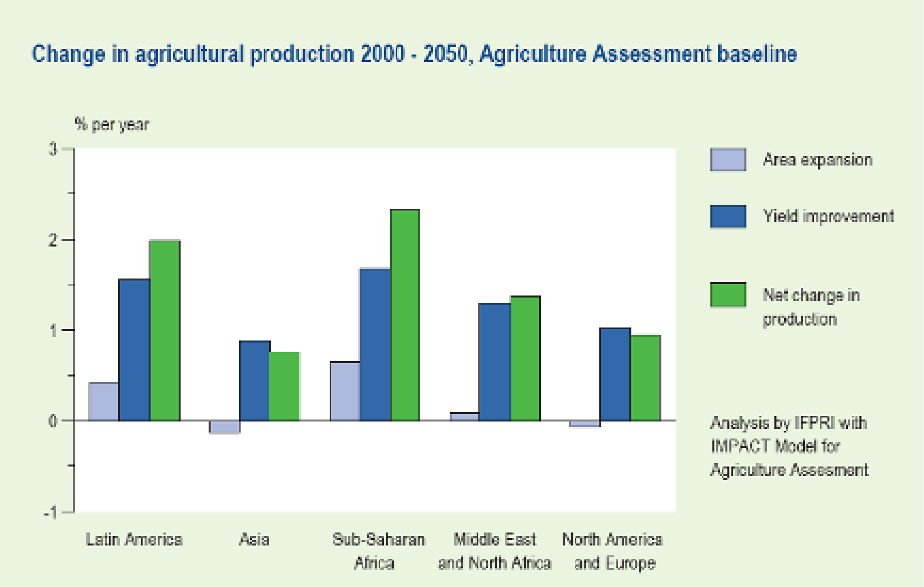

Figure 3.6 Causes of changes in agricultural production between 2000 and 2050 according to the IAASTD.

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.

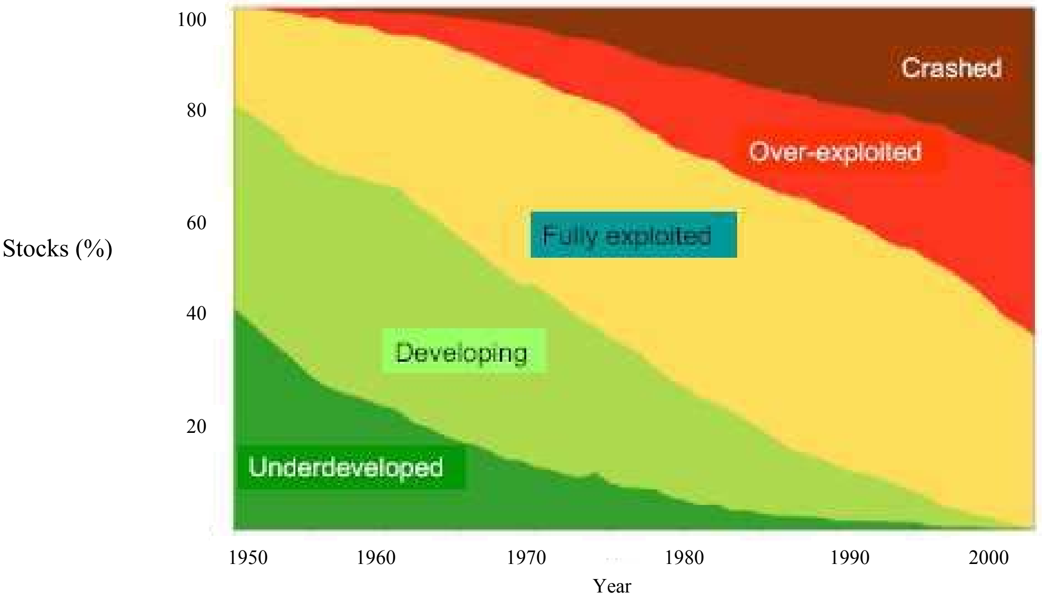

Figure 3.7 Changes in degree of exploitation of stocks of marine fish species (source: Alder, Trondheim/UN conference on Ecosystems and people, October 29-November 2, 2007. Original source: Sea Around Us project, 2007: Cited in Braat & ten Brink, 2008)

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.

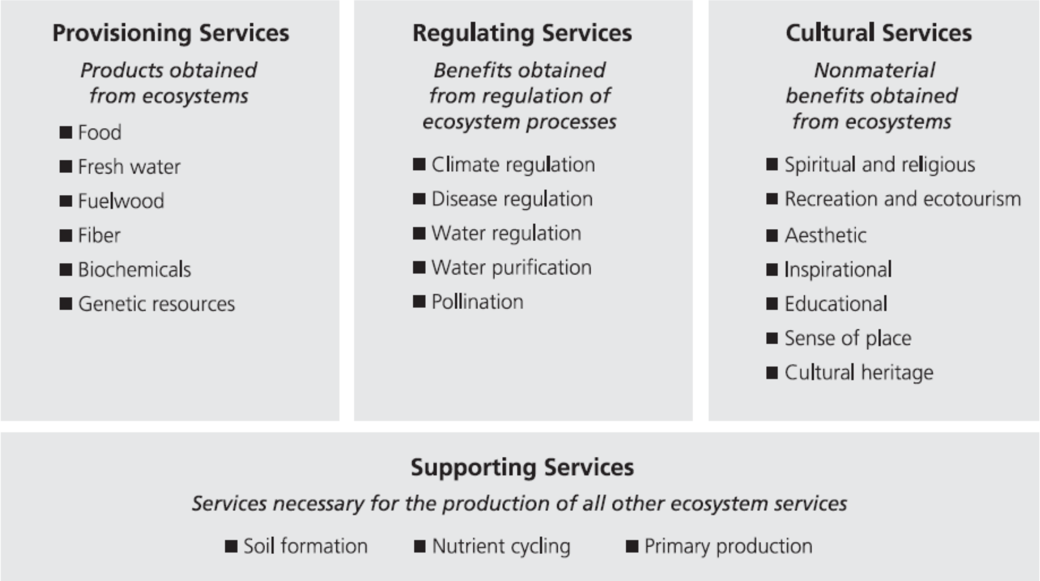

Figure 3.8 Ecosystem service framework.
Source**:** MA (2003).

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).

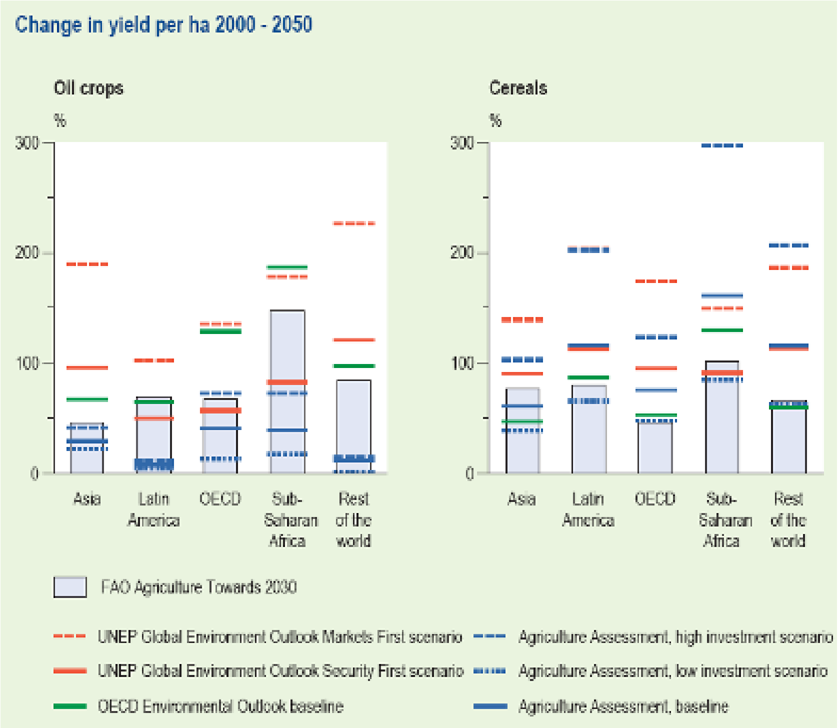

Figure 3.9 Increase in crop yields between 2000-2050, according to the FAO and three of the assessments discussed in this report. (Source: Bruinsma (ed), 2003; UNEP, 2007; IAASTD, 2008; OECD, 2008. Taken from Kok *et al.* 2008).

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 0.5º x 0.5º 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, 1º 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 sequestration, erosion control, water quality	species richness (habitat requirements 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.

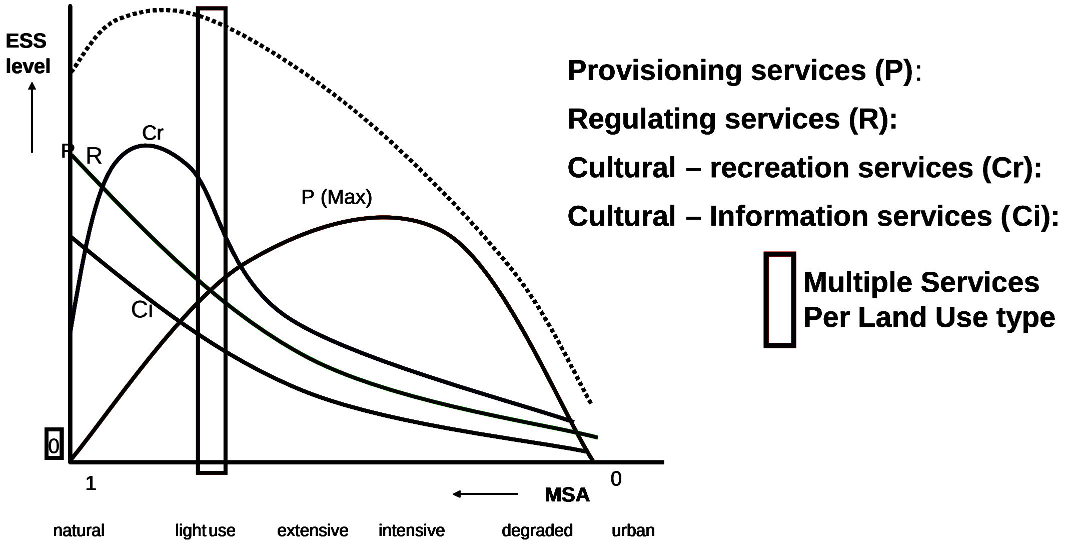

Figure 4.1 Generalised functional relationships between ecosystem service level (Y-axis) and degree of land use intensity (corresponding to decreasing MSA values; X-axis)

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.

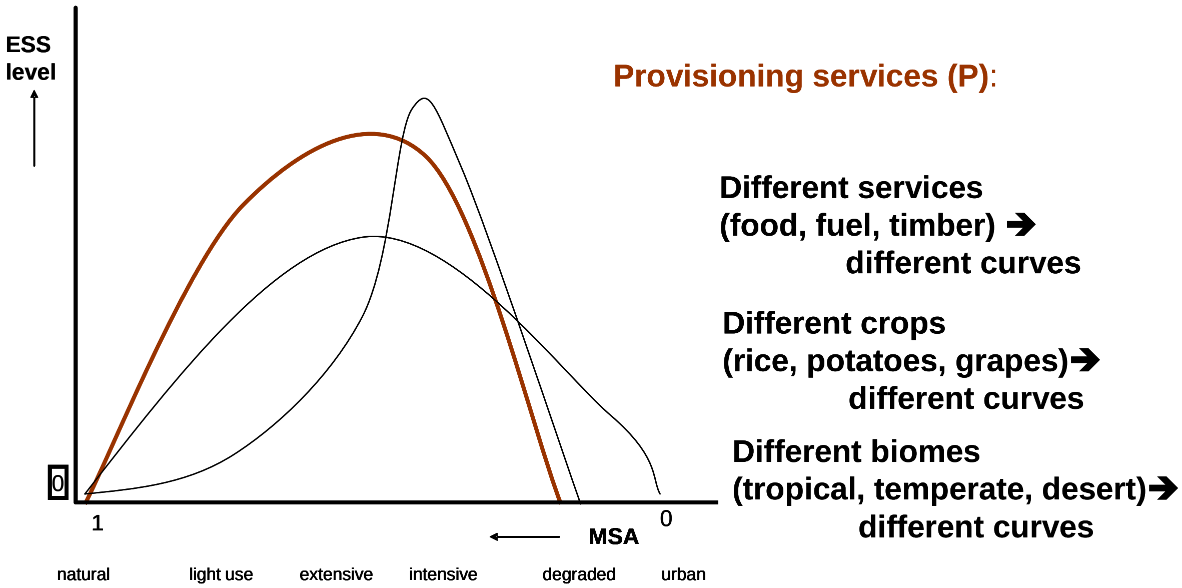

Figure 4.2 Generalised functional relationships between ecosystem service level (Y-axis) and degree of land use intensity (corresponding to decreasing MSA values; X-axis). The graph shows that the exact curves might differ for different groups of provisioning services (different services, crops, and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

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[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

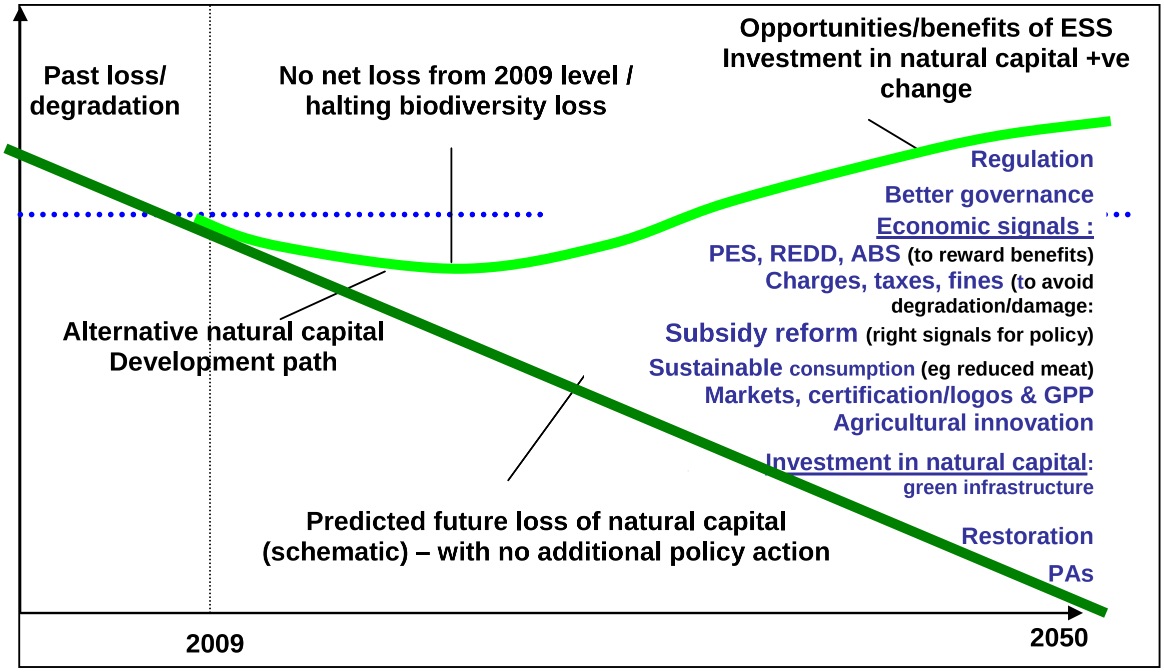
Very few of the global assessments studies have scenarios which deal with biodiversity and ecosystems services explicitly. The analysis carried out by the IMAGE-GLOBIO toolbox for GBO2 is a rare example, at least at the global scale (see sCBD and MNP, 2007). The GBO2 scenarios should be further developed, 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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SCENARIOS AND MODELS FOR EXPLORING FUTURE TRENDS OF BIODIVERSITY AND ECOSYSTEM SERVICES CHANGES

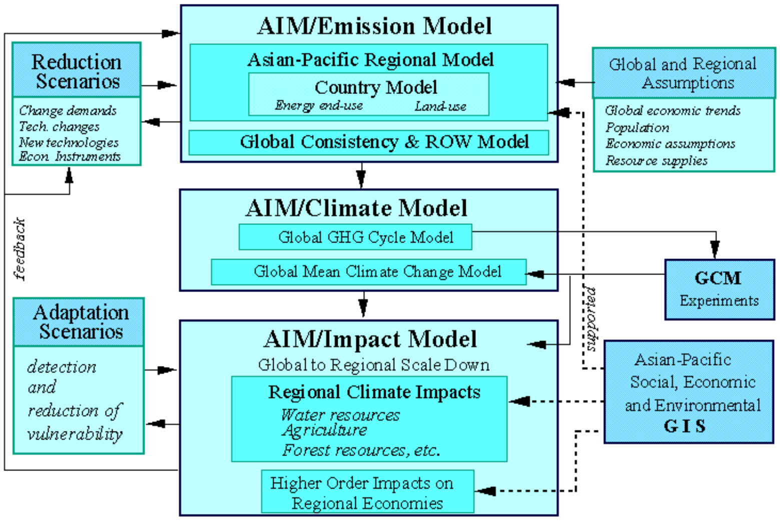
FINAL APPROVED REPORT 27th August 2009

1 APPENDICES OF CHAPTER 2: Identification and Overview of Available Models

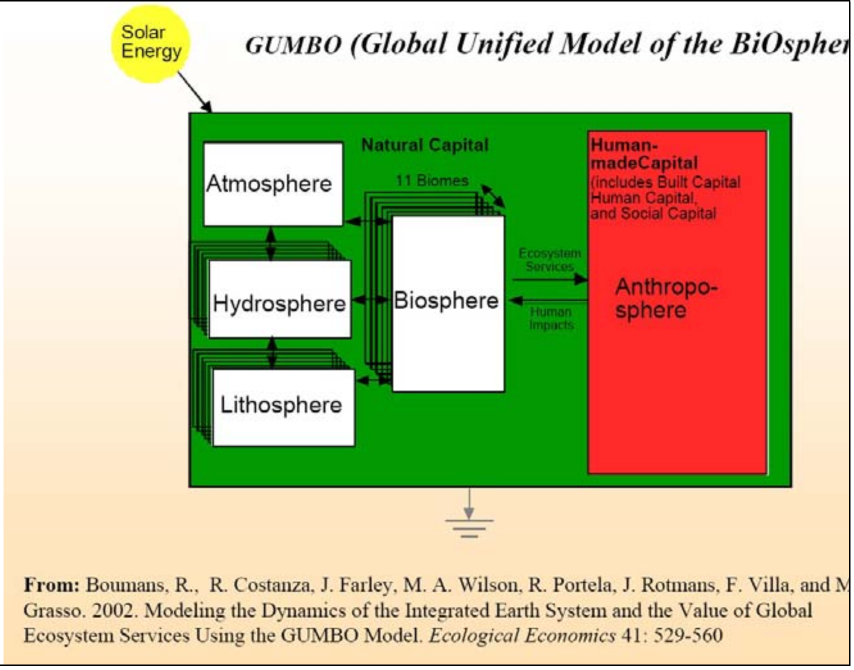
1.1 General description of all selected models

1.1.1 Integrated Assessment Models

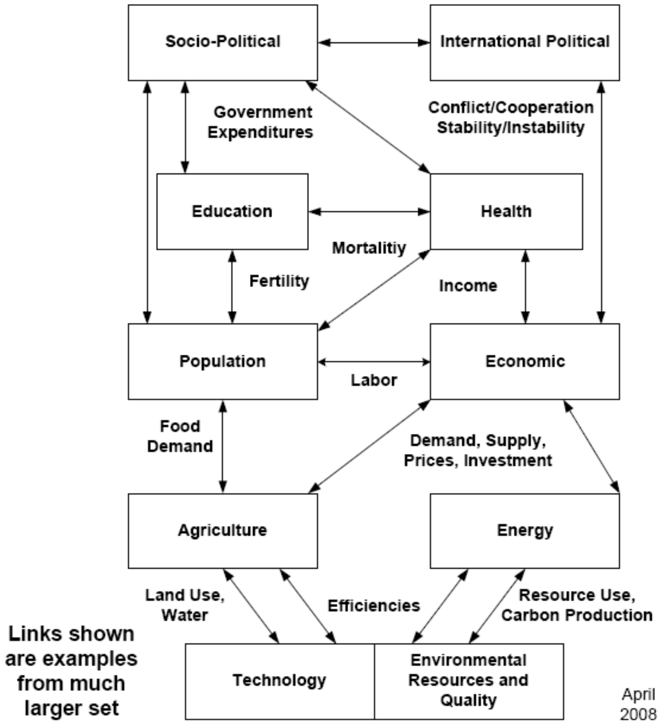
Model name	**AIM**
Full model name	Asian Pacific Integrated Model
Model type	integrated assessment model
Subtype	
Thematic coverage	effects of policies on climate change and resource supply
Input (key drivers and pressures)	socio-economic trends and governmental policies
Output (key variables)	energy consumption, land use change affecting water supply, vegetation changes (agriculture, forestry production), human health (malaria spread)
Geographical coverage and resolution	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), resultion: 5º by 5º
Temporal coverage and resolution	from 1990 to 2100, 5 year time steps until 2030 (+2050, 2075, 2100)
Analytical technique	Dynamic systems model
Model developers and/or owners	National Institute for Environmental Studies, Japan
Model development history	1st version in 1994, latest update website: feb 2008
Target Group/users	AIM 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. 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.
Calibration	Not available
Validation	Not available
Uncertainty analysis	Not available
Key reference	Kainuma et al., (2004), Kainuma et al., (2002; http://www-iam.nies.go.jp/aim/book/clim_pol_assess.htm)
Level of integration	Submodels are: the greenhouse gas emission model (AIM/emission), the global climate change model (AIM/climate), and the climate change impact model (AIM/impact). Estimates greenhouse gas emissions and assesses policy options to reduce them, predicts changes in global temperatures and effects on natural environments and socio-economy; integrates bottom-up national modules with top-down global modules, feedbacks between the three modules; country level models are linked to 'rest of the world'
Scenarios used	SRES, GEO-scenarios
Links to other models	AIM has been used together with IMAGE, WaterGAP, Polestar and EwE/EcoOcean in the IPCC and GEO-4 assessment.
Ease of use/accessibility	Not available for download
Website	http://www-iam.nies.go.jp/aim/index.htm

Model structure	

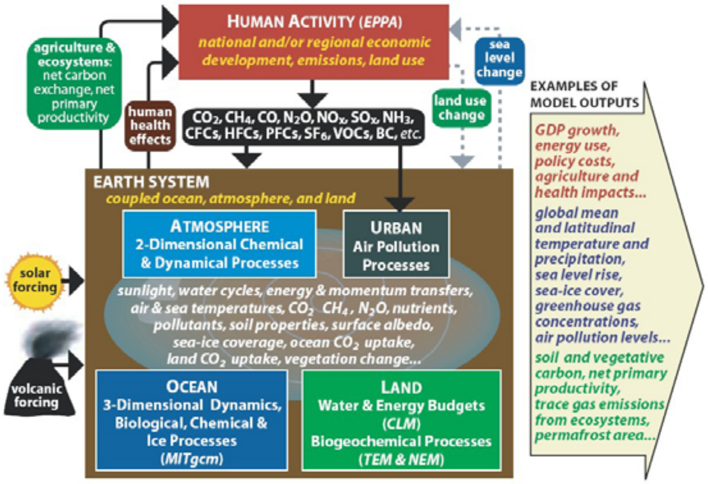
Model name	**GUMBO**
Full model name	global unified metamodel of the biosphere
Model type	integrated assessment model
Subtype	
Thematic coverage	complex, dynamic interlinkages between social, economic and biophysical systems on a global scale, focusing on ecosystem goods and services and their contribution to sustaining human welfare
Input (key drivers and pressues)	Human population and GWP (economic goods and services) changes (economic investments, consumption)
Output (key variables)	global temperature, atmospheric carbon, sealevel, water, fossil and alternative energy consumption, area of different land covers, knowledge, human, built and social capital, physical and monetary values for 11 ecosystem services, per capita food and welfare
Geographical coverage and resolution	global, 11 biomes globally aggregated, not spatially explicit
Temporal coverage and resolution	Base year: 2000, projections until 2100, annual time steps, historical data since 1900
Analytical technique	dynamic systems model, meta-model (GUMBO relationships are base don outputs of more complex and computational intense models)
Model developers and/or owners	R. Costanza & R. Boumans, National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, CA
Model development history	first published: 2002, integrated into MIMES, modeling software: STELLA
Target Group/users	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) internation collaborators.
Calibration	Historical callibration with time series from 1900/1950 to 2000 for 14 key variables (out of 930, of which: global temperatures and atmospheric carbon content) for which quantitative time-series data was available produced an average R2 of 0.922.
Validation	Not available
Uncertainty analysis	Not available
Key reference	Boumans et al., 2002, Werners et al., 2004, Costanza et al., 2007
Level of integration	Both ecological and socioeconomic changes are endogenous to the model, with a pronounced emphasis on interactions and feedbacks between the two. Dyamic feedback between human technology, economic production, welfare and ecosystem services.

	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 substitutablility between natural and social, human and built capital.
Links to other models	GUMBO is a metamodel which uses output from complex global models as input (which models are used, was not specified).
Scenarios used	MIMES/GUMBO, SRES
Ease of use/accessibility	The model can be downloaded and run on the average PC to allow users to explore for themselves the complex dynamics of the system and the full range of policy assumptions and scenarios. Commerical and consultancy uses have to be coordinated with developers/University of Vermont.
Website	http://ecoinformatics.uvm.edu/projects/the-gumbo-model.html
Comments/remarks	The current version of the model contains 234 state variables, 930 variables in total, and 1715 parameters (Boumans et al., 2002)
Model structure	 **From:** Boumans, R., R. Costanza, J. Farley, M. A. Wilson, R. Portela, J. Rotmans, F. Villa, and M Grasso. 2002. Modeling the Dynamics of the Integrated Earth System and the Value of Global Ecosystem Services Using the GUMBO Model. *Ecological Economics* 41: 529-560

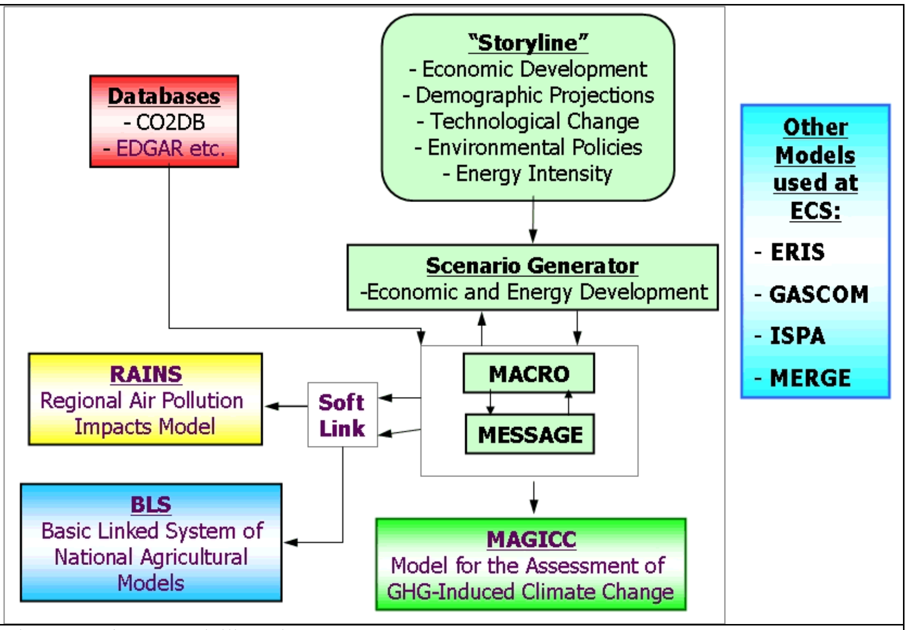
Model name	**IFs**
Full model name	International Futures simulator
Model type	integrated assessment model
Subtype	
Thematic coverage	climate change, energy, agriculture, demography, economy, political and others, possible to add: education, human well-being including poverty
Input (key drivers and pressures)	Current situation describing demography, economic, agricultural, energy, socio-political, international political, environmental situation. The relationship functions between and within modules can be altered, depending on scenario assumption
Output (key variables)	Future situation describing demography, economic, agricultural, energy, socio-political, international political, environmental situation.
Geographical coverage and resolution	Global (with details for 182 regions/countries), not spatially explicit
Temporal coverage and resolution	Base year: 2000, projections until 2100 with annual time steps
Analytical technique	dynamic systems model (partial equilibrium modelling and multiple agent approaches), economic model: CGE

Model developers and/or owners	Barry Hughes, Graduate school of international studies University of Denver. Model development is supported by a range of different foundations and funding sources.
Model development history	1st version: 1980, current version: 2006
Target Group/users	Ifs began as an educational tool and is mainly used for educational purposes. The model is increasingly being used in policy analysis and international assessments (e.g. UNEP).
Calibration	Initialized with data primarily from the 1995–2005 period and a very large data associated data base (nearly 1000 series) from a wide range of sources
Validation	runs of the model from 1960 through 2000 have been compared with data series from the same sources for key model variables
Uncertainty analysis	Not available
Key reference	Hughes & Hillebrand, 2006
Level of integration	The overall model incorporates different sub-models, including the Population sub-model, the Economic sub-model, the Agricultural sub-model, the Educational sub-model, the Energy sub-model, the Socio-Political sub-model, the International Political sub-model, the Environmental sub-model, the Technology sub-model, and the Health sub-model.
Links to other models	unkown
Scenarios used	Includes own scenario-building tool
Ease of use/accessibility	Ease-of-use is high. No special permission is needed. Model is available online: www.ifs.du.edu
Website	http://www.ifs.du.edu/
Comments/remarks	Description copied from EEA, 2008
Model structure	 **Figure 2 The modules of International Futures (IFs)**

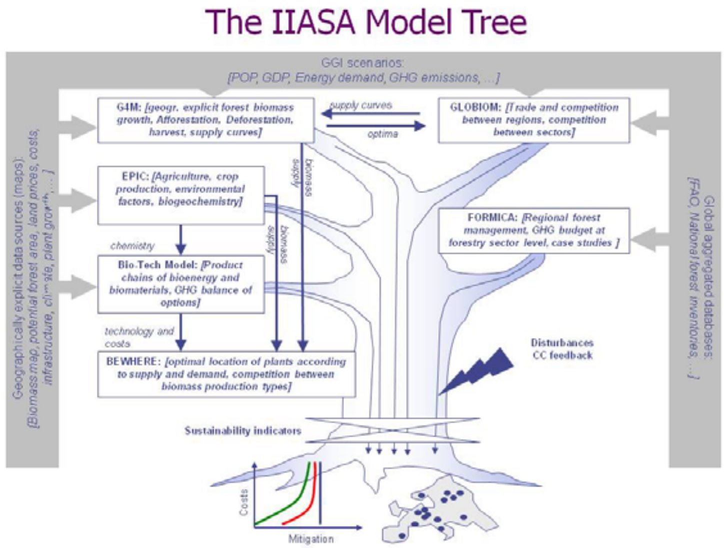
Model name	**IGSM**
Full model name	integrated global system model

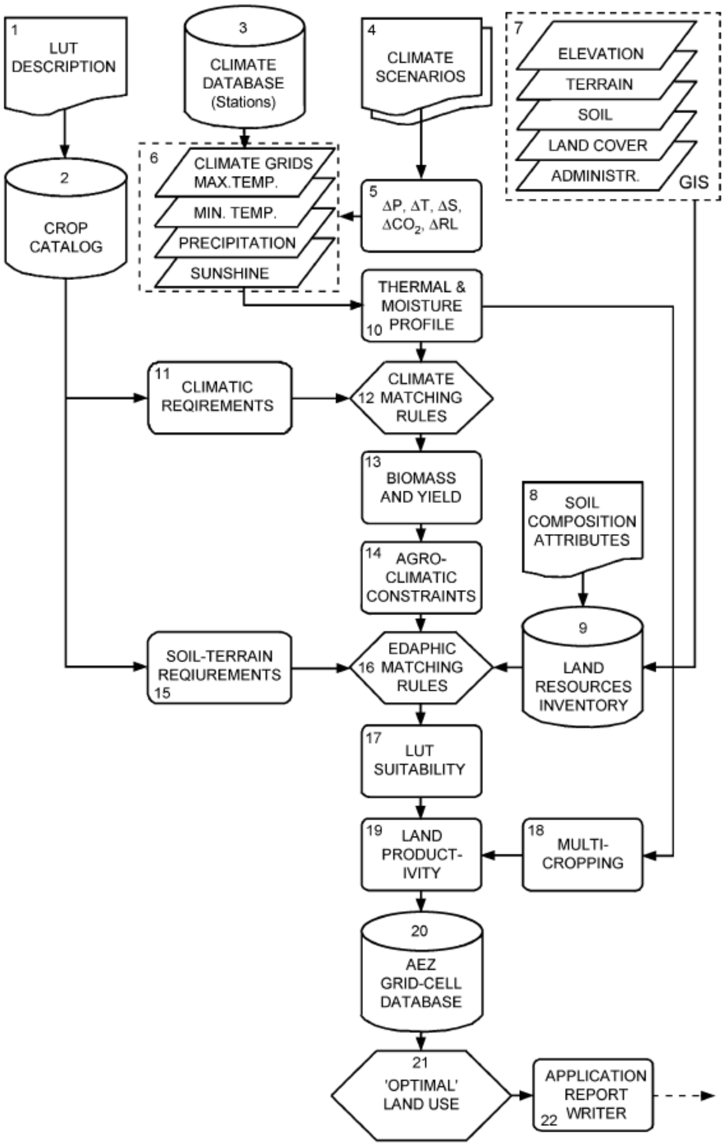
Model type	integrated assessment model
Subtype	
Thematic coverage	economics, climate change and ecosystems
Input (key drivers pressures)	capital, labour, land, fossil energy reserves
Output (key variables)	emission greenhouse gases, temperature, precipitation, sea level rise
Geographical coverage and resolution	global, 16 regions with special studies on European countries, 0.5º by 0.5º to 4º by 4º grid, depending on submodel used for the biogeochemical part
Temporal coverage and resolution	time steps: 10 minutes (atmosphere) to 5 years (policy analysis)
Analytical technique	dynamic system model (economy: general equilibrium)
Model developers and/or owners	Massachusetts Institute of Technology
Model development history	1st version: 1999, current version: IGSM 2.3 (2005)
Target Group/users	IGSM is used to study causes of global climate change and potential social and environmental consequences, and the effects on different policies (carbon tax, biofuel programm; US, EU).
Calibration	Unknown
Validation	unknown
Uncertainty analysis	Prinn et al., 1999, Paltsev et al., 2005
Key reference	Prinn et al, 1999, Sokolov et al., 2005 http://globalchange.mit.edu/pubs/abstract.php?publication_id=696, http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt124.pdf
Level of integration	Different submodels, including TEM (carbon cycle), CLM (land use, energy), NEM (emissions), EPPA(economics, energy): emission model, a coupled atmosphere-ocean-land surface model with feedbacks of climate change on human activities
Links to other models	economic model built on GTAP dataset
Scenarios used	
Ease of use/accessibility	Model not available
Website	http://globalchange.mit.edu/igsm/
Model structure	 **Figure 1**. Schematic of the MIT Integrated Global System Model Version 2 (IGSM2).

Model name	**IIASA Integrated Assessment Modeling Framework** **Including IIASA-ECS modelling and IIASA/FOR modelling cluster**
Full model name	
Model type	integrated assessment model
Subtype	
Thematic coverage	energy system planning, energy policy analysis, and scenario development, economics, climate change, agriculture
Input (key drivers and pressures)	population development, economic development, technological change, environmental policies, energy intensity
Output (key variables)	greenhouse gas emission, temperature change, development of least-cost mitigation scenarios, water supply and demand (water scarcity index), crop production
Geographical coverage and resolution	global, 0.5' grid
Temporal coverage and resolution	10 year time steps
Analytical technique	dynamic system modelling
Model developers and/or owners	IIASA (International Institute for Applied Systems Analysis)
Model development history	UNIX based system , new models and modules are constantly developed and integrated into the existing framework
Target Group/users	In 1998, IIASA-ECS completed a five-year joint study with the World Energy Council (WEC). The study analyzed six alternative global energy scenarios extending to 2100. The MESSAGE model is a systems engineering optimization model used for medium- to long-term energy system planning, energy policy analysis, and scenario development [24]. The model provides a framework to represent an energy system with all its interdependencies, from resource extraction, imports and exports, conversion, transport, and distribution to the provision of energy end-use services, such as light, space conditioning, industrial production processes, and transportation. The IIASA/FOR modelling cluster focusses on forestry, carbon sequetration and biofuel production.
Calibration	Global statistics (FAO) were used for calibration of different model components.
Validation	Different (sub-) models have been validated and applied in many studies on national, regional and global scales.
Uncertainty analysis	Böttcher et al., 2008
Key reference	Riahi & Röhrl, 2000, Keppo et al., 2007, Fischer er al., 2005, Fischer et al., 2007
Level of integration	The IIASA integrated modeling approach consists of several models that represent two different model suites: First the ECS-model cluster with scenario-generator, MESSAGE-MACRO (macro-economy, energy supply and environmental impact), AEZ-BLS (agricultural-economic), DIMA (Dynamic Integrated Model of Forestry and Alternative Land Use) and MAGICC (climate change indusced by greenhouse gas emissions), those models are linked (including some feedback loops). The second group with CHARM (runoff), RAINS (air pollution), EPIC (agriculture), FORMICA (regional forest management), G4M (forestry), GLOBIOM (trade and competiton), BEWHERE (optimal land allocation) constitutes the FOR modelling cluster.
Links to other models	Different sub-models have links to other IIASA models. The agro-ecologic model AEZ (agro-ecological zone) is used by FAO to analyse present and future land resources. CAPRI is used for the estimation of agricultural demand.
Scenarios used	SRES, climate scenarios (HADCM3, ECHAM, CSIRO, CGCM2, NCAR-PCM) Fischer et al., 2005
Ease of use/accessibility	Models not available online
Website	http://www.iiasa.ac.at/Research/ECS/docs/models.html
Model structure	The IIASA-ECS modelling cluster:



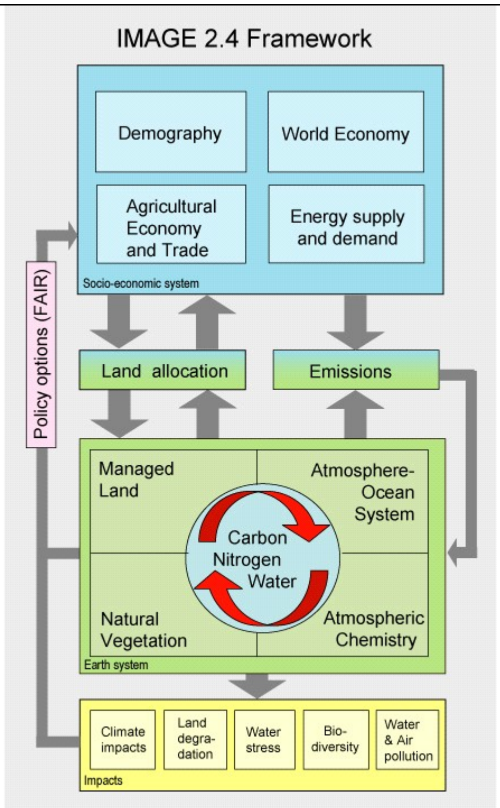
The IIASA/FOR modelling cluster:



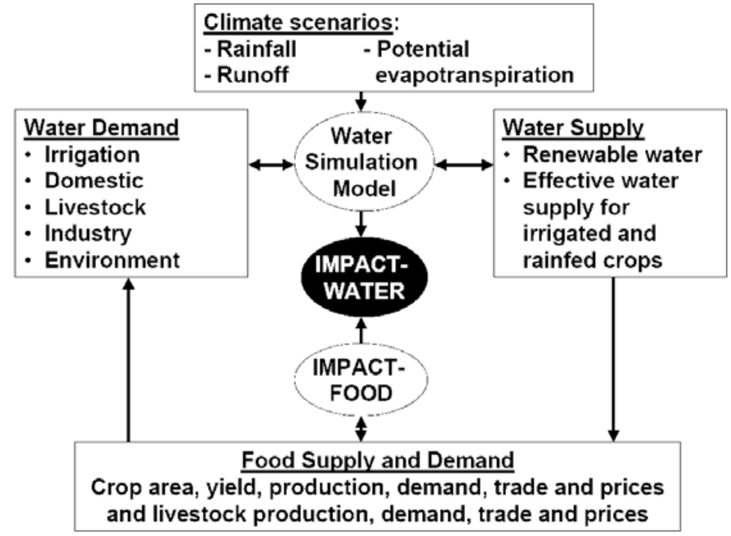
	 Fig. 1. Information flow and integration in the agro-ecological zone modeling.

Model name	**IMAGE**
Full model name	Integrated model to assess the global environment
Model type	integrated assessment model
Subtype	
Thematic coverage	Demography, world economy, agriculture, energy supply and demand, emissions, land allocation, carbon, nitrogen and water cycle, climate change, land degradation
Input (key drivers and pressures)	Population projections (from UN, IIASA, or from PHOENIX), economic drivers, technological development, policy options
Output (key variables)	concentrations, emissions, energy, climate, effects of climate, land use, food production and demand
Geographical coverage and	Global (with details for 24 world regions (energy, trade emissions)) or 0.5º x 0.5º grid (land cover, land use)

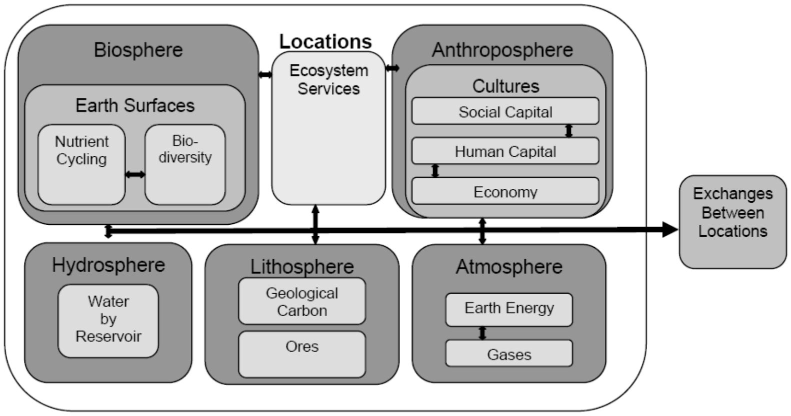
resolution	
Temporal coverage and resolution	time period covered: 1970-2100 (historical data from 1900), time steps: from monthly to 5 years
Analytical technique	dynamic systems model with different sub-modules
Model developers and/or owners	Netherlands Environmental Assessment Agency
Model development history	1st version: 1990, latest version: 2.4, software: FORTRAN/UNIX
Target Group/users	Designed to support science-policy dialoges, for scenario-development (for IPCC, OECD, MA).
Calibration	IMAGE is calibrated against historical data from 1765-2000 for carbon and climate, and data from 1970-2000 for energy and agriculture. These data were derived from large international databases (*e.g.* FAO).
Validation	Submodels have been validated.
Uncertainty analysis	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. Sensitivity analysis: Rotmans 1990. Furthemore IMAGE has been reviewed by an expert advisory board: http://www.rivm.nl/bibliotheek/rapporten/500110003.pdf
Key reference	http://www.pbl.nl/en/publications/2006/IntegratedmodellingofglobalenvironmentalchangeAnoverviewofIMAGE2.4.html
Level of integration	Same drivers are used for energy, industry and land use, consistency between scenarios, feedback between different submodels
Links to other models	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.
Scenarios used	SRES, MA, GEO, OECD, IAASTD, EURuralis
Ease of use/accessibility	not available
Website	http://www.mnp.nl/en/themasites/image/index.html

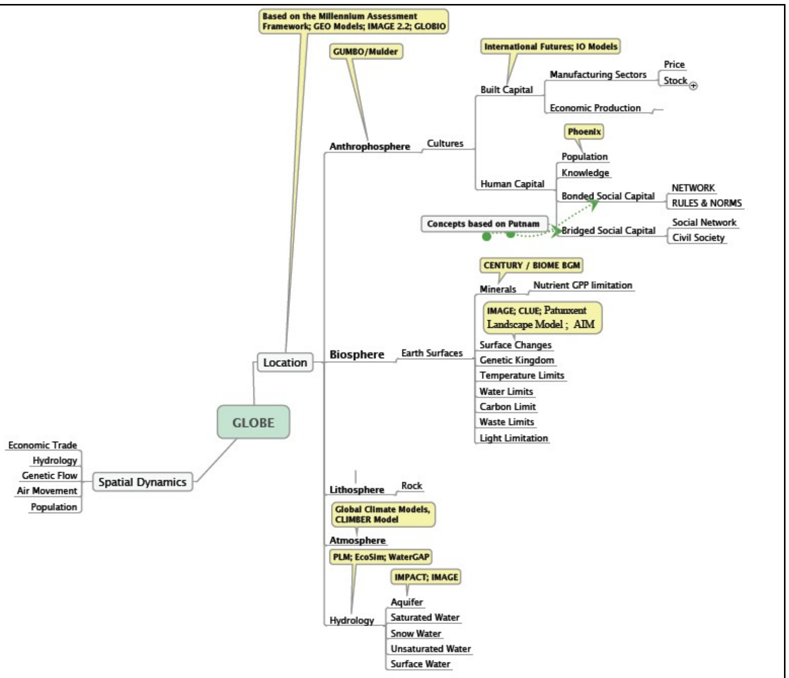
Model structure	

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 and pressures)	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, 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 (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 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)
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 (MNP, Netherlands), AIM (Nat'l Inst for Env Studies, Japan) and WaterGAP (Univ. of Kassel).
Scenarios used	MA, IAASD scenarios
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 hase been taken from EEA, 2008
Model structure	

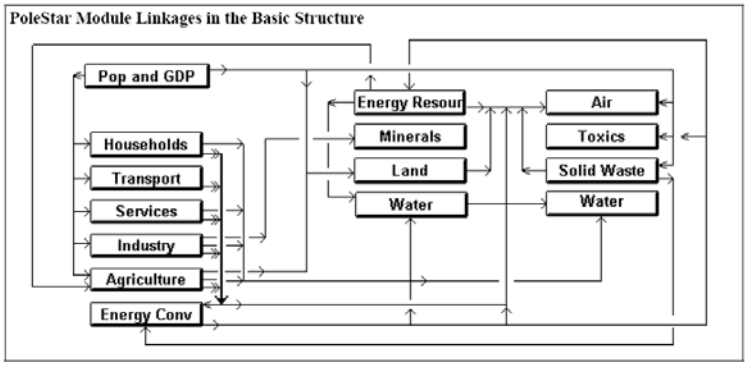
Model name	**MIMES**
Full name	**Multiscale integrated model of ecosystem services**
Model type	integrated assessment model
Subtype	
Thematic coverage	dynamics and tradeoffs among natural, human, built and social capital, joint economic and social valuation of ecosystem services, based on physical ecosystem models
Input (key drivers and pressures)	climate, land use, socio-economic drivers
Output (key	global temperature, atmospheric carbon, sealevel, water, fossil and alternative energy

variables)	consumption, area of different land covers, knowledge, human, built and social capital, physical and monetary values for 11 ecosystem services, per capita food and welfare
Geographical coverage and resolution	global, 1º by 1° resolution
Temporal coverage and resolution	unknown
Analytical technique	meta-model, dynamic system model
Model developers and/or owners	The Gund Institute for Ecological Economics, University of Vermont, USA, together with University of Sao Paulo, Helmholtz CER, Wageningen University, Palawan State University, Boston University, Florida Institute of Technology, Kansas University, Michigan State University, Stanford University, University of Denver, USDA Forest Service, National Center for Atmospheric Research
Model development history	1st version: 2007, MIMES builds on the GUMBO model to allow for spatial explicit modeling at various scales, software: simile
Target Group/users	The MIMES project aims to integrate participatory model building, data collection and valuation, to advance the study of ecosystem services for use in integrated assessments. (http://www.uvm.edu/giee/mimes/media.htm)
Calibration	Not available
Validation	Not available
Uncertainty analysis	Not available
Key reference	http://www.uvm.edu/giee/publications/Boumans_Costanza_GWSP%20Chapter_2007.pdf
Level of integration	Both ecological and socioeconomic changes are endogenous to the model, with a pronounced emphasis on interactions and feedbacks between the two. Dyamic feedback between human technology, economic production, welfare and ecosystem services.
Links to other models	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.
Scenarios used	MIMES/GUMBO scenarios.
Ease of use/accessibility	MIMES can be dowloaded at: http://www.uvm.edu/giee/mimes2/downloads.html requires simile software
Website	http://www.uvm.edu/giee/mimes2/
Comments/remarks	Global maps of ecosystem services from the MIMES model can be found at: http://www.gulfofmaine.org/EBMWorkGroups/docs/Roelof-Boumans-presentation-at-Oct2007-WorkGroup1-2-meeting.pdf
Model structure	**Figure 1.** *General outline of the MIMES model: The multiscale integrated Earth Systems model* 

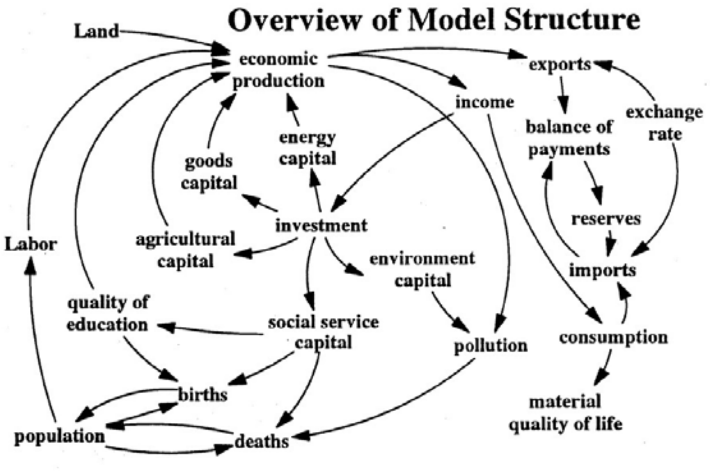
	

1.1.2 Scenario-building tools

Model name	**PoleStar**
Full model name	
Model type	scenario building and planing tools
Subtype	
Thematic coverage	Accounting model that combines exogenous economic, resource and environmental information on a global and regional level
Input (key drivers and pressures)	GDP and population development, more specified socio-economic drivers, environmental drivers (resources, pollution)
Output (key variables)	water and energy use, oil reserves left, CO_2 emissions, agricultural requirements, pollution, poverty
Geographical coverage and resolution	PoleStar is applied at community, national, regional and global level.
Temporal coverage and resolution	Base: 1996
Analytical technique	Meta-model
Model developers and/or owners	PoleStar was conceived in 1991 by Gordon Goodman, Director of Stockholm Environment Institute (SEI) and Paul Raskin, President of Tellus Institute and Director of SEI's Boston Center. Dr. Raskin has supervised the design and development of the software and its national, regional and local applications.
Model development history	1st version 1991
Target Group/users	Scenarios were quantified using the PoleStar software and used in numerous global studies including UNEP’s Global Environment Report series, the U.S. National Academy of Sciences’ Board on Sustainable Development report Our Common Journey, the World Water Vision and the OECD Environmental Outlook.
Calibration	unknown
Validation	unknown
Uncertainty	unknown

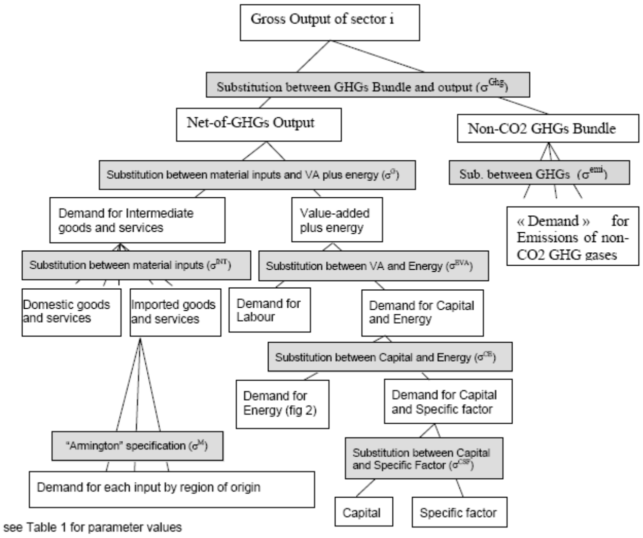
analysis	
Key reference	http://www.sei.se/mediamanager/documents/Publications/Future/polestar_v2000.pdf
Level of integration	
Links to other models	PoleStar has been used in the GEO-4 assessment, linked with AIM, IMAGE, WaterGAP and EwE/EcoOcean.
Scenarios used	GSG scenarios were quantified using PoleStar.
Ease of use/accessibility	Easy to use software tool for sustainability studies, both scenario-building tool and database of current indicators, flexible and user-friendly framework for building and assessing alternative development scenarios, user manual (http://www.seib.org/polestar)
Website	http://www.polestarproject.org/, http://www.seib.org/polestar
Model structure	

Model name	**Threshold 21**
Full model name	
Model type	Integrated scenario building and planing tools
Subtype	
Thematic coverage	national development, policies
Input (key drivers)	policy options, socio-economic factors, resources, technology
Output (key variables)	GDP
Geographical coverage and resolution	focussed on the national level, globally applicable, not spatially explicit
Temporal coverage and resolution	50-100 years
Analytical technique	dynamic simulation tool (uses Montecarlo optimization techniques)
Model developers and/or owners	Millennium Institute
Model development history	1st version 1994, programming software: Vensim
Target Group/users	First version was a country-level model for national decision makers focussed on national development. It is a user-friendly, systems thinking software program that permits users to organize, access and analyze necessary information for making prudent decisions on sustainable development strategy. It is the first computer analysis tool to integrate human, economic and environmental concerns into one model and is uniquely designed for national application. Threshold 21 (T21) is a dynamic simulation tool designed to support comprehensive, integrated long-term national development planning. T21 supports comparative analysis of different policy options, and helps users to identify the set of policies that tend to lead towards a desired goal. This insight into how different indicators of development interact with one another to produce an outcome deepens users understanding of development challenges.
Calibration	Country level data are used to calibrate the national models, if possible, otherwise international data sources (World Development Indicators, FAOSTAT, World Population

	Prospects, Energy Statistics and International Financial Statistics) are used.
Validation	T21 has been validated through a variety of tests, including effective simulation of historical periods. (http://www.threshold21.com/integrated_planning/tools/T21/validationstudy.html)
Uncertainty analysis	Not available
Key reference	http://www.systemdynamics.org/conferences/1995/proceed/papersvol1/barne022.pdf
Level of integration	High level of integration: 800 variables in different sector modules (demographics, agricultural production, health care, food and nutrition, international trade, national accounts, social services, energy, energy efficiency, goods production, education and environment) are dynamically linked. Individual sectors can modelled in a more elaborate or simple version, several countr-specific versions have been developed (e.g. Bangladesh, USA, Italy, China, Ghana)
Links to other models	unknown
Ease of use/accessibility	PC-based, user-friendly tool, open source, library for download, requires active role of user in the definition of the model structure.
Website	http://www.millenniuminstitute.net/integrated_planning/tools/T21/
Model structure	 Overview of Model Structure Figure 1: Overview of Threshold 21

1.1.3 Economic models

Model name	Env-Linkages
Full model name	
Model type	general economic model
Subtype	
Thematic coverage	macro-economy and climate (carbon emissions)
Input (key drivers)	socio-economic factors, policy instruments (carbon taxes, tradable emission permits, regulatory policies), labour, capital, energy, technology
Output (key variables)	GDP/capita, production of food (crops, livestock), household consumption
Geographical coverage and resolution	global, aggregated in 34 countries/regions
Temporal coverage and resolution	Base year: 2001, annual time steps
Analytical technique	general equilibrium model

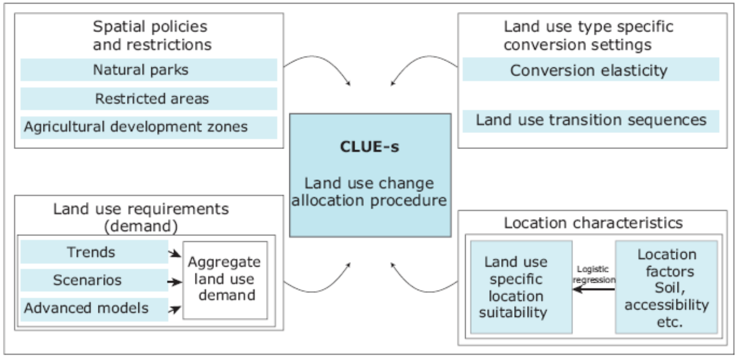
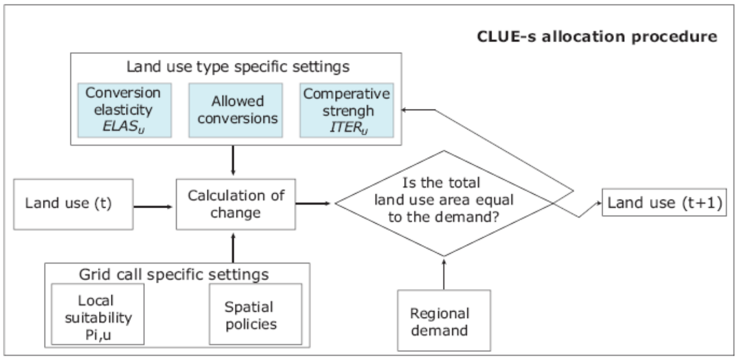
Model developers and/or owners	Environment Directorate of the OECD Secretariat
Model development history	Env-Linkages is based on the GREEN model ans was further developed into JOBS. Software: GAMS
Target Group/users	This model has been developed to assess the economic impact of abating Greenhouse Gases using several different economic instruments. It is used by the World Bank for research on global economics.
Calibration	unknown
Validation	Not available
Uncertainty analysis	Not available
Key reference	http://lysander.sourceoecd.org/vl=2821760/cl=15/nw=1/rpsv/workingpapers/18151973/wp_5kz7wcbr7l9n.htm, van Mensbrugghe (2005): LINKAGE technical reference document version 6.0
Level of integration	The different modules are well-integrated.
Links to other models	Within the OECD environmental outlook, Env-Linkages has been linked to IMAGE, TIMER and LEITAP (version of GTAP).
Ease of use/accessibility	Model is not available
Website	http://www.olis.oecd.org/olis/2008doc.nsf/linkto/eco-wkp(2008)61
Model structure	**Figure 1. Structure of production in ENV-Linkages**  Note: see Table 1 for parameter values

Model name	**GTAP**
Full model name	**Global Trade Analysis Project**
Model type	general economic model
Subtype	
Thematic coverage	Agro-economy
Input (key drivers)	production functions including capital, labour and land prices
Output (key variables)	calculates consumption and trade of agricultural products
Geographical coverage and resolution	Country-level, not spatially explicit
Temporal coverage and resolution	Base: 1995-2005
Analytical technique	general equilibrium model
Model developers and/or owners	Purdue University, together with collaborators worldwide
Model development	current version: GTAP 7, a dynamic version of GTAP is also available

history	(GDyn)
Target Group/users	The underlying GTAP database combined with the model is used by most individuals and agencies exploring the effects of different policies on aricultural trade.
Calibration	GTAP was calibrated against the GTAP-database.
Validation	Global Trade Analysis: Modeling and Applications, T.W. Hertel (ed.), Cambridge University Press, 1997, chapter 14; https://www.gtap.agecon.purdue.edu/resources/download/1813.pdf
Uncertainty analysis	https://www.gtap.agecon.purdue.edu/resources/download/39.pdf
Key reference	Global Trade Analysis: Modeling and Applications, T.W. Hertel (ed.), Cambridge University Press, 1997; https://www.gtap.agecon.purdue.edu/resources/download/1736.pdf
Level of integration	The different modules are well-integrated.
Links to other models	GTAP has been linked to IMAGE (van Meijl et al., 2006): IMAGE provides land-supply curves, yields and yield changes
Ease of use/accessibility	GTAP6.2a can be downloaded at: https://www.gtap.agecon.purdue.edu/models/current.asp
Website	https://www.gtap.agecon.purdue.edu/
Comments/remarks	Like all models, general equilibrium models have their limitations. By their very size, they may lack the detail of sector-specific models. Many of the parameters have not been estimated specifically for the model, and such models are difficult to validate in the traditional sense. The static framework limits treatments of savings, capital accumulation and stockholding, and the dynamic gains from trade cannot be calculated. The macro side is also rather limited, precluding some of the effects of changes in interest rates and exchange rate that may follow liberalisation. Nonetheless, for the purpose of analysing world trade issues such as agricultural liberalisation and regional integration, the GTAP model and database remains one of the best tools available. (Frandsen et al., 2000)
Model structure	not available

1.1.4 Land-use models

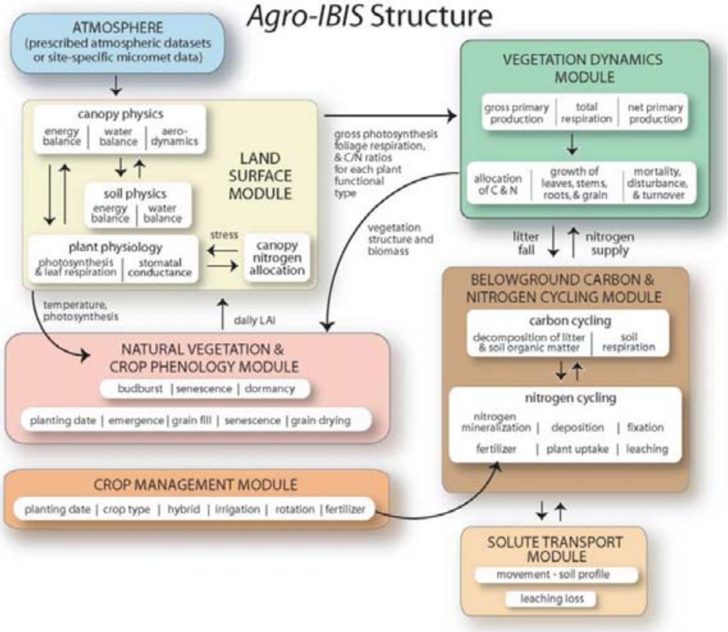
Model name	**CLUE**
Full model name	conversion of land use and its effects
Model type	land use model
Subtype	
Thematic coverage	land use, agriculture, urbanization
Input (key drivers and pressures)	land use maps, remote sensing of land cover or census data on land use, demographic change, land use requirements (based on trends, scenarios or macro-economic modelling), spatial policies, (assumed) location factors
Output (key variables)	land cover/ land use change
Geographical coverage and resolution	Europe (EU-27), also case studies in a.o. Costa Rica, Ecuador, Honduras, the Netherlands, China, Java, Phillippines, Malaysia, Vietnam, Kenya, USA, 1x1km, case studies between 30m and 32km
Temporal coverage and resolution	20-40 years, time steps: monthly to annual
Analytical technique	hybrid model (systems dynamic and empirical statistical, alternatively: cellular automata mechanism)
Model developers and/or owners	Department of Environmental sciences Landscape Centre Wageningen University.
Model development history	1st version: mid 1990s, ongoing
Target Group/users	The CLUE model has been used by a large number of both universities and governmental research institutes from all over the world. Case study versions for a variety of regions exists.
Calibration	Calibration is based on observed land use patterns and, if possible, based on

	historic data. For some case studies calibration is helped by interviews with land managers.
Validation	Validation is based on historic land use changes for various case studies. Pontius, R.G. et al., 2007. Comparing the input, output, and validation maps for several models of land change. Annals of Regional Science. In press.
Uncertainty analysis	Has been performed for some parameters in a number of case studies including the use of monte-carlo techniques.
Key reference	A wide range of scientific publications (full list at www.cluemodel.nl): e.g. Verburg, P.H., Soepboer, W., Veldkamp, A. Limpiada, R. Espaldon, V., Sharifah Mastura S.A. 2002. Modeling the Spatial Dynamics of Regional Land Use: the CLUE-S Model. Environmental Management 30(3): 391–405.
Level of integration	High level of integration among land use sectors and spatial-temporal dynamics including path-dependence and spatial interactions. Feedbacks with environmental indicators can be addressed by tight coupling of the model with indicator models. Regional biophysical module, regional land use objectives module and local land use allocation module. Interactions between neighbouring grid-cells.
Links to other models	In many projects, including EURURALIS and SENSOR the land requirements are based on macro-economic modelling results from models such as GTAP, NEMESIS or IMAGE.
Ease of use/accessibility	Full version with technical support of the model is only available for collaborative projects. Others may use the model signing a memorandum of understanding excluding the commercial use of the model and requirement of proper referencing.
Website	www.cluemodel.nl
Comments/remarks	Description taken from EEA, 2008
Model structure	 

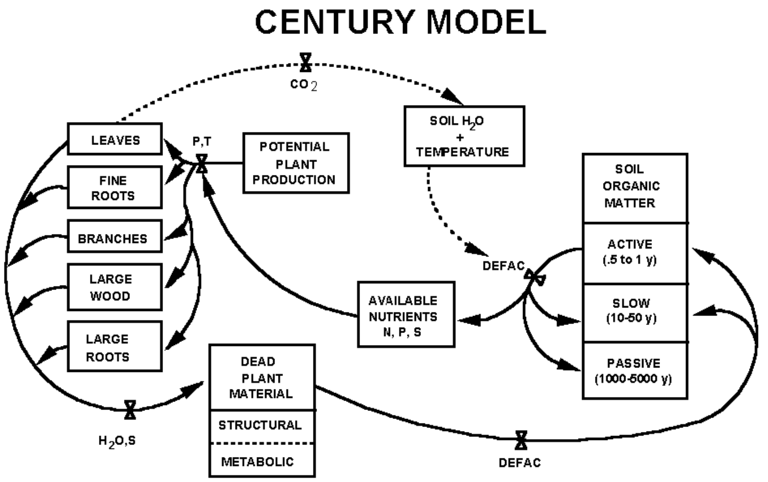
1.1.5 Biogeochemical models

Model name	**Agro-IBIS**
Full model name	

Model type	biogeochemistry model
Subtype	agriculture
Thematic coverage	Natural terrestrial vegetation plus agriculture
Input (key drivers and pressures)	climate, soil texture, farm management (fertilization, irrigation)
Output (key variables)	Vegetation cover, crop yield, LAI, N mimeralization, CO_2 flux, N leaching, water cycling, energy balance (crops: maize, soybean, winter and spring wheat)
Geographical coverage and resolution	currently only run for North America, global application planned, 0.5° grid, model implementation also desired on field and precision agriculture scale (100m^2 respectively 25m^2).
Temporal coverage and resolution	time steps for calculations: hourly; for output: annual
Analytical technique	Dynamic systems model (process-based model)
Model developers and/or owners	SAGE- Center for Sustainability and the Global Environment, University of Wisconsin-Madison
Model development history	IBIS is a dynamic global vegetation model (DGVM). The coupled crop-climate model also examines the impact that agricultural land use has directly on the climate system through changes in biogeochemical cycling and the associated changes to land surface properties. Codes are written in FORTRAN.
Target Group/users	Primarily a research model, Agro-IBIS has been used extensively in the North American Carbon Program (NACP).
Calibration	Agricultural module was calibrated to the maize yield of the Upper Mississippi basin during the late 1990s (Kucharik & Brye, 2003).
Validation	Kucharik & Brye, 2003: all processes were modelled with reasonable accurancy (within 20% error), except for soil N; Kucharik, 2003 (Earth Interactions 7): simulation of US maize yields and comparison with national yield databas for regional scale (1958-1994); slight overestimation of high yields and underestimation of low yields, Kucharik & Twine (2007): comparision with AmeriFlux site at the Mead, Nebraska, Twine & Kucharik (2008): comparison of LAI and absorped photosynthetically active ratiation with remote-sensing data; LAI of conifers was underestimated and LAI of grasslands overestimated.
Uncertainty analysis	not available
Key reference	Donner & Kucharik, 2003, Kucharik & Brye, 2003; for IBIS: Foley et al., 1996 and Kuchrik et al., 2000
Level of integration	feedbacks between vegetation, crop and soil module
Links to other models	Agro-IBIS has not been linked to other models.
Ease of use/accessibility	IBIS can be downloaded, Agro-IBIS is not available
Website	none

Model structure	

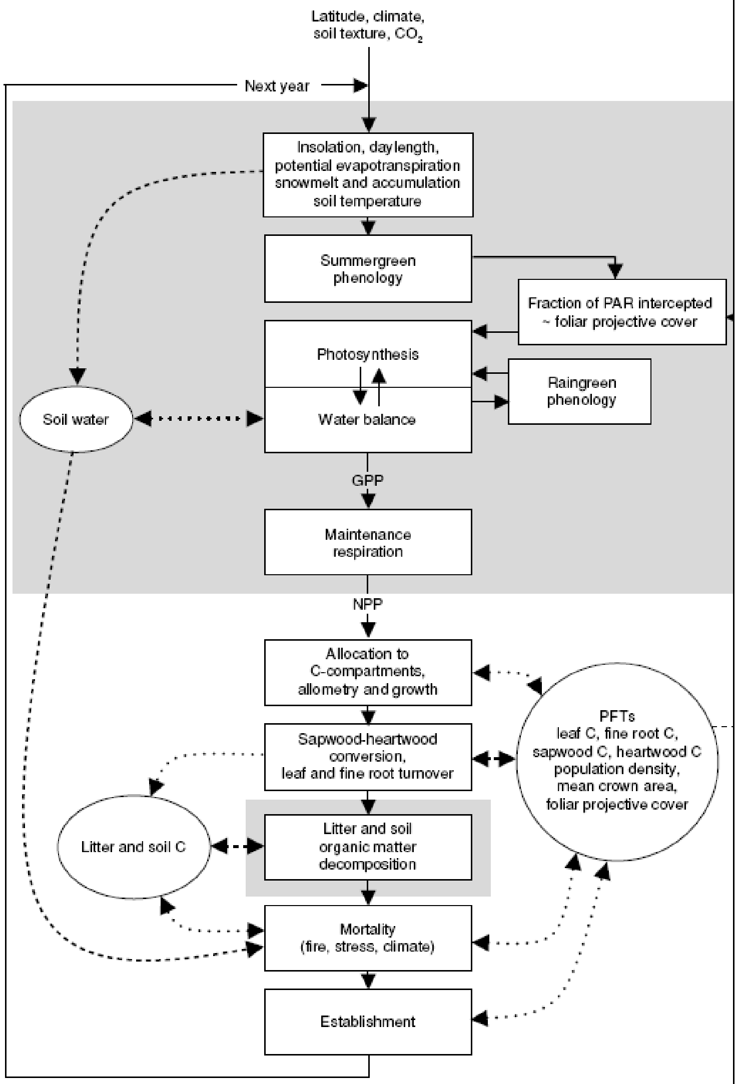
Model name	**CENTURY**
Full model name	
Model type	biogeochemistry models
Subtype	Agriculture, grasslands, forests
Thematic coverage	carbon, nutrient, and water dynamics
Input (key drivers and pressures)	climate, site conditions, land use/management (including fire, grazing, fertilization, irrigation, crop rotations, tillage practices)
Output (key variables)	soil water, decomposition, SOC, grass, tree and crop production, CO_2 flux, C, N, P and S balance
Geographical coverage and resolution	not spatially explicit, aggegation on the basis of land management (submodules: cropland and grassland, forest, savanna)
Temporal coverage and resolution	CENTURY simulates C, N, P, and S dynamics through an annual cycle over time scales of centuries and millennia. time steps: monthly (there is also a version with daily time steps: DayCent)
Analytical technique	equilibrium model
Model developers and/or owners	Colorado State University
Model development history	1st version: 1987, current version: CENTURY 5 software: the code has been rewritten in C++ for version 5, and modified to use platform-independent configuration and output files
Target Group/users	CENTURY has been used extensively for global change research. The model has been executed in over 22 different areas in the world. It can be used to assess the impacts of regional climate change on a variety of important grassland ecosystems.
Calibration	http://www.iemss.org/iemss2006/papers/w2/333_Liu_2.pdf
Validation	Parton et al., 1993, Gilmanov et al., 1997, Kamoni et al., 2007
Uncertainty analysis	Not available
Key reference	Parton et al., 1988, Parton et al., 1994, a complete list of references is given at http://www.nrel.colostate.edu/projects/century5/
Level of integration	soil, water, grassland and forest sub-models, interactions via C and N cycle, shading and competition
Links to other models	CENTURY has been coupled to vegetation growth models (Laurenroth et al.,

	1993) such as STEPPE.
Ease of use/accessibility	Century 5 is a research version of the model, it can be obtained upon request, Century 4 is freely available at: http://www.nrel.colostate.edu/projects/century/
Website	http://www.nrel.colostate.edu/projects/century5/
Comments/remarks	CENTURY was especially developed to deal with a wide range of cropping system rotations and tillage practices for system analysis of the effects of management and global change on productivity and sustainability of agroecosystems.
Model structure	

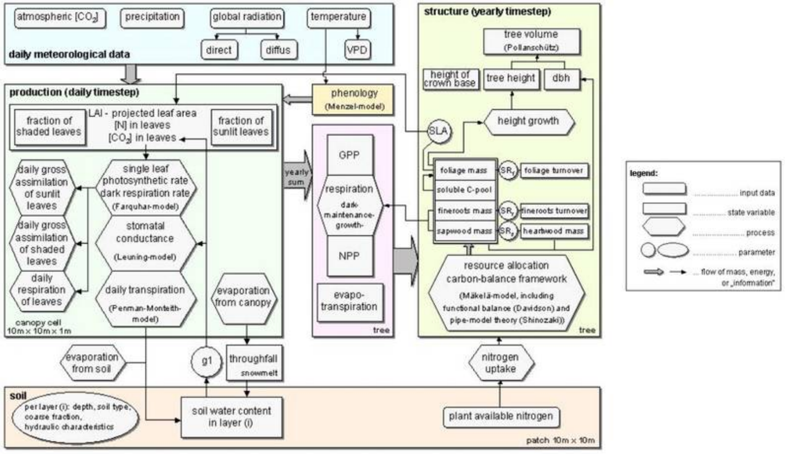
Model name	**IBIS**
Full model name	integrated biosphere simulator model
Model type	biogeochemistry model
Subtype	Dynamic global vegetation model
Thematic coverage	terrestrial ecosystems (vegetation with energy, water and carbon exchange, nutrient cycling)
Input (key drivers and pressures)	climate, soil texture
Output (key variables)	energy, water and CO_2 exchange between plants and atmosphere, plant growth and competition, nutrient cycling and soil physics
Geographical coverage and resolution	Global, 0.5 - 4°
Temporal coverage and resolution	time steps: day/month, aggregation: annual
Analytical technique	Dynamic system model (process-based)
Model developers and/or owners	SAGE- Center for Sustainability and the Global Environment, University of Wisconsin-Madison
Model development history	1st version described: 1996, current version: IBIS 2.6 (2008). IBIS was designed to explicitly link land surface and hydrological processes, terrestrial biogeochemical cycles, and vegetation dynamics within a single physically consistent framework
Target Group/users	IBIS was developed as a first step toward gaining an improved understanding of global biospheric processes and studying their potential response to human activity.
Calibration	IBIS has been calibrated for several to field data (energy and carbon flux, Delire & Foley, 1999) and biome averages (e.g. NPP, SOC, LAI, Kucharik et al., 2000).
Validation	Kucharik et al., 2000: Comparision of model results with historical data from 1965 to 1994, for several ecosystems all over the globe

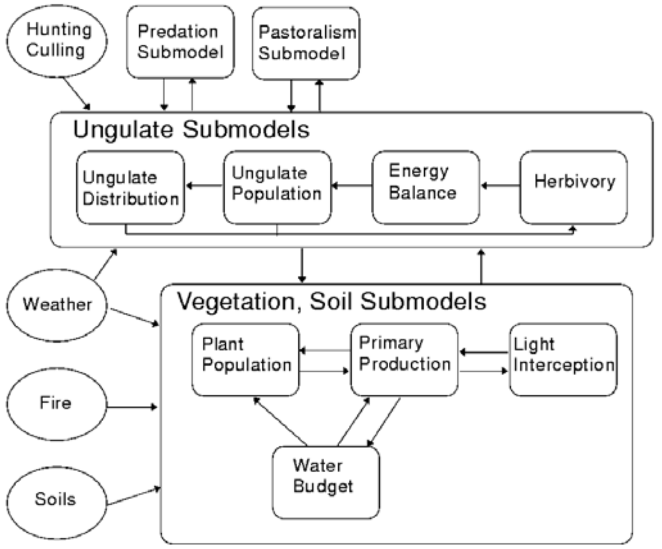
Uncertainty analysis	unknown
Key reference	Kucharik et al., 2000, Foley et al., 1996
Level of integration	IBIS was constructed to link explicitly land surface and hydrological processes, terrestrial biogeochemical cycles, and vegetation dynamics within a single, physically consistent framework. An agricultural submodule has been included: Agro-IBIS
Links to other models	unknown
Ease of use/accessibility	IBIS 2.6 and input files can be downloaded inclusive user guide at http://www.sage.wisc.edu/download/IBIS/ibis.html but no help is provided, listserve and user discussions exist, http://daac.ornl.gov/MODELS/guides/IBIS_Guide.html
Website	http://www.sage.wisc.edu/download/IBIS/ibis.html
Model structure	Not available

Model name	**LPJmL**
Full model name	Lund-Potsdam-Jena dynamic global vegetation model including managed land
Model type	biogeochemistry models
Subtype	Dynamic general vegetation model
Thematic coverage	Dynamic global vegetation model, including agriculture
Input (key drivers and pressures)	monthly climate, soil type and atmospheric CO_2 concentration, land management, land use change
Output (key variables)	vegetation cover (fraction of different plant functional types per grid cell), CO_2 exchange, seasonal water balance (runoff volumes), annual NPP, crop production
Geographical coverage and resolution	global, 10’ or 0.5º grid cells
Temporal coverage and resolution	time steps: day/month
Analytical technique	Dynamic systems model
Model developers and/or owners	Potsdam Institute for Climate Impact Research. The LPJ model was originally developed by a consortium led by I. Colin Prentice (then Max-Planck-Institute for Biogeochemistry, Jena; now at Bristol University), Wolfgang Cramer (PIK), and Martin Sykes (Lund University). The name derives from the three locations Lund-Potsdam-Jena but is no longer to be interpreted that way. Managed by a small steering committee, the consortium conducted regular meetings and consultations with key users of LPJ.
Model development history	Originally a model to predict natural vegetation cover (based on the BIOME family), there is also a version including an agriculture module (LPJmL (managed lands)); current version LPJ3 (with and without managed lands). LPJ was originally written in FORTRAN, for LPJ version 2 C++ has been used, the current version LPJ 3 was programmed in C.
Target Group/users	LPJ has been used in numerous studies on responses and feedbacks of the biosphere in the Earth System (e.g., Brovkin et al., 2004; Lucht et al., 2002; Schaphoff et al., 2006; Sitch et al., 2005).
Calibration	NPP, biomass, NEP and seasonal carbon cycle have been calibrated against station measurements.
Validation	LPJ has been validated from the stand to the global scale (Hickler et al., 2004) Cramer et al., 2001: Comparison of 6 global vegetation models, Bondeau et al., 2007: comparison with historical data
Uncertainty analysis	Jung et al., 2007a, Jung et al., 2007b, Wolf et al., 2008 (for LPJ-Guess)
Key references	Sitch et al., 2003, Bondeau et al., 2007
Level of integration	The different modules are well-integrated.
Links to other models	LPJ has been included in the ATEAM vulnerability assessment tool. Currently work is ongoing to link LPJ to IMAGE.
Ease of use/accessibility	open and unrestricted access, LPJ can be downloaded (upon request) at http://www.pik-potsdam.de/research/cooperations/lpjweb/lpj-lpjml-versions

Website	http://www.pik-potsdam.de/research/cooperations/lpjweb
Comments/remarks	Decline in stand productivity in mature forests is not simulated as age structure is not modelled. Nitrogen cycling and uptake is not modelled, nitrogen limitation is therefore not included in vegetation growth.
Model structure	

Model name	**PICUS**
Full model name	
Model type	biogeochemistry models
Subtype	forestry
Thematic coverage	stand-level foresty model (dynamic succession) (managed plantations and natural forest, multi- and single species)
Input (key drivers and pressures)	climate, forestry management, disturbances, N deposition
Output (key variables)	timber yield, vegetation composition, carbon, nitrogen cycle
Geographical coverage and	temperate forests, Europe, 100m^2 patches

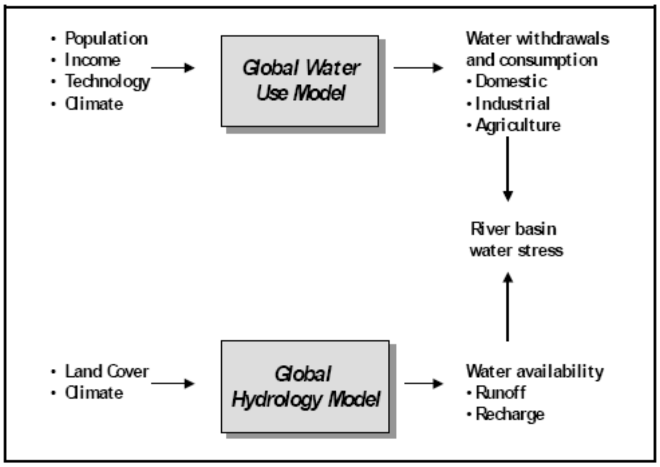
resolution	
Temporal coverage and resolution	monthly time steps with annual integration
Analytical technique	Dynamic systems model (process-based); individual tree-based model
Model developers and/or owners	University of Natural Resources and Apllied Life Sciences, Vienna
Model development history	published: 2001, current version: PICUS 2.0. PICUS 1.2 was a gap model to capture competition and canopy structre, PICUS 1.3 included an physiological growth function. PICUS 1.4 included soil C and N cycling.
Target Group/users	PICUS was originally developed as a decision support tool for forest managers. It simulates forest succession in the complex topography of the Eastern Alps in central Europe. The original gap-model was complemented with the 3-PG model in version 1.3. Current version PICUS v1.4
Calibration	PICUS was calibrated against data from national forest inventory.
Validation	Testing against independent long-term growth and yield data revealed good correspondence between observed and predicted values of volume production and stand structure (Seidl et al., 2005, Badeck et al., 2001)
Uncertainty analysis	Not available
Key reference	Lexer & Honniger, 2001, Seidl et al., 2005, Seidl et al., 2007, Seidl et al., 2008
Level of integration	The different modules are well-integrated.
Links to other models	PICUS has been used together with EURO-FOR, OSCAR (regional models), ForAG/FASOM (global), AROPAj (regional agriculture) and EFEM-DNDC (agriculture at farm level) in the ENFA/INSEA assessment. It has been combined with the wood products model (WPM) to evaluate carbon storage in wood products (Seidl et al., 2007).
Ease of use/accessibility	Model is not available
Website	http://wwwt3.boku.ac.at/picus.html?&L=1
Comments/remarks	The hybridization of PICUS with 3-PG in version 1.3 aims at combining the abilities of gap models with regard to interand intra-specific competition, multi-species and multi-layered stand structure and general applicability with the benefits of a widely applied, robust stand-level estimate of forest production based on the concept of radiation use efficiency.
Model structure	

Model name	**SAVANNA**
Full model name	
Model type	biogeochemistry models
Subtype	biome model
Thematic coverage	vegetation, animal population model and management in grassland, shrubland, savanna and forested ecosystems
Input (key drivers and pressures)	climate, vegetation type, topology, human management (stocking densities), fire
Output (key variables)	plant and animal distribution (for functional groups), water and nutrient cycling, livestock production, sustainability of systems, thresholds, habitat suitability
Geographical coverage and resolution	regional, resolution depending on input data and studied ecosystem (100-1000 grid cells)
Temporal coverage and resolution	time period: depending on climate input, time horizon: 5-50 years, time steps: weekly
Analytical technique	Process-based model (dynamic systems model)
Model developers and/or owners	Mike Coughenour, National Resource Ecology Laboratory, Colorado State University
Model development history	first published 1985, model has modified for various purposes. Originally developed for pastoralism in African savannas it has been applied to other ecosystems (Mongolian steppe, North American prairie, Rocky Mountain National Park) as well.
Target Group/users	Originally developed for African savannas (pastoralism), but has been applied extensively to North American national parks as ecosystem management tool. Includes forests and shrublands, too.
Calibration	Model was calibrated to plant growth data.
Validation	SAVANNA has been validated by comparing predicted with actual vegetation cover and NPP (e.g. Christensen et al., 2003)
Uncertainty analysis	Not available
Key reference	Coughenour & Chen, 1997, Ludwig et al., 2001
Level of integration	High level of integration of plant and animal stystems with abiotic (water) and management factors.
Links to other models	Linked to PHEWS to model Household economics.
Ease of use/accessibility	available at http://www.nrel.colostate.edu/ftp/coughenour/pubs_lock/index.php?Directory=Manual_1993
Website	http://www.nrel.colostate.edu/projects/savanna/
Model structure	 Figure 1

1.1.6 Hydrological models

Model name	**(E-) SWAT**
Full model name	(Enhanced) Soil and Water Assessment Tool
Model type	Hydrological models
Subtype	
Thematic coverage	physically based, semi-distributed, continuous time, watershed model
Input (key drivers and pressures)	land use (including details on management), topography, soil and climate
Output (key variables)	runoff, sediment yield, deep aquifier recharge
Geographical coverage and resolution	calculations are done on the scale of sub-watersheds
Temporal coverage and resolution	daily time steps
Analytical technique	empirical-statistical
Model developers and/or owners	public domain model, actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA
Model development history	1st version: 1998, current version SWAT 2005, see also: http://www.card.iastate.edu/environment/items/asabe_swat.pdf
Target Group/users	SWAT was developed to assess the impact of land management and climate patterns on water supply and nonpoint source pollution in large, complex watersheds with varying soil, landcover, and management conditions over long periods.
Calibration	SWAT has beeen calibrated for application to many different watersheds, e.g. http://www.mssanz.org.au/MODSIM07/papers/49_s11/InfluenceOfScales11_Heathman_.pdf; http://www.card.iastate.edu/publications/DBS/PDFFiles/05wp396.pdf
Validation	SWAT has been validated for many single watersheds, e.g. http://www.card.iastate.edu/publications/DBS/PDFFiles/05wp396.pdf
Uncertainty analysis	Yang et al., 2008
Key reference	http://www.card.iastate.edu/environment/items/asabe_swat.pdf
Level of integration	The different modules are well-integrated.
Links to other models	unknown
Ease of use/accessibility	SWAT can be downloaded at: http://www.brc.tamus.edu/swat/
Website	http://www.brc.tamus.edu/swat/
Model structure	Not available

Model name	**WaterGAP**
Full model name	Water – Global Assessment and Prognosis
Model type	hydrological model
Subtype	
Thematic coverage	Water availability, water use, water quality (industry, agriculture and domestic)
Input (key drivers and pressures)	climate, land cover (livestock density, area irrigated), population size and electricity production
Output (key variables)	Water withdawals and water availability (discharge, annual renewable water resources)
Geographical coverage and resolution	global, country, river basin (1162 basins included), grid cells 0.5° by 0.5°

Temporal coverage and resolution	Base: 1995, Climate base 1961-1990, daily time steps for water balance, annual time steps for industrial and livestock water use, results for 1995, 2025 and 2075
Analytical technique	Empirical-statistical
Model developers and/or owners	Developed by the Centre for Environmental Systems Research of the University of Kassel, Germany, in cooperation with the National Institute of Public Health and the Environment of The Netherlands (RIVM). Development since 2003 by the Universities of Kassel and Frankfurt.
Model development history	1st version 1996, current version: WaterGAP 2
Target Group/users	Developed as a tool for global analysis of water resources. Used in various global and continental resource assessment (World in Transition, World Water Vision, World Water Developement Report (UNSECO), MA)
Calibration	Hydrological model was calibrated to 30 years data from 724 discharge measurement stations; where data are available, socio-economic model parameters are calibrated for countries.
Validation	For validation, the predicted annual discharge values were compared to measured values at the 724 calibration stations and with data from other basins (Alcamo et al., 2003a). Validation for socio-economic estimates was done as well (Döll & Siebert, 2002).
Uncertainty analysis	a first estimate of the geographical variation in uncertainty of calculations is made, based on the "goodness of-fit" of the model to observed historical data
Key reference	www.usf.uni-kassel.de/usf/forschung/projekte/watergap.en.htm Alcamo et al. (2003); Alcamo et al., (2003b)
Level of integration	feedbacks between water cycle and water use submodel
Links to other models	WaterGAP has been used in several assessments (OECD, GEO, MA) in combination with IMAGE, IMPACT and EcoSim and AIM. Based on WaterGAP, a global model of terrestrial nitrogen (WaterGAP-N) has been developed.
Ease of use/accessibility	Model is not available for download.
Website	http://www.geo.uni-frankfurt.de/ipg/ag/dl/forschung/WaterGAP/index.html
Model structure	 **Fig. 1** Block diagram of the WaterGAP model.

Model name	**WBM (+)**
Full model name	Water Balance Model
Model type	Hydrological models
Subtype	
Thematic coverage	water cycle
Input (key drivers	climate and surface cover, population, irrigated area

and pressures)	
Output (key variables)	sustainable water use: water use/withdrawl (agriculture, domestic, industry) versus water discharge
Geographical coverage and resolution	0.5° by 0.5° grid
Temporal coverage and resolution	daily time steps, output on annual basis
Analytical technique	empirical-statistical
Model developers and/or owners	M. Vörösmarty, Water System Analysis Group, Universityof New Hampshire
Model development history	unknown
Target Group/users	unknown
Calibration	unknown
Validation	unknown
Uncertainty analysis	unknown
Key reference	Vörösmarty et al., 1989, Vörösmarty et al., 2000
Level of integration	unknown
Links to other models	unknown
Ease of use/accessibility	A detailed description of the model is available at: http://www.asb.cgiar.org/BNPP/phase2/ifpri/description_ water_ balance_model_10jul2003.doc
Website	Not available
Model structure	Not available

1.1.7 Biodiversity models

Model name	**BII**
Full model name	**Biodiversity intactness index**
Model type	Biodiversity model
Subtype	Indicator model
Thematic coverage	biodiversity loss due to land use change
Input (key drivers and pressures)	land use (also needed: reference conditions for biodiversity) land use types: protected, moderately used, degraded, cultivated, plantation and urban
Output (key variables)	relative measure of biodiversity intactness (percentage of original population) BII is a richness-and-area weighted average of the population impact of a set of land use activities, on a given groups of organisms, in a given area.
Geographical coverage and resolution	Regional (Southern Africa), scale of aggregation: 10^4 to 10^6 km^2
Temporal coverage and resolution	dependent on input (land use maps/predictions)
Analytical technique	empirical-statistical: expert opinion
Model developers and/or owners	The biodiversity intactness index was first developed by R. J. Scholes and R. Biggs for the Southern African Millennium Ecosystem Assessment (case study for MA).
Model development history	Different approaches have been proposed by several authors (including species occurence versus abundance)
Target Group/users	The BBI is an assessment tool designed to give an indication of current state and past changes in biodiversity. 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.
Calibration	The BBI has been calibrated on data for Southern Africa.

Validation	Valuation in biodiversity monitoring programmes: Lamb et al., 2009
Uncertainty analysis	Hui et al., 2008: biodiversity intactness variance as formal measure of uncertainty (case study: South Africa)
Key reference	Scholes & Biggs, 2004, Buckland et al., 2005, Nielsen et al., 2007
Level of integration	Not applicable (only land use as driver)
Links to other models	Not available (potential links to land use models)
Ease of use/accessibility	Calculation algorithm is given in Scholes & Biggs, 2004. Species richness information is needed for calculation.
Website	Not available
Model structure	The BII is calculated as: $BII = (\sum_i \sum_j \sum_k R_{ij} A_{jk} I_{ijk}) / (\sum_i \sum_j \sum_k R_{ij} A_{jk})$ where R_{ij} = richness (number of species) of taxon i in ecosystem j, and A_{jk} = area of land use k in ecosystem j

Model name	**EUROMOVE**
Full model name	
Model type	Biodiversity model
Subtype	Bioclimatic envelope model
Thematic coverage	biodiversity in relation to climate change
Input (key drivers and pressures)	climate change, current plant distributions
Output (key variables)	changes in plant species number and distribution (stable, increase, decrease)
Geographical coverage and resolution	Europe, $2500km^2$ grid cells (dependent on input data)
Temporal coverage and resolution	baseline: 1990/1995, results reported for 2025, 2050 and 2100, annual time steps
Analytical technique	empirical bioclimatic envelope modelling based on realized niches, species-based logistic regression model by which occurrence probabilities can be calculated for almost 1400 European vascular plant species
Model developers and/or owners	Netherlands Environmental Assessment Agency
Model development history	published: 2002
Target Group/users	Used to support climate change impact research at European level; including applications for the European Environment Agency, evaluation of policies to halt biodiversity loss
Calibration	Calibrated on 1990 data – all multiple logistic regression analyses resulted in statistically significant models (α = 0.01). On average, the deviance explained (D) was 42%, indicating a relatively high predictive power.
Validation	Not available
Uncertainty analysis	Not available
Key reference	Bakkenes et al., 2002, Bakkenes et al., 2006
Level of integration	Not applicable
Links to other models	EUROMOVE uses climate data from IMAGE model.
Ease of use/accessibility	Model not available online.
Website	Not available
Comments/remarks	Description copied from EEA, 2008
Model structure	Not available

Model name	**GARP-based species distribution models**
Full model name	GARP=Genetic Algorithm for Rule-set Production
Model type	Biodiversity model
Subtype	Bioclimatic envelope model
Thematic coverage	biodiversity in relation to climate change

Input (key drivers and pressures)	climate change, also required: plant species distribution
Output (key variables)	number of species, species distribution maps
Geographical coverage and resolution	GIS-based, spatial explicit approach, local/regional, depending on input (species presence data)
Temporal coverage and resolution	Depending on climate change input
Analytical technique	ecological niche modelling, based on genetic algorithms
Model developers and/or owners	D. Stockwell and A. Boston (University of California, San Diego, Environmental Resources Information Network (ERIN))
Model development history	The GARP was first implemented at the Environmental Resources Information Network (ERIN) (Boston and Stockwell 1994).
Target Group/users	
Calibration	Model is calibrated based on presence data of species in relation to environmental variables
Validation	Stockman et al. (2006) tested the performance of GARP to predict spider distribution in California based on a limited number of museum specimens. Conclusion: simple bioclimatic envelope models perfomed better than GARP.
Uncertainty analysis	unknown
Key reference	Boston & Stockwell, 1995, Stockwell, 2006
Level of integration	Not applicable
Links to other models	Not applicable
Ease of use/accessibility	methodology is available online: www.lifemapper.org/desktopgarp
Website	Not available
Comments/remarks	The GARP models are a model family, not a single model with different equations.
Model structure	Not available

Model name	**GLOBIO**
Full model name	Global Methodology for Mapping Human Impacts on the Biosphere
Model type	Biodiversity model
Subtype	Indicator model
Thematic coverage	effects of climate change, land use change, infrastructure development and nitrogen deposition on biodiversity
Input (key drivers and pressures)	Land cover, land use and land use intensity, infrastructure, atmospheric N deposition, climate (precipitation and temperature)
Output (key variables)	Mean Species Abundance (MSA)
Geographical coverage and resolution	global, (0.5º by 0.5º for climatic data, 1km by 1km for land use data)
Temporal coverage and resolution	Depending on input data
Analytical technique	empirical-statistical model: Dose-response relationships between fragmentation, infrastructural development
Model developers and/or owners	UNEP-DEWA, UNEP-WCMC, UNEP-GRID-Arendal, Netherlands Environmental Assessment Agency
Model development history	1st version: 2001, current version GLOBIO3
Target Group/users	GLOBIO is aimed at providing information for understanding ongoing trends and depicting future trends in regional and global assessments. GLOBIO3 is a quantitative model used in the assessment of policy options for reducing global biodiversity loss. The model is used in global studies, such as the OECD Environmental Outlook, GEO4 and COPI/TEEB.
Calibration	Not applicable

Validation	Not available
Uncertainty analysis	Not available
Key reference	Alkemade et al. (2009)
Level of integration	Different pressures (land use change and fragementation, pollution) are well-integrated, double-counting is avoided (pollution affects biodiversity only in natural areas while it is included in land use effects for managed land).
Links to other models	Uses land use and N emission output from IMAGE and is thereby linked to land use/land cover and economics
Ease of use/accessibility	not available, however description of the parameters used can be found in Alkemade et al. (in press) and Alkemade et al. (2006)
Website	http://www.globio.info/
Model structure	Not available

Model name	**MIRABEL**
Full model name	Models for Integrated Review and Assessment of Biodiversity in European Landscapes
Model type	Biodiversity model
Subtype	Indicator model
Thematic coverage	biodiversity
Input (key drivers and pressures)	pollution (eutrophication, nitrogen deposition, acidification, climate change) and land use (urbanization trasnport, farming intensification, drainage irrigation, land abandonment, afforestation, habitat fragmentation)
Output (key variables)	trends in pressures, status of threatened habitats
Geographical coverage and resolution	28 European countries, 13 ecological regions, using CORINE land cover map
Temporal coverage and resolution	Impact forecasts for 2010 and 2050 (climate)
Analytical technique	empirical-statistical model: based on expert opinion
Model developers and/or owners	Centre for Ecology and Hydrology Merlewood Research Station, UK,
Model development history	Model was developed for the European Environment Agency (EEA)
Target Group/users	MIRABEL was initially developed in response to a requirement to predict habitat change in the context of a 1998 assessment of the state of the environment in Europe.
Calibration	Not available
Validation	Not available
Uncertainty analysis	Not available
Key reference	Petit et al., 2001
Level of integration	unknown (effects based on expert opinion)
Links to other models	uses input from CARMEN, RAINS, IMAGE, EUTREND and LARCH for pressures/drivers
Ease of use/accessibility	Model is not available
Website	Not available
Model structure	Not available

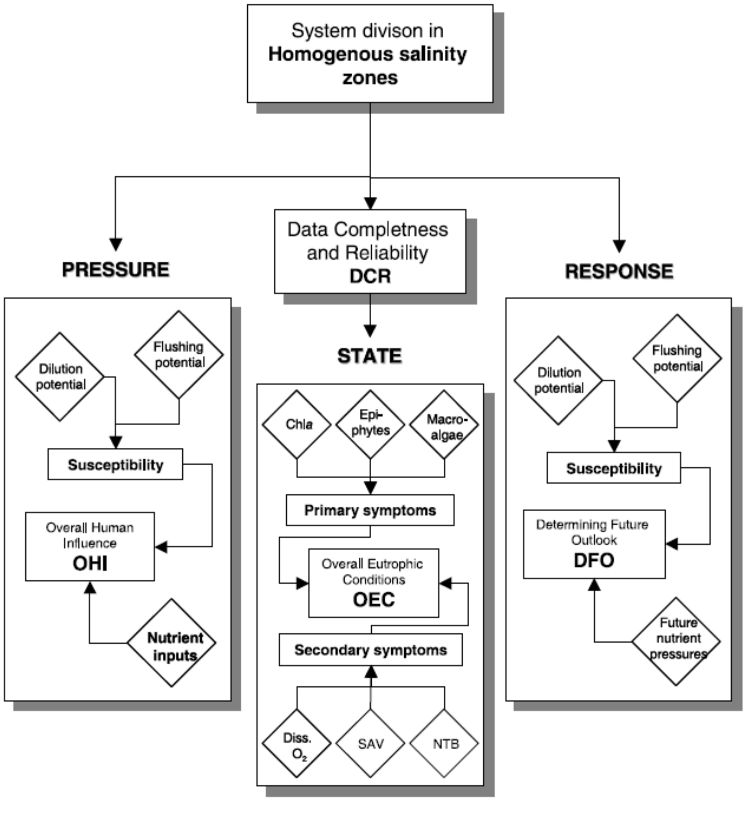
Model name	**SAR**
Full model name	Species area relationship
Model type	Biodiversity model
Subtype	Indicator model
Thematic coverage	Biodiversity loss due to habitat loss
Input (key drivers and pressures)	habitat loss (climate change via IMAGE, van Vuuren et al., 2006), N deposition

Output (key variables)	number of species
Geographical coverage and resolution	global, calculated for different biogeographical units (biomes, ecoregions), not spatially explicit
Temporal coverage and resolution	For the MA projections were done until 2050.
Analytical technique	empirical-statistical (based on species area relationship $S = cA^z$), where S= number of species, A= area, z and = constants
Model developers and/or owners	Relationship is based on ecological theory discussed by for example Arrhenius, 1921, McArthur & Wilson, 1967 and Rosenzweig, 1995.
Model development history	The species area relationship was applied as an indicator of biodiversity in the Millennium Ecosystem Assessment (MA, 2005a).
Target Group/users	The SAR has not been applied for large-scale biodiversity assessments after the MA.
Calibration	Not available
Validation	Not available
Uncertainty analysis	uncertainty analysis was done by van Vuuren et al., 2006
Key reference	Pimm et al., 1995, Pimm et al., 2006, van Vuuren et al, 2006
Level of integration	Next to the species-area relationship, in the MA methodology also nitrogen deposition was incorporated as pressure on biodiversity (MA, 2005e).
Links to other models	During the MA the changes in the species area relationship was based on land use changes calcualted by the IMAGE model.
Ease of use/accessibility	Equations have been published and calculations can easily by done.
Website	none
Model structure	Not available

1.1.8 Ocean Models

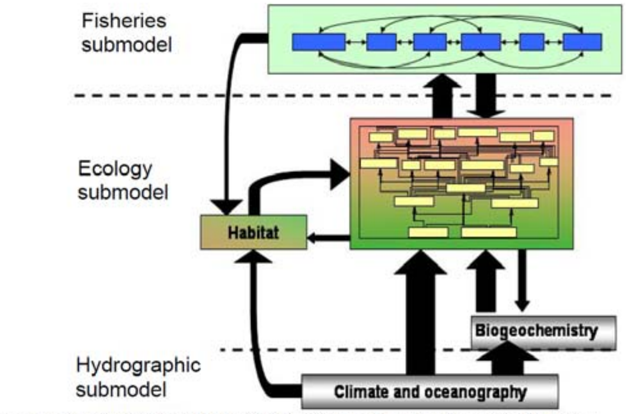
Model name	**ASSETS**
Full model name	Assessment of Estuarine Trophic Status
Model type	Biogeochemistry models
Subtype	Hydrology
Thematic coverage	Water quality, Trophic status, Human influence
Input (key drivers and pressures)	Comparison of anthropogenic land-based and oceanic nutrient loading with natural background concentrations, estimates of susceptibility; Nitrogen and Phosphorous levels, Chlorophyll a and macroalgae growth, algal dominance changes, loss of SAV, dissolved oxygen, harmful algae coverage; susceptibility, capacity of the system to dilute and/or flush nutrients, predictions of nutrient loading based on expected population increase, planned management actions, and expected change sin watershed uses.
Output (key variables)	Indicator of Overall Human Influence on the system; An assessment of the current state of the system; and the future Response of the system under different scenarios.
Geographical coverage and resolution	Estuarine/Watershed level. Currently, there are 157 assessed estuarine systems in ASSETS primarily based in the U.S. But there are a number of international records. Resolution of output is based the the bathymetry grid used, however the details are not specified in the peer-reviewed methodology.
Temporal coverage and resolution	Provides an assessment of current state (sets reference conditions) and forecasts future outlook based on the susceptibilty of the system and one of three options: 1) Future nutrient pressures decrease; Future nutrient pressures are unchanged; and Future nutrient pressures are increase. Temporal resolution is not specifically defined and is referred to as 'Future Outlook' based on data such as demographic projections.
Analytical technique	A screening model that uses a Pressure-State-Response framework
Model developers and/or owners	ASSETS was devloped from the National Estuarine Eutrophication Assessment (NEEA) methodology originally developed by a team of people from NOAA, other federal and state agencies, private organisations, colleges and universities. ASSETS was

	developed by a team of NOAA scientists and researchers from the EU, working at the Institute for Marine Research (IMAR).
Model development history	ASSETS was developed from the National Estuarine Eutrophication Assessment (NEEA) that was lauched in 1990. 1990 - 1998: Data and information of 138 estuaries and coastal waters was collected from approximately 400 scientists using an expert knowledge engineering approach. Five regional reports detailed conditions and trends of 16 indicator variables within US estuarine and coastal systems. 1998 - 1999: Data and information from the Estuarine Eutrophication Survey Synthesis to NEAA and development of eutrophication assessment method. 2001: Improvement of NEAA and development into ASSETS. 2002: NEEA Update workshop and guidance document. 2003 - 2005: Application of NEAA/ASSETS methodology to update 13 North and Mid-Atlantic systems and development of a human use indicator to complement the ASSETS eutrophication indicators through a partnership with UMD, UNH, UMASS, Maine State Planning Office, and EPA (funding through CICEET). 2003: Application of the NEEA/ASSETS methodology to 10 estuarine and coastal systems in the European Union (Portugal); Research into the addition of typology criteria for eutrophication symptom range definitions. 2004: Development of the http://www.eutro.org website, listing ASSETS scores for systems from the US, EU (Germany, Ireland, Portugal), and China. COMPASS initiative, bringing together ad hoc group from the EU and the US in order to examine a possibel harmonization between OSPAR-COMPP and ASSETS. 2005: Application of ASSETS methodology to North East National Estuarine Research Reserve(NERR) systems using the System Wide Monitoring Data (SWMP) (funding through CICEET – Cooperative Institute for Coastal and Estuarine Environmental Technology). Preparation of a University of Maryland Center for Environmental Studies – NOAA partnership in order to apply the NEEA/ASSETS methodology via an online survey and National Workshop to update the National Estuarine Eutrophication Assessment for 138 US estuaries and coastal waterbodies. Preparation of a joint US-EU-China initiative (NOAA-IMAR-SOA) in order to apply ASSETS to Chinese coastal systems, and further develop and test the methody.
Target Group/users	Managers and Policy-makers: NEEA's aim was to define the United States national resource base and develop a national assessment capability and the aim of the ASSETS project was to provide an update and improve NEEA, using real data that was consistent with the philosophy of the original work but more robust in methodology.
Calibration	The ASSETS approach has been intercalibrated with the original NEEA work is demonstrated for 82 U.S. Estuaries in the key reference paper.
Validation	Conclusions are validated against a more extensive set of data from the original NEEA survey.
Uncertainty analysis	Not Specified
Key reference	Bricker et al. (2003).
Level of integration	Limited - based on assessment of eutrophication/water quality only.
Links to other models	No links with other models are specified. Related assessments and programmes include: Comparison and Assessment of Eutrophication (COMPASS); EPA National Coastal Assessment (NCA); CICEET Gulf of Maine Project:data acquisition and development of metrics and indices to describe the status and track trends of nutrient related water quality in estuaries and coastal waters; NOAA National estuarine Eutrophication Assessment Update Program.
Ease of use/accessibility	Good - use of clear, colour-coded system. ASSETS application is freely available for download at: http://www.eutro.org/register/. It is available in four languages including Chinese. Results for the applications of ASSETS are available through the website: http://www.eutro.org/syslist.aspx. User manual is not available however the ASSETS programme includes a tutorial.
Website	http://www.eutro.org/
Comments/remarks	By focusing on commonalities and differences between U.S. And E.U. estuarine systems and coastal zones, ASSETs may provide a stepping stone towards a unified system or systems which may accomodate the diversity of pressure, state, and responses of both regions.

Model structure	 Fig. 1. Flow chart of the ASSETS methodology.

Model name	**Atlantis**
Full model name	
Model type	Biogeochemical
Subtype	
Thematic coverage	Ecosystem modelling, fisheries management
Input (key drivers and pressures)	Biogeochemical ecosystem model (consumption, production, waste production, migration, predaqtion, recruitment, habitat dependency, and natural andd fishing mortality); Hydrographic transport model; Fisheries fleet statistics (target, byproduct and bycatch groups, gear type (and associated selectivity curve and habitat impacts), habitat dependency, discarding, and effort allocation submodels).
Output (key variables)	Marine ecosystem dynamics are represented by spatially explicit submodels that simulate hydrographic processes, biogeochemical factors driving primary production, food web relations among functional groups, crude habitat interactions, and fishing fleet behaviour.
Geographical coverage and resolution	Atlantis has been applied at a fine scale (specific bays/current systems) in a number of locations, initially around Australia but also the Californian Current. The spatial geometry of the model is one made up of polygons which correspond to the geographical form of the study area. The area and shape of the polygons reflect the speed with which physical variables change with particular parts of the study area. This modelling approach is advantageous as it can be modified to nest fine-scale models within a coarser scale resolution.
Temporal coverage and resolution	For computational efficiency, a daily time step is used wherever possible. Within the biological modules however, a daily timestep may make the

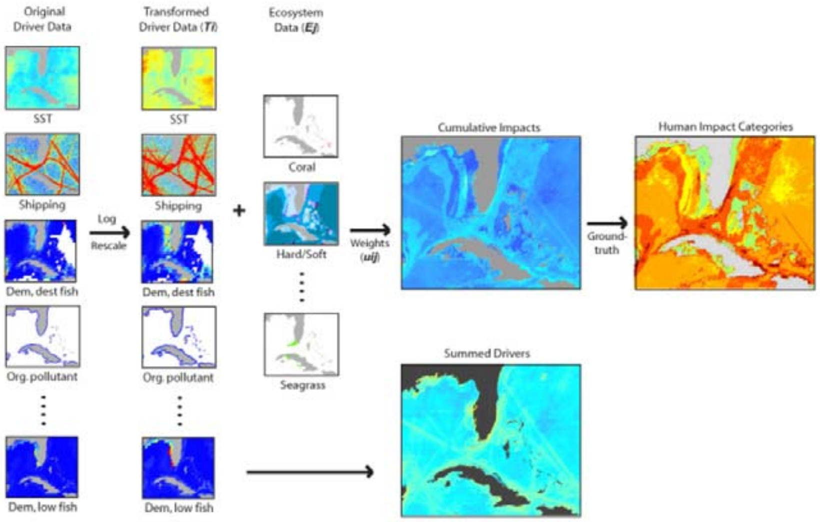
	variables with fast dynamics become unstable. Therefore, while some groups (e.g. Fish) work on a daily time step other groups (e.g. phytoplankton) use an adaptive timestep, which is repeated until a full 24-h period has been completed. In the orginal Bay Model 2 (BM2), from which Atlantis was derived, the model runs span a 20-yr time period (beginning after a 10 yr burn-in period) with output recorded every 14 days. Simulations lasting 100 yrs were also undertaken to check for long period cycles and to verify that the models had reached a representative state at the end of the 30 yr period.
Analytical technique	Deterministic, spatially explicit model.
Model developers and/or owners	Elizabeth A. Fulton, Commonwealth Scientific and Industrial Research Organization (CSIRO), Division of Marine Research, Australia. Funding for Atlantis is provided by NOAA NMFS, NOAA Fisheries and the Environment (FATE), NOAA NMFS Economic Program, Moore Foundation, and the Packard Foundation.
Model development history	Atlantis was developed from a series of models that explored optimal ecosystem model complexity. A precursor to Atlantis, the integrated Generic Bay Ecosystem Model (IGBEM) (Fulton et al. 2004a), was a combination of the biological modules of the European Regional Seas Ecosystem Model (ERSEM) and the physical processes and spatial layout of the Port Philip Bay Integrated Model. Efforts to simplify the physiological processes in IGBEM resulted in the Bay Model 2 (BM2), a more parsimonious framework that still effectively captures system dynamics. Atlantis is a modified version of BM2, established to improve upon ecosystem based fishery management tools (text taken from Brand et al. 2007).
Target Group/users	Atlantis is targetted at those involved in ecosystem/fisheries Management Strategy Evaluation (MSE), in which management policies and assessment methods are tested against simulations that represent a real ecosystem and its complexities. For example, the model can identify trade offs between species, fleets and management goals, and to identify effects of management policies. It is not intended for tactical management, for instance setting quotas for target stocks. Atlantis has been applied to more than 15 ecosystems, primarily in the temperate waters of Australia and the US, and has been rated in high regard by the United Nations Food and Agriculture Organisation (FAO).
Calibration	Atlantis is calibrated to a wide range of data depending upon the area to which it is being applied. Tuning needs to be carried out until all groups persist and numerical stability is acheived. Model calibration currently involves trial and error and some users have calibrated the model manually due to long model run times that prevent the searching of the parameter space with automated procedures (Brand et al. 2007). The tuning procedure can use, as a reference point, values from the literature or outputs of other models such as Ecopath.
Validation	Model outputs are referenced against actual environmental data available for the area. This does potentially restrict the model to use in areas where a great deal of information is already available.
Uncertainty analysis	As Atlantis incorporates a great many parameters (despite being originally scaled down from the IGBEM model) a systematic sensitivity analysis is impractical. However, Fulton et al. (2004) recommends the use of factor screening to identify the most sensitive parts of the model and the exploration of the effects of the resulting restricted set of parameters.
Key reference	Fulton et al., 2004a; Fulton et al., 2004b; Fulton et al., 2005; Brand et al. 2007
Level of integration	Good - links biological, chemical, ecological, and fisheries data.
Links to other models	The model has not yet been integrated into a wider assessment process. Atlantis is built from a number of biological, physical, and fisheries sub-models.
Ease of use/accessibility	Modelling process is complex and would need to be carried out by a specialist. Background publications are readily available in the scientific literature, however technical papers are relatively inaccessible and the model developers would need to be contacted for further information. The model

	cannot be downloaded.
Website	http://www.csiro.au/science/ps3i4.html
Model structure	 Figure 1. Schematic of Atlantis modules for oceanography, ecology, and fishing. This paper discusses the ecology and hydrographic submodels.

Model name	**Aus-ConnIe**
Full model name	Australian Connectivity Interface
Model type	Biogeochemistry models
Subtype	Oceanography, Connectivity
Thematic coverage	Ocean circulation, larval dispersal, larvel recruitment, contaminant dispersal.
Input (key drivers and pressures)	Sea level (Altimeter and Tide gauges); Wind fields; Particle trajectories; Geostrophic currents; Wind forced components; Estimates of ocean currents;
Output (key variables)	Maps showing land masses, the 200m depth contour, and spatial connectivity statistics for the user specified source or sink.
Geographical coverage and resolution	Australia; 0.5 degree geographical grid; All statistics were based on currents and trajectories computed at a fixed depth of Z = 20m, which was taken to be representative of surface waters where larval concentrations tend to be highest.
Temporal coverage and resolution	Monthly and quarterly statistics are available, calculated as T (dispersion period = 10 and 20 days for monthly, and 30, 40, 60, and 80 days for the quarterly. Probailities were calculated from day 1 of the calender month/quarter to day T, then from day 2 to day T+1, until reaching the last day of the month/quarter. The probabilities were then avergaed to give a probability distribution representative of that month/quarter.
Analytical technique	Statistical model which analyzes of the particle trajectory information to give the following for each grid cell: 1) The probablilty that particles beginning within any user specified region willl be inside the grid cell at the end of the dispersion period (i.e. lifetime); 2) The probability that particles beginning within any user specified region will reach the grid celll before the end of the dispersion period; 3) The probability that particles arriving within any user specified region were inside the grid cell exactly one dispersion period previously; and 4) The probability that particles arriving within any specified region were inside the grid cell anytime within the previos dispersion period.
Model developers and/or owners	Aus-Connie was developed as part of the Strategic marine Fund for the Marine Environment (SRFME), a joint venture between CSIRO and the Western Australian State Government. Team: Scott Condie (Project leader), Jim Mansbridge (Statistical Programming), Jason Waring (Senior Web Interface/Designer), Irshad Nainar (Web Interface/Database), and Madeleine Cahill (Altimetry Analysis).
Model development history	Aus-Connie was developed in 2003 and is based on JEMS-Connie, a connectivity tool developed by CSIRO Marine Research as part of the North West Shelf Joint Environmental Management Study (NWSJEMS). JEMS-

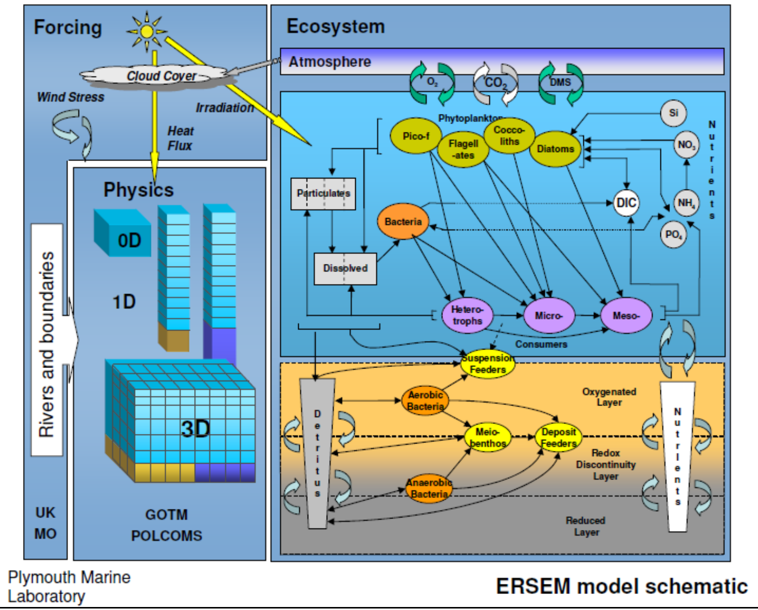
	Connie differs in that the domain is restricted to the North West Shelf of Western Australia, and the statistics were derived particle trajectories using hydrodynamic current fields. Access to JEMS-Connie is restricted.
Target Group/users	Aus-ConnIe has been developed as a web-tool for marine scientists and managers to investigate the large-scale patterns of spatial connectivity around Australia associated with ocean currents.
Calibration	Ocean current data are calibrated from: sea level anomolies (Topex/Poseidon satellite altimeter (9.9 day global cycle); ERS satellite altimeter (35 day global cycle); and tide-gauges from the Australian coastline); Temperature and Salinity measurements (a range of sources including the NODC World Ocean Atlas 1994 hydrographic data; CSIRO RV Franklin; RV Southern Surveyor; and SRV Aurora Australis); and Wind fields (NCEP-NCAR 40-year Reanalysis data set).
Validation	The model has been validated through comparisons with all the World Ocean Circulation Experiment (WOCE) satellite tracked surface drogued drifters in the region from January 1994 to December 1999.
Uncertainty analysis	Not Specified
Key reference	Condie et al., 2005
Level of integration	Limited - based on oceanographic variables of ocean currents.
Links to other models	No links with other models are specified. Aus-ConnIe was developed from the JEMS-Connie model.
Ease of use/accessibility	Relatively simple, the user must select: 1) A region of interest on the map (0.5 degree resolution); 2) Whether the selected region represents a source or a sink; 3) The year and month(s) on which the connectivity statistics will be based; 4) The dispersion period (10, 0r 20 days fro monthly or 30, 40, 60 or 80 days for quarterly); and 5) Whether the connectivity probabilities are based only on particle distribution at the end of the dispersion period (after lifetime), or on all the particle distributions that occur over the dispersion period (within lifetime).
Website	http://www.per.marine.csiro.au/aus-connie/index.html
Model structure	Not available

Model name	**Cumulative Threat Model for the global ocean**
Full model name	
Model type	Biodiversity model
Subtype	Indicator model
Thematic coverage	Human influence, ecological change, threat indices
Input (key drivers and pressures)	Expert survey; 17 anthropogenic drivers of ecosystem change - weighted by their estimated ecological impact; maps of 14 marine ecosystems; models of 6 marine ecosystems.
Output (key variables)	A single comparable estimate of cumulative human impact on 20 ecosystem types.
Geographical coverage and resolution	Global but can be applied at the local- and regional-scale; 1km^2 resolution grid.
Temporal coverage and resolution	Datasets used are from a number of different year-ranges and so no specific output time is specified. The model implies that is it representing a reference level for current (2008) cumulative human impact, however this is not specifically discussed in the published paper or the supplementary materials.
Analytical technique	Ecosystem-specific, multi-scale, spatial, additive model
Model developers and/or owners	Benjamin S. Halpern and team at UCSB. The work was funded by the National Center for Ecological analysis and Synthesis (NCEAS) and supported by the National Science Foundation and a grant from the David and Lucile Packard Foundation to evaluate ecosystem based management in coastal areas.
Model development history	Model published in 2008.
Target Group/users	The model is aimed at managers, conservation groups, and policymakers, and has been widely used by many organisations since its publication (Web of Knowledge records

	33 citations for this paper since February 2008). The model has been as a layer in documents designed to inform policy makers on threats and protection priorities for marine systems.
Calibration	Weighting of the different datasets was calibrated through an expert survey that assessed the vulnerability of each ecosystem to each driver on the basis of 5 ecological traits.
Validation	Impact scores were 'ground-truthed' using global estimates of the condition of marine ecosystems from previous studies; Results with weighting values from the expert survey (which assessed the vulnerability of each ecosystem to each driver on the basis of 5 ecological traits) were very similar to simulated values, with values slightly but significantly different from null expectations for the categories of very low, medium, medium high, and very high impact. Also, tested an alternative cumulative impact model based on the average driver-by-ecosystem impact scores rather than the sum. There was a very high correlation between outputs of the summed vs. average models showing that the spatial pattern of relative impact is very similar under either model. There was also a positive correlation between the average cumulative impact scores and ocean condition in the ground truth regions. Using the new regression equation from this groundtruth correlation led to very similar percents of the ocean in each impact category compared to the summed model.
Uncertainty analysis	Good - Model considers a broad range of anthropogenic drivers including climate change, pollution, invasive species, and fisheries.
Key reference	Halpern et al., 2008
Level of integration	Good - Model considers a broad range of anthropogenic drivers including climate change, pollution, invasive species, and fisheries.
Links to other models	The model has not yet been integrated into a wider assessment process. Previously published models were used to develop data layers and dstribution models of 6 marine ecosystems were created through this process.
Ease of use/accessibility	Modelling process is relatively complex, however the final outputs and data layers are available for download through the internet and the cumulative index is easily understandable with the following categories: Very Low impact, Low impact, Medium impact, Medium High impact, High impact, and Very High impact.
Website	http://www.nceas.ucsb.edu/GlobalMarine
Model structure	

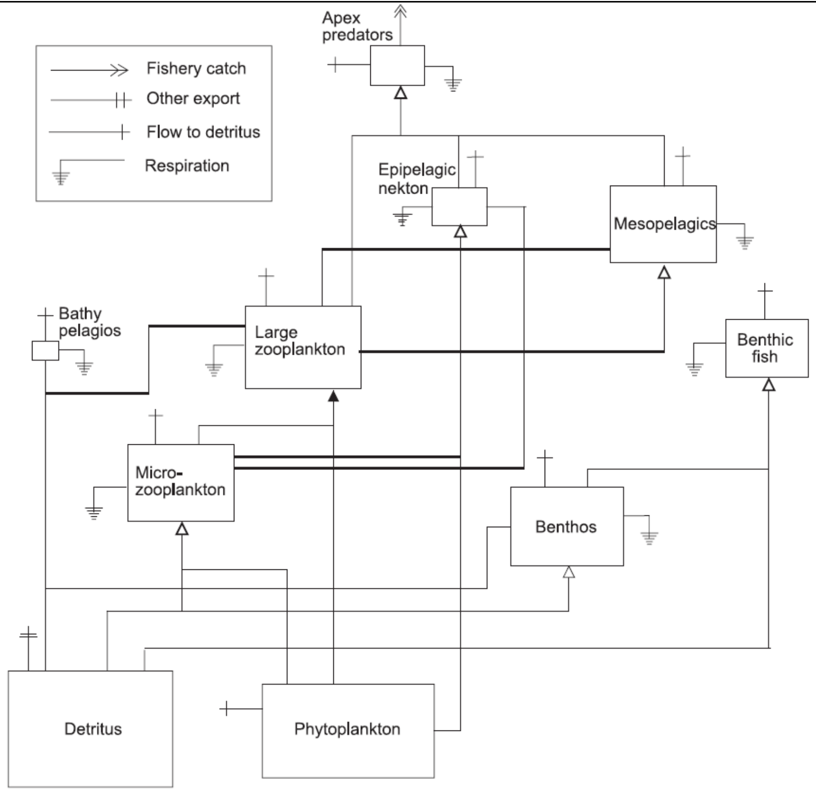
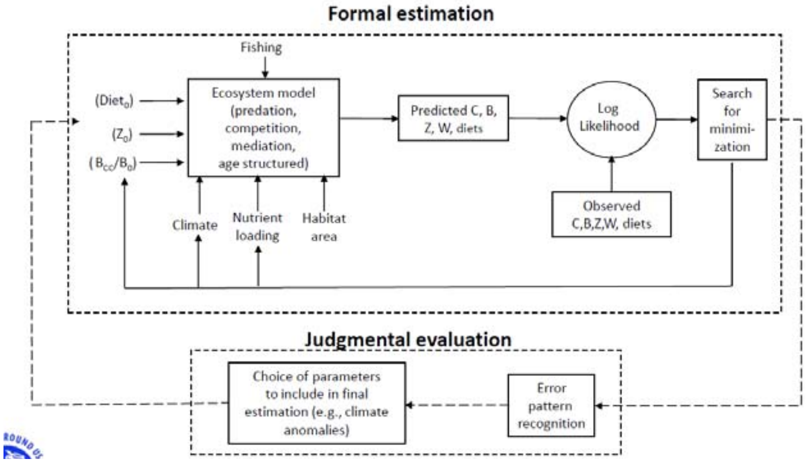
Model name	**ERSEM II**
Full model name	European Regional Seas Ecosystem Model
Model type	Biogeochemical model
Subtype	ocean
Thematic coverage	Annual nutrient cycling, Regional Seas, physical parameters, biological parameters, benthic and pelagic coupling.

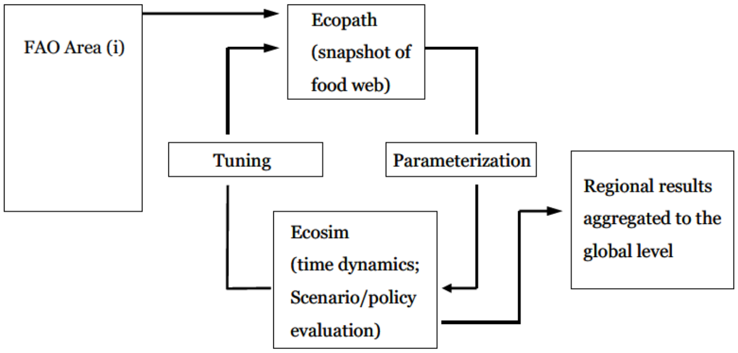
Input (key drivers and pressures)	Pelagic model: Phytoplankton (regulating factors; carbon dynamics; phosphorous dynamics; nitrogen dynamics; silicate dynamics; sinking of phytoplankton); Pelagic bacteria (Environmental regulating factors; Carbon dynamics; Nutrient Dynamics); Microzooplankton (Carbon dynamics; Nutrient dynamics); Mesozooplankton (Carbon dynamics; Nutrient dynamics; The assimilation balance); Pelagic nutrients; Dissolved oxygen and reduction equivalents (Oxgen re-aeration); and Dissolved and particulate organic matter. Benthic model: Benthic organisms (Environmental regulating factors; Carbon dynamics; Filter feeders; Nutrient dynamics; Assimilation balance); Benthic decomposers (Environmental regulating factors; Carbon dynamics; Nutrient dynamics; Assimilation balance); The organic matter in the sediments; Benthic nutrients and other dissolved components (Inputs to the benthic nutrients model; Ammonium; Nitrate; Phosphate; Silicate; Reduction equivalents; Dissolved organic matter); Oxygen distribution in the sediments; Shifting of the layers.
Output (key variables)	Simulations of the annual cycles of carbon, nitrogen, phosphorus and silicon in the pelagic and benthic components of the marine ecosystem.
Geographical coverage and resolution	Dependent on resolution of the model that it is coupled to. ERSEM's upper boxes extend from the surface to 30 m, the lower boxes from 30 m to the bottom. When coupled to high resolution hydrodynamic models, ERSEM can be applied over large geographical scales. ERSEM could be adapted for other regions as it is essentially a generic model which is then coupled to an appropriate physical model for a region, such as the General Ocean Turbulence Model (GOTM). ERSEM has been shown to be equally applicable in tropical and warm temperate systems such as the Arabian Sea, Mediterranean and Irish Seas (Allen, Blackford and Radford, 1998; Allen, Sommerfield and Siddorn, 2002; Crise et al., 1999). Studies of land-ocean interaction have ranged from shallow coastal lagoons to an assessment of riverine influence on the North Sea basin. Basin scale and open ocean applications in 1, 2 and 3 dimensions
Temporal coverage and resolution	Dependent on resolution of the model that it is coupled to. When coupled to high resolution hydrodynamic models, ERSEM can be applied over large temporal scales. ERSEM also provides a model mesocosm environment that can be expected to react in a qualitatively correct manner to seasonal, regional and inter-annual variations. ERSEM model can reproduce long term inter-annual variations in mesozooplankton biomass seen in the CPR dataset.
Analytical technique	Statistical analysis of ecosystem dynamics.
Model developers and/or owners	ERSEM II was developed by a consortium of organisations, namely: Netherlands Institute for Sea Research (NIOZ); Plymouth Marine Laboratory (PML); Institut fur Meereskunde, University of Hamburg; Scottish Office Agriculture and Fisheries Department Marine Laboratory; Culterty Field Station, University of Aberdeen; Department of Statistics and Modelling Science, University of Strathclyde; Ecological Modelling Centre, Joint Department of DHI/VKI; Carl von Ossietzky University. ERSEM II was an EU Project in the Marine Science and Technology programme (MAST).
Model development history	ERSEM I was developed from 1990-1993. ERSEM II was developed from 1993-1996 with the objective of developing a generic model system of the cycling of carbon and the macro-nutrients nitrate, ammonium, phosphate and silicate in the temperate shelf seas of Europe. ERSEM II has since been applied to a range of other environments. Details of the versions of ERSEM are as follows: the 15-box version ERSEM I, based on a subdivision of the North Sea simulation area into 10 upper and 5 lower boxes; the 130-box version ERSEM II, based on a subdivision of the North Sea into 85 upper and 45 lower boxes; the 138-box version of ERSEM, called COCOA (COntinental COastal Application), based on a subdivision of the North Sea into 93 upper and 45 lower boxes with refined boxes in the southern North Sea and along the British and Danish coasts. Programming language: FORTRAN
Target Group/users	Scientists, policy-makers and managers. One of the main objectives of the ERSEM II project was to develop a model system with a prognostic

	capability in order for it to be useful as a decision-support tool.
Calibration	The major data sources that were used to calibrate the ERSEM datasets were a) datasets of original observations compiled in the ECOMOD database of the Institut für Meereskunde (IfM) of the University of Hamburg and b) a dataset of monthly mean values of phosphate, nitrate, ammonium, silicate and chlorophyll, provided by the International Council of the Sea (ICES) for IfM. The dataset from ICES was based on data of the years 1985-1994 from the north-west European shelf, using a 1° x 1° resolution, as for ERSEM II. ICES provided climatological arithmetic means, medians, standard deviations and quantiles for the five parameters mentioned.
Validation	The ERSEM model's range of processes provides confidence in its predictive capabilities. For example, recent work has demonstrated that the ERSEM model can reproduce long term inter-annual variations in mesozooplankton biomass seen in the Continuous Plankton Recorder (CPR) dataset. ERSEM's prognostic capability has been tested by making a 40-year-long hindcast with realistic physical forcing and realistic river inputs.
Uncertainty analysis	Not specified
Key reference	ERSEM-II European Regional Seas Ecosystem Model II (1993-1996), Journal of Sea Research (special issue), 1997, 38(3-4).
Level of integration	Limited - focuses on lower trophic levels of pelagic and benthic systems. However this model is deemed generic when coupled with a qualitatively accurate physical model and so exhibits high interoperability with other types of data.
Links to other models	ERSEM was conceived as a generic model, which, when coupled to a qualitatively correct physical model, such as the General Ocean Turbulence Model (GOTM), should be capable of correctly simulating the spatial pattern of ecological fluxes throughout the seasonal cycle and across eutrophic to oligotrophic gradients of the North Sea.
Ease of use/accessibility	Modelling process is complex and would need to be carried out by a specialist. All methods are fully and transparently published and discussed in the scientific literature and ftp site (http://web.pml.ac.uk/ecomodels/ersem.htm). The model is not yet downloadable from the PML website although there is a link to it meaning that it possibly may be available in the future - for further information on this contact modelling@pml.ac.uk.
Website	http://web.pml.ac.uk/ecomodels/index.html
Model structure	

Model name	**EwE, Ecospace & EcoOcean**
Full model name	**Ecopath with Ecosim, Ecospace & EcoOcean**
Model type	Biogeochemical model
Subtype	Ecosystem model
Thematic coverage	Trophic interactions, population dynamics, ecosystem valuation, simulations.
Input (key drivers and pressures)	Ecopath requires input of three of the following four parameters: Biomass; Production/Biomass ratio (or total mortality); Consumption/Biomass ratio; and Ecotrophic efficiency for each of the functional groups in the model. Ecosim inherits its initial key parameters from the base Ecopath model, and can incorporate (and benefits from) time series data, e.g. those available from single species stock assessments. This can include fishing effort or fishing mortality data. Ecospace also relies on the Ecopath mass-balance approach for most of its parameterisation. Additional inputs are movement rates used to compute exchanges between grid cells, estimates of the importance of trophic interactions (top-down vs. bottom-up control), and habitat preferences for each of the functional groups included in the model. EcoOcean builds on EwE by incorporating 43 functional groupings, global datasets of catches, ex-vessel prices, biomass and distant water fleets from teh Sea Around Us project and the fleet statistics from FAO.
Output (key variables)	Ecopath creates a static mass-balanced snapshot of the resources in an ecosystem and their interactions, represented by trophically linked biomass 'pools'. The biomass pools consist of single species, or species groups representing ecological guilds. Pools may then be further split into ontogentic (juvenile/adult) groups that can then be linked together in Ecosim. Ecosim provides a dynamic simulation capability at the ecosystem level. Biomass flux rates among pools are expressed as a function of time varying biomass and harvest rates. Ecosim allows variable speed splitting to enable efficient modelling of the dynamics of both 'fast' (phytoplankton) and 'slow' groups (whales). It computes the effects of micro-scale behaviours on macro-scale rates: top-down vs. bottom-up control incorporated explicitly. Ecosim also includes biomass and size structure dynamics for key ecosystem groups (incorporating: multi-stanza life stage structure by monthly cohorts, density- and risk-dependent growth; adult numbers, biomass, mean size accounting via delay-difference equations; stock-recruitment relationship as an 'emergent' property of competition/predation interactions of juveniles. Predator prey interactions are moderated by prey behaviour to limit exposure to predation, such that biomass flux patterns can show either bottom-up or top-down control. This is a critical concept in Ecosim - that consumption rates or flows may be limited by 'risk management' behaviours of prey and predators at very small space-time scales. Through repeated simulations Ecosim allows for the fitting of predicted biomasses to time series data. Together, EwE build on the traditional stock assessment, using much more of the information available from these, while integrating to the ecosystem level. Ecospace represents biomass dynamics over two-dimensional space as well as time, i.e. biomasses are represented by equations and as varying with spatial coordinates as well as with time. EcoOcean provides a global database of fishing effort thus providing the opportunity to look at the future of marine biodiversity using a depletion index as a proxy for changes in species composition and abundance under different scenarios.
Geographical coverage and resolution	Multi-scale, ecosystem models. Ecospace is the only component that provides spatial representation and uses user-defined grid cells. EcoOcean uses the 19 FAO statistical areas of the world as its finest geographical scale. These areas can then be aggregated to a global total.
Temporal coverage and resolution	Ecopath does not have a temporal component. Ecosim provides data in monthly intervals in order to allow for seasonality and short life-spans. Ecospace time intervals are user defined, ranging from relatively short timescales (0.2 years) to longer time scales (2yrs). EcoOcean is run from monthly time steps from the year 1950.
Analytical technique	Ecopath = mass-balance model; Ecosim = time-dynamic model; Ecospace = spatial simulation model; EcoOcean = stratified global model.
Model developers and/or owners	Fisheries Centre, University of British Columbia. Key developers include Daniel Pauly, Carl Walters and Villy Christensen. EwE is sponsored by the Sea Around Us Project, the UBC Fisheries Centre, and Lenfest Ocean Futures.
Model development	1992: Ecopath methodology published; 1997: Ecosim methodology published; 1999:

history	Ecospace methodology published; 2000: Ecosim II methodology published; 2007: EcoOcean methodology published.
Target Group/users	EwE is aimed at policy-makers, scientists, and managers. EwE has been used in fisheries policy exploration exercises with the FAO at a workshop at University of British Columbia in 2000. EwE has also been a component of global environmental assessments, in particular the Millennium Ecosystem Assessment and the GEO-3 and -4. EcoOcean has been included in the scenario exploration for GEO-4.
Calibration	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 and rerun until exernal validation is achieved. EcoOcean is parameterised using an array of global databases, most of which are developed/made available through the Sea Around Us Project (www.seaaroundus.org).
Validation	Models are fitted to time series refernece 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: Set up an Ecosim model and reference time series (of forcing inputs like fishing rates, and indices of temporal system response like relative biomasses and estimated total mortality rates). Examine the simulated and observed time patterns of response indices, look for groups that show large discrepancies in time pattern (trend), with particular emphasis on groups that have high biomass and are important prey or predator for other groups. As an example, sardines and anchovy in a Benguela model (Shannon et al., 2004) showed upward trend in data but not in initial simulation results. Focus in turn on each such group, and examine alternative hypotheses for the discrepancy (by varying appropriate parameters to see if the model fit is improved). EcoOcean modelled fisheries effort for 1950-2003 were validated against the reported totals for this period and fell within 10% of the reported total.
Uncertainty analysis	Semi-Bayesian sampling routine is employed to explicitly consider the numerical uncertainty associated with the inputs.
Key reference	Ecopath: Christensen & Pauly (1992),Ecosim: Walters et al. (1997)72; Ecosim II: Walters et al., (2000); Ecospace: Walters et al. (1999); EwE overview: Pauly et al., (2000), –Christensen et al. (2000), Christensen et al., (2005); EcoOcean: Alder et al., (2007)
Level of integration	Good - links traditional stock assessment data with actual population dynamics to provide a realistic system model that is integrated at the ecosystem level. This can then be combined with management regimes in Ecospace (e.g. Marine protected areas) and fisheries data in EcoOcean. The models in this series are linked in a hierarchical manner (i.e. outputs of Ecopath feed into Ecosim, outputs of EwE feed into Ecospace, and these outputs feed into Ecoval).
Links to other models	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 MA, 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. EcoOcean was also used to inform the IAASTD (AgAssessment). EcoOcean is also being developed as a marine equivalent of the MSA produced by the GLOBIO assessment.
Ease of use/accessibility	Modelling process is complex and would need to be carried out by a specialist. However, all methods are fully and transparently published and discussed in the scientific literature. All data sets and the model are freely available to download online at: http://www.nceas.ucsb.edu/GlobalMarine
Website	http://www.ecopath.org/
Model structure	Ecopath:

	 EcoSim:  EcoOcean:

	 **Figure 1.** Process for EcoOcean model

Model name	**GEEM**
Full model name	General Equilibrium Ecosystem Model
Model type	Biogeochemical model
Subtype	Ecosystem model
Thematic coverage	Trophic interactions, population dynamics, fisheries management, resource valuation, simulations.
Input (key drivers and pressures)	For each species in the food web being studied the following energy parameters are used: embodied energy; energy supplies; variable respiration; fixed respiration; and growth rates.
Output (key variables)	For each species in the food web being studied the following energy parameters are calculated for period t: populations; energy demands; energy prices; and net energies.
Geographical coverage and resolution	Multi-scale, ecosystem model based around food webs. Resolution measures are not applicable as spatial representation of outputs is not available.
Temporal coverage and resolution	For the individual organism the model is non-stochastic and time is omitted. Omitting time eliminates dynamic aspects such as age structure issues, however it is necessary for tractability and to be consistent with applied general equilibrium (AGE) models. The model has two components: short-run and long-run equilibrium. The short run is defined as that time over which the populations of all species are constant. In the long-run, populations of species are variable; they adjust to move toward a long-run equilibrium in which all organisms have zero net energy and the short run equilibrium conditions hold. In long-run outputs, time steps are defined by period t.
Analytical technique	Statistical model which captures salient biological functions and provides numerical simulations of marine food webs, which can be then integrated with extant economic models.
Model developers and/or owners	The model was originally developed by John Tschirhart at the Department of Economics and Finance, University of Wyoming. This research was supported by a U.S. Environmental Protection Agency grant and by the State of Wyoming.
Model development history	The GEEM methodology was originally published in the Journal of Theoretical Biology in 2000. It has since been built on and applied by many members of the scientific community.
Target Group/users	The model is recognised as being primarily aimed at policy-makers as it is assumed that improved policies will follow from models that incorporate both economies and ecosystems. As models of economies already exist, the aim of this approach was develop an ecosystem model that is compatible with these economic models and which also captures salient biological features. Besides these benifits, the GEEM is also identified as being useful for addressing purely biological issues and so is also targetted at the scientific community. GEEM has been recognised by FAO as an approach for

	integrating ecosystem considerations into their fisheries models.
Calibration	Parameters within the boundaries defined by the validation methodology can be calibrated through statistical estimation applied to sample data from well defined populations. E.g. To estimate a supply function for an organism, data would include calories of energy and grams of biomess exchenged between predator and prey under varying climatic conditions and abiotic surroundings.
Validation	The bounds on parameters can be set through validation by the following data: observations about the relationships between population densities and predation; necessary and sufficient conditions for a maximum to the net energy problem; and estimates of ecological efficiences. In the simulations, parameter values were chosen so that the computed ecological efficiences were within an order of magnitude of efficiences observed in field work.
Uncertainty analysis	Not specified
Key reference	Tschirhart, 2008
Level of integration	Limited - model only considers energy interactions and the trophic dynamics of an ecosystem. However, when linked with an economic model, economic valuation of these relationships under change can be quantified and thus provide an end result with a much higher level of integration.
Links to other models	The model has not yet been integrated into a wider assessment process. The model is designed to be linked with a general equilibrium economic model by identifying key variables that influence both systems and determining where to incorporate them. Humans interact with ecosystems in a myriad of ways that can be addressed by augmenting the net energy expression in the GEEM. Species populations are the most likely candidates for ecosystem variables that can be included in economic models.
Ease of use/accessibility	Modelling process is complex and would need to be carried out by a specialist. However, all methods and results are fully and transparently published and discussed in the scientific literature. The model cannot be downloaded.
Website	Not applicable
Comments/remarks	The overall goal is to develop a general equilibrium ecosystem model that yields organisms' demands for and supplied of biomass, and to design the model in a way that allows it to be integrated with a general equilibrium model of an economy. Numerical simulations in the key reference use a marine food web in Alaska to illustrate the model and to show several simultaneeous predator/prey relationships, prey switching of the top predator, and energy flows through the web.
Model structure	Not available

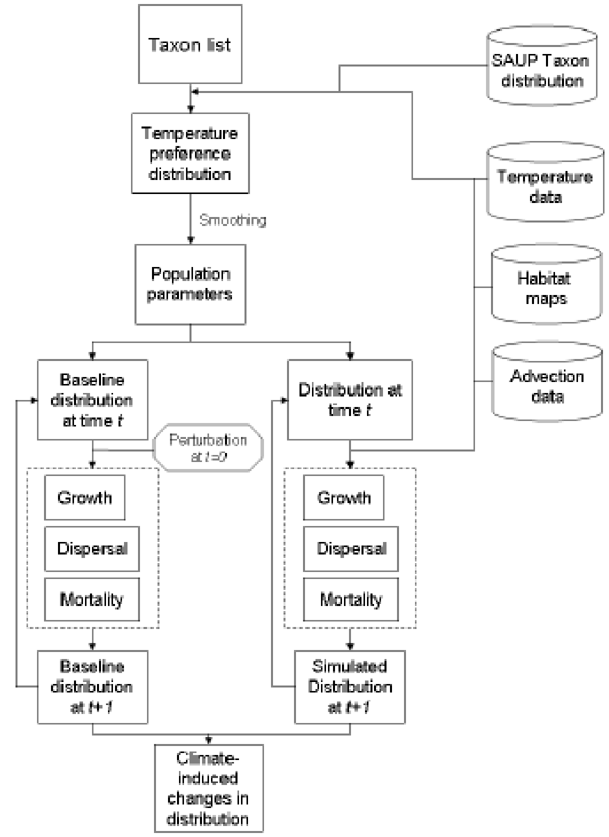
Model name	**ICTHYOP**
Full model name	
Model type	Biogeochemistry model
Subtype	Biodiversity, population dynamics and connectivity
Thematic coverage	Icthyoplankton dynamics, connectivity, species transport
Input (key drivers and pressures)	Individuals are characterised by state variables: age (day), length (mm), stage (egg, yolk-sac larva, or feeding larva), location (longitude/latitude) and depth (m), and status (alive or dead). The physical environment is characterised by ocean state variables: current velocities (m s-1), temperature (*C), and salinity. The physical inputs are archived from oceanic simulations of the "Regional Oceanic Modelling System" (ROMS) or the "Model for Applications at Regional Scale" (MARS).
Output (key variables)	Icthyop offers two functioning modes. The first allows a visualisation of the transport of virtual eggs and larvae in a user friendly graphic interface. The second mode enables the running of a series of simulations based on pre-defined sets of parameters, with a minimalist interface.
Geographical coverage and	The environmental state variables are provided on a discrete three-dimensional grid by archived simulations of the ROMS or MARS oceanic

resolution	models. An example of a typical spatial scale used to characterise the environment is the ROMS southern Benguela configuration grid. It extends from 28 - 40*S and from 10 - 24*E. The horizontal resolution ranges from 9km at the coast to 16km offshore. The vertical resolution ranges from 1 to 4.7m at the surface and from 3.1 to 1030m at the bottom of the ocean. The Icthyop model sees the Eulerian velocity field at the same spatial scale as the Eulerian primitive equation models. Subgridscale parameterisations can be added in the IBM to address scales unresolved by the primitive equation models. The fields of salinity, current velocities, and temperature are interpolated in space to provide values at any individual location in Icthyop.
Temporal coverage and resolution	In ROMS, the current velocities, temperature, and salinity are typically averaged over time and stored every day or so. In Icthyop, they are interpolated in time to feed the Icthyop IBM time step. Simulations consist of tracking the locations and properties of the individuals (typically during a few weeks or months). 'Daytime' in Icthyop is defined as from 7am to 7pm. All temporal variables can be adjusted in Icthyop by the user.
Analytical technique	individual-based model (IBM) designed to study the effects of physical and biological factors on the dynamics of fish eggs and larvae.
Model developers and/or owners	This Java piece of software is a collaborative work between Institut de Recherche pour le Developpement (IRD, teams R079 GEODES and R097 ECO-UP) from France, University of Cape Town (UCT) and Marine & Coastal Management (MCM) from South Africa, and Instituto del Mar del Peru (IMARPE) from Peru. The main contact for this work is Christophe Lett (IRD) and can be contacted at christophe.lett@ird.fr. PREVIMER provided financial support for this project.
Model development history	The program is written in Java and requires the Java Runtime Environment (JRE). The tool is distributed as a package that contains the program code, libraries and a basic example of ROMS output file. The Ichthyop project also includes the Public javadoc. Icthyop was most recently updated/redeveloped in 2008. Previous/modified versions of this method have been used since 2002 and 10 peer-reviewed publications concerning Icthyop have been released in this 6 year period. All references can be found at http://www.ur097.ird.fr/projects/ichthyop/index.php.
Target Group/users	The aim of Icthyop is to provide an easily available, user-friendly model for icthyoplankton dynamics. Through providing this tool, Icthyop aims to help structure the community (assumed to be primarily academic and government scientists) that uses such tools. Previous (prior to 2008)/modified versions of this tool have been used to investigate the effects of physical and biological factors on the dynamics of anchovy (Engraulis encrasicolus, Engraulis ringens) and sardine (Sardinops sagax) ichthyoplankton in the southern Benguela and in the northern Humboldt upwelling systems. These works associated Institut de Recherche pour le Développement (IRD, teams R079 GEODES and R097 ECO-UP) from France, University of Cape Town (UCT) and Marine & Coastal Management (MCM) from South Africa, and Instituto del Mar del Perú (IMARPE) from Peru. All references can be found at http://www.ur097.ird.fr/projects/ichthyop/index.php.
Calibration	Icthyop is calibrated to user defined variables on icthyoplankton and to the ROMS/MAR physical variables on temperature, salinity and current velocity.
Validation	The advection part of the movement submodel has been tested by recording trajectories of individuals and comparing them to trajectories obtained using two other Langrarian tools ("Roff" and "Ariane").
Uncertainty analysis	Not specified
Key reference	Lett et al., 2008
Level of integration	Limited - focuses primarily on the biological aspects of icthyoplankton and the physical parameters that affect their dynamics.
Links to other models	The model has not yet been integrated into a wider assessment process. Icthyop is designed to be linked to either the ROMS or MARS models to supply physical parameters, and can also be linked to models that have been integrated with ROMS or MARS. For example, plankton concentrations can be provided if a NPZD biogeochemical model is coupled to ROMS. Icthyop

	itself is a product of five integrated sub-models.
Ease of use/accessibility	Good - Icthyop is designed to be accessible and easy to use. The software is freely available for download and a user manual is available at http://www.ur097.ird.fr/projects/icthyop/. Output files are in netcdf format and can be post-processed easily. Routines in R can be sent upon request for plotting trajectories or computing the numbers of individuals transported from pre-defined release (spawning) areas to pre-defined destination (recruitment) areas. Ichthyop is a tool designed to be shared within the community using models coupling physics with ichthyoplankton dynamics. Though it has been historically developed to study the dynamics of small pelagic fish ichthyoplankton in upwelling systems, Ichthyop is a generic tool in the sense that it incorporates the most important processes involved in ichthyoplankton dynamics. Using Ichthyop for other species in other systems may imply a few changes in the source code (e.g., changing the growth function, implementing a specific larval vertical migration scheme, etc.). This code is organized simply, commented and documented, which should make it easy to modify by a user with basic programming skills.
Website	http://www.ur097.ird.fr/projects/ichthyop/index.php
Model structure	Not available. Icthyop consists of five sub-models: Spawning, Movement, Growth, Mortality, and Recruitment.

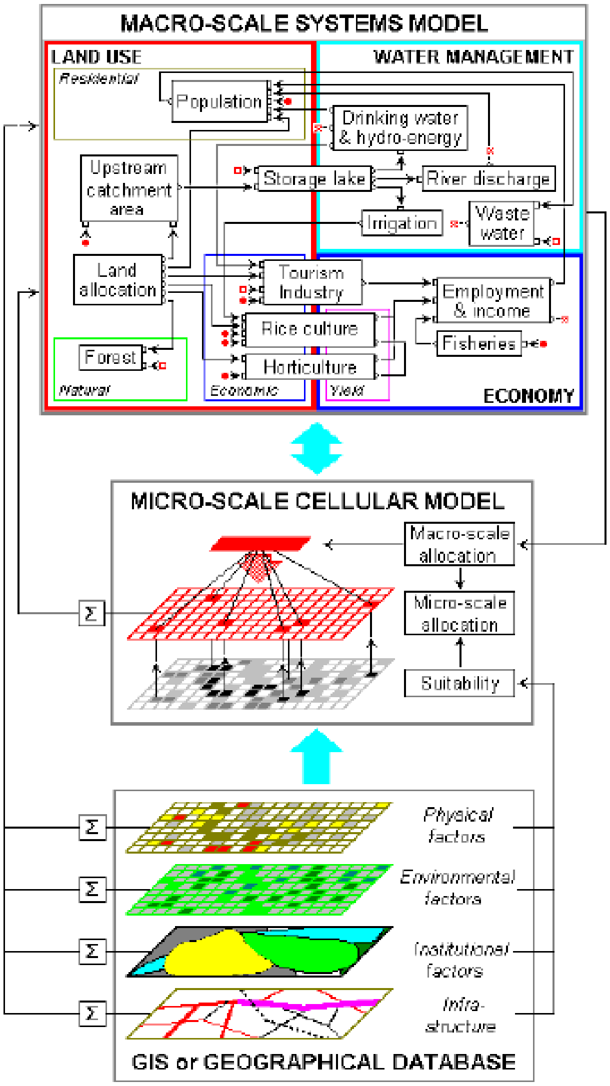
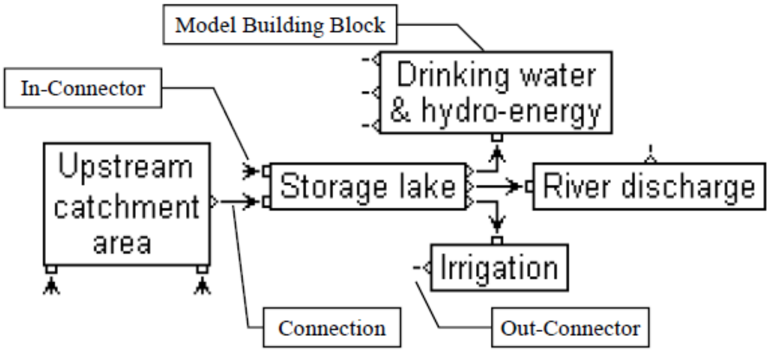
Model name	**Impact of Climate Change on Global Biodiversity**
Full model name	
Model type	Biodiversity model
Subtype	Bioclimatic Envelope Model
Thematic coverage	Climate change, global marine biodiversity, species turnover, niche-based model
Input (key drivers and pressures)	Current species distribution (latitudinal range; depth range; affinity to certain habitats; known distribution boundaries from published literature or expert knowledge); Environmnetal preferences of species (sea water temperature; bathymetry; habitats; and distance from sea ice); Population dynamics (Larval and adult dispersals; immigration; intrinsic population growth and extirpation; carrying capacity of area); Climate change projections to 2050 (NOAA/GFDL Coupled Model amd SRES Scenarios); Logistic population growth model.
Output (key variables)	Predicted changes in species distributions (changes in abundance per time/cell/species) - results for summer and winter distributions are provided seperately; Average frequency of invasion and local extinction events to identify hotspots of climate induced impacts; Median polward shift in distribution centroids.
Geographical coverage and resolution	Global; 30' X 30' grid cell size. Can be scaled to local and regional levels.
Temporal coverage and resolution	Species preferences are calculated from environmental data from 1980 to 2000. Model provides current species richness (average from 2001 to 2005), then future predictions for 2050 (average from 2040 to 2060).
Analytical technique	Bioclimatic Envelope Modelling
Model developers and/or owners	The model was developed by William Cheung, Vicky Lam, and Daniel Pauly at the Sea Around Us Project, Fisheries Centre, Aquatic Ecosystems Research Laboratory University of British Columbia. The model development was funded partially by the University of Western Australia and is a contribution of the Sea Around Us Project, which was initiated and is funded by the Pew Charitable Trusts. The application of the model to assessing the impact of climate change on marine biodiversity was funded by the Pew Charitable trusts through the Sea Around Us Project.
Model development history	Model published in 2008. This publication will be the first of several planned articles on global warming effects on marine communities and fisheries, with the model at its core being gradually modified and improved as applications

	are completed.
Target Group/users	The model currently gives policy-makers, the scientific Community, and the public a quantitative picture of the scale of the issue. The authors consider that the global analysis presented in the paper is a first step towards developing marine conservation policy in the face of climate change. This global picture is also effective in building consensus and initiating actions among nations, societies and stakeholders to address this problem. As the model is developed to be accurate at finer scales, the results can help design management systems and develop indicators and monitoring programmes.
Calibration	Species distributions were initially calibrated to the Sea Around Us Project (http://www.seaaroundus.org) data and were then further refined by incorporating habitat preference data from FishBase (http://www.fishbase.org) for fish and SeaLifeBase for other taxa (http://www.sealifebase.org). Climate scenarios were calibrated to the NOAA Geophysical Fluid Dynamics Laboratory (GFDL).
Validation	The model was validated in the following ways: Simulated changes in distributions of four commercially exploited species in 30 years under two scenarios of global sea temperature change from SeaLifeBase and FishBase datasets as well as from Phillips et al. (1992) for the Western Australian rock Lobster; the possible effects of climate-change induced shifting of coral reefs on associated species was evaluated using the UNEP-WCMC coral reef dataset; key aggregate features of the results (e.g. Annual rate of latitudinal shift) correspond to the available field estimates; finally the effect of change in sea ice coverage on polar species was tested based on information from perr-reviewed literature. Future results from local and regional studies can be used to validate the model, and past climate and species distribution data can be used to assess the accuracy of predictions from the model.
Uncertainty analysis	The model is suitable for undertaking uncertainty analyses. Sensitivity analyis of major parameters showed that the direction of the projections are robust to the uncertainty of those parameters.
Key reference	For Model Background: Cheung et al., 2008 For Model Application: Cheung et al., (in press)
Level of integration	Good - Biodiversity data (bioclimate model is combined with population dynamics making it more robust) is integrated with oceanographic measures, and climate change scenarios.
Links to other models	The model has not yet been integrated into a wider assessment process. The overall model described is formed through the linking of a range of models and scenarios: NOAA/GFDL Coupled Models; SRES Climate Scenarios; Logistic population growth model; Population-dynamic model; Advection-diffusion reaction model for larval dispersal; ECOSPACE (Eulerian spatial ecosystem simulation model)
Ease of use/accessibility	Complex modelling process, however the output distribution maps are simple to understand. All distribution maps are available through the http://www.seaaroundus.org website. All methods are fully and transparently published and discussed in the scientific literature, however, output maps are not yet freely available online.
Website	Not applicable

Model structure	

Model name	**RamCo**
Full model name	
Model type	Integrated dynamic model
Subtype	Decision Support System
Thematic coverage	Coastal zone, assessment, decision support, management
Input (key drivers and pressures)	Spatial information from GIS and static and/or descriptiveGIS operations. This occurs on two scales: Micro-scale drivers include sea use functions (seagrass; coral reef); Land Use functions (Agriculture; Rice culture; Shrimp culture; Industry; Tourism; Urban residential; Rural residential; Mangrove; Nature/forest); and Land use features (Sea; Inland water; Airport; Harbour; Beach); and Macro-scale drivers based around land use, water, ecology and the economy.
Output (key variables)	An almost complete integrated model of the coastal zone, from which the user can specify which variables are most relevant to their needs.
Geographical coverage and resolution	Version 1.0 and 2.0 are applied to the Coastal zone of SW Sulawesi (Indonesia). RAMCO can handle cellular models with dimensions up to 500 by 500 cells. In its actual form, it is most useful for modelling problems on grids which resolution varies from 50 to 500 meters. RamCo has the capability to deal with spatial dynamics at different levels within the same integral models. More in particular RAMCO models will generally have two strongly coupled components: one for macro-level, long range and large scale processes and a second one for processes operating on the micro-level, short range and micro-scale. Sub-models will in general operate at one level, but may exchange information with sub-models at the other level.
Temporal coverage and resolution	Model allows for a multi-temporal dynamic modelling framework. The time horizon is 25 years.
Analytical technique	Integrated spatial models in which natural, social and economic processes are fully

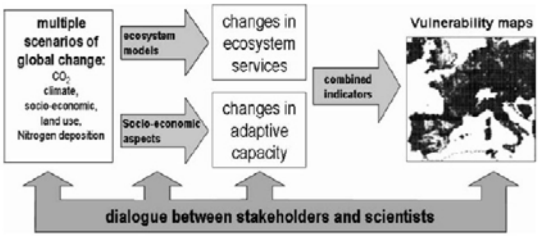
	linked on an appropriate detailed scale. A RAMCO model consists of Model Building Blocks (MBB's) that contains the code required to calculate and execute mathematical operations varying from a single operation (such as the sum of two numbers) to a list of operations (set of mathematical equations). MBB's are connected to one another by means of MBB Connectors.
Model developers and/or owners	RamCo was financed by and is a product of the National Institute for Coastal and Marine Management (RIKZ) and the associated Coastal Zone Management centre (CZM), the Hague, the Netherlands. It was developed by the consortium consisting of INFRAM BV (Zeewolde, the Netherlands), RIKS, Twente University (Enschede) and Maastricht University. RamCo 1.0 - was developed as part of the project: "RAMCO: Generic Decision Support System for the Rapid Assessment phase of Sustainable Coastal Zone Management" financed by the National Institute for Coastal and Marine Management (RIKZ), Rijkswaterstaat, and the associated Coastal Zone Management Centre (CZMc), Contract RKZ-308 and carried out by the consortium consisting of INFRAM bv (Zeewolde, main contractor), and RIKS bv (Maastricht). RamCo 2.0 - 2.0 of RAMCO is the result of the Land Water Environment Information technology (LWI) - Project "Integral Systems Analysis", in the "LWI - Estuaria and Coasts" project group. The developers group consists of: INFRAM bv, RIKS bv, and WL|Delft Hydraulics (Delft). The Technical University of Twente, Department of Civil Engineering Technology & Management, (Enschede) participated as a sub-contractor of INFRAM bv.
Model development history	RAMCO was originally developed in October 1996 for the National Institute for Coastal and Marine Management (RIKZ) and the associated Coastal Zone Management Centre (CZMc). The version 2.0 of RAMCO is the result of the Land Water Environment Information technology (LWI) - Project "Integral Systems Analysis", in the "LWI - Estuaria and Coasts" project group (user manual is dated 1999). The SW Sulawesi model makes extensive use of knowledge gathered in project W01.60 of the Netherlands Organization for the Advancement of Tropical Research (WOTRO). This scientific material remains the full property of WOTRO.
Target Group/users	RamCo is aimed primarily at policy makers working in coastal zone management. The end-users of RamCo 2.0 are: National Institute for Coastal and Marine Management (RIKZ) and the associated Coastal Zone Management Centre (CZMc), and the Netherlands Organization for the Advancement of Tropical Research (WOTRO). RamCo has been applied to a coastal zone near Ujung Pandang in south-west Sulawesi (Indonesia). It shows how - in the next 25 years - the coastal zone strongly urbanizes under the influence of a growing population (annual growth ± 3%) and the external economic growth. RamCo allows policy-makers to test their policy choices under the influence of climate changes, demographic growth, or changing economic demand.
Calibration	Not specified
Validation	The model has a validity interval incorporated within which the parameters must be kept.
Uncertainty analysis	Not Specified
Key reference	Uljee et al., 1999, available at: http://www.riks.nl/RiksGeo/projects/ramco/RamCo2.pdf For the Sulu Sulawesi Case study: de Kok & Wind, 1996 and de Kok & Wind, 1999
Level of integration	Excellent - physical, environmental, economic and social processes that typical coastal zone dynamics generally, and those of Sulawesi in particular. To achieve this, use is made as much as possible of existing scientific knowledge, methods, models and databases.
Links to other models	The model has not yet been integrated into a wider assessment process. RamCo integrates existing models dealing with physical, ecological and socio-economic impacts of coastal zones have been reviewed and adapted in view of their integration into a multi-scale, multi-temporal dynamic modelling framework
Ease of use/accessibility	Demos of the model and the user's guide are available through the RIKS website (http://www.riks.nl/projects/RamCo). Appears relatively easy to use, but presently is only applicable for the SW Sulawesi region. Neither software development with the tools provided in the RAMCO package nor the application of the RAMCO package to a case study is permitted. Software or application development and

	further usage or marketing of the RAMCO package will only be accepted following the purchase of a full version of the package.
Website	http://www.riks.nl/projects/ramco
Model structure	 

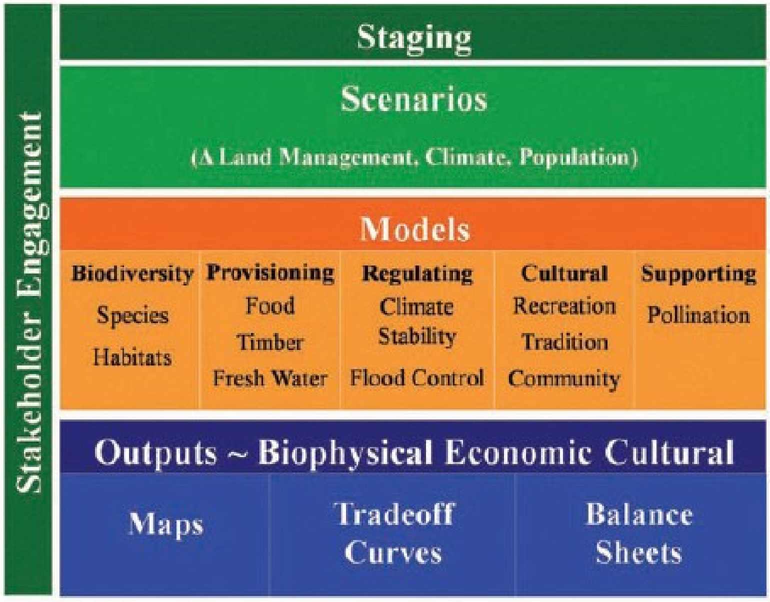
Model name	**Reefs at Risk**
Full model name	
Model type	Biodiversity model
Subtype	Indicator model
Thematic coverage	Coral reefs, marine biodiversity, human influence, threat indices
Input (key drivers and pressures)	Coastal development threat factors (Cities; Settlements; Airports and Military bases; Mines; Tourist resorts; Embayments); Marine-based Pollution threat factor (Ports; Oil-related threats; Shipping-related threats); Overexploitation threat factor (Overfishing; Destructive fishing); Inland Pollution and Erosion threat factor (Hydrological modelling and geographic overlays).
Output (key variables)	A map based indicator of problem areas around the world where in the absence of good management, coral reef degradation might be expected, or predicted to occur shortly, given ongoing levels of human activity.
Geographical coverage and resolution	Global coral reefs; 4km resolution
Temporal coverage and resolution	Assessment of current state (1998) - does not include likely future threats posed by population growth or climate change.
Analytical technique	Results are based on a series of distance relationships correlating mapped locations of human activity such as ports and towns, oil wells, coastal mining activities, and shipping lanes, with predicted risk zones of likely environment degradation. Detailed subnational statistics on population density, size of urban areas, and land cover type were also incorporated into the analysis. Data on rainfall and topography was also used to help estimate potential run-off within watersheds. Distance rules defining threat zones were established for each component indicator using information on the known locations of more than 800 reef sites documented as degraded by human activity by one of the four factors. Minimum distances were esblished through expert review and input, and by determining the most conservative set of rules that, when taken in aggregation for any one of the four threat categories, encompassed at least two-thirds of all known degraded sites affected by activities related to that category. Reefs are graded as under "low", "medium" or "high" threat.
Model developers and/or owners	The initial Reefs at Risk Global Analysis was published as a joint venture by the World Resources Institute (WRI), International Center for Aquatic Living Resources Management (ICLARM), World Conservation Monitoring Centre (WCMC), and the United Nations Environment Programme (UNEP). Lead authors: Dirk Bryant, Lauretta Burke, John McManus and Mark Spalding. The report received funding from UNEP, The Bay Foundation, The David & Lucile Packard Foundation, The Henry Foundation, The Swedish International Development Cooperation Agency, and the United States Environment Protection Agency.
Model development history	1998: "Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs" published; 2002: "Reefs at Risk in South-East Asia" regional analysis was released; 2003: Methodology was used for a local analysis on "Highlighting coral reefs in Coastal Planning and Management in Sabah, Malaysia"; 2004: "Reefs at Risk in the Caribbean" regional analysis was released; 2005: methodology was used to produce the "Belize Coastal Threat Atlas". The Reefs at Risk model is still being further developed for a Reefs at Risk Revisited analysis to provide an update of the original Reefs at Risk analysis a decade on. The update will use improved modeling methods and higher-resolution data to provide a detailed examination of human pressures on coral reefs, implications for reef condition, and projections of associated economic impacts in coastal communities. This analysis will be 20 times more detailed than the original Reefs at Risk and will also include climate-related threats, such as coral bleaching and ocean acidification.
Target Group/users	The model was calibrated to a standard four kilometre resolution consistent with the dataset of shallow coral reefs from the World Conservation Monitoring Centre. This was carried out to mitigate spatial accuracy issues associated with using a range of different datasets.
Calibration	The model was calibrated to a standard four kilometre resolution consistent

	with the dataset of shallow coral reefs from the World Conservation Monitoring Centre. This was carried out to mitigate spatial accuracy issues associated with using a range of different datasets.
Validation	Draft risk maps were revised and vetted at a global workshop attended by coral reef experts from around the world. Final draft maps underwent a second series of review by these and other experts. Overall, the Reefs at Risk indicator accurately classifies over 80 percent of sites known to be degraded by humans as "at risk". This was based on a comparison between Reefs at Risk results and 800 sites documented in ICLARM's Reefbase (v.2) as having been degraded by human activity.
Uncertainty analysis	Not specified, however, uncertainties are recognised based on the inconsistencies, age, and lack of availability of datasets. A number of regions are identified in the Technical Notes of the report where actual threats may not be accurately represented by the Reefs at Risk indicator based on expert review.
Key reference	Bryant et al., 1998 Available online: http://pdf.wri.org/reefs.pdf
Level of integration	Good - uses a variety of datesets to represent anthropogenic threat including data on population, resources, tourism, pollution from fuel and transport, fisheries including destructive fishing practices, and hydrological models to represent inland pollution and erosion.
Links to other models	The model has not yet been integrated into a wider assessment process. Hydrological modelling was used in the development of the inland pollution and erosion threat factor and then integrated into the overall Reefs at Risk model.
Ease of use/accessibility	Modelling process is clear and well described in the online report. Outputs are easy to understand as spatial maps with the threat indices being categorised as low, medium, or high risk. The publication is free to access at: http://www.wri.org/publication/reefs-risk-map-based-indicator-potential-threats-worlds-coral-reefs and some of the data layers and GIS models are available to download for free from the WRI website. CDRom with all the data layers and GIS models used in the analysis are available from WRI fon request. Contact Lauretta Burke for more information: lauretta@wri.org .
Website	http://www.wri.org/publication/reefs-risk-map-based-indicator-potential-threats-worlds-coral-reefs
Model structure	Not available

1.1.9 Regional models/assessments

Model name	**ATEAM**
Full model name	Advanced Terrestrial Ecosystem Analysis and Modeling
Model type	regional assessment
Subtype	
Thematic coverage	vulnerability of ecosystem services: agriculture, forestry, carbon storage and energy, water, biodiversity and tourism
Input (key drivers and pressures)	socioeconomic factors, atmospheric greenhouse gas concentrations, climate factors, and land use
Output (key variables)	vulnerability maps for different ecosystem services (agriculture, wood production, carbon storage, soil fertility, biodiversity, natural beauty)
Geographical coverage and resolution	Europe 15 + Norway and Switzerland, 10' by 10' grid
Temporal coverage and resolution	1990, 2020, 2050, 2080
Analytical technique	link between ecosystem service provision and land use (socio-economic indicators extrapolated via regression models and aggregated via fuzzy models) meta-model
Model developers and/or owners	Potsdam Institute for climate impact research (PIK), Centre d'Ecologie Fonctionelle et Evolutive (CEFE), ETH Zürich, Wageningen University, Max Planck Institute für Biogeochemie, Lund University, Université Catholique de Louvain, Centre de Recerca Ecológica i Aplicacions Forestals (CREAF), Institute for arable crops research (RES), University of Southamption (SOTON), Universidad de Castilla-La Mancha (UCLM), European Forest Institute (EFI),
Model development history	first results published: 2005
Target Group/users	The goal of the ATEAM project was to develop climate scenarios for Europe, employed a suite of ecosystem and hydrological models in order to test estimate the sensitivity of systems to these changes, developed indicators of adaptive capacity for the potential risks, engaged in an extensive, projectlong dialogue with stakeholders about methods and results, and initiated a high-level training component for its methods, leading to five international summer schools
Calibration	Not available
Validation	Not available
Uncertainty analysis	Not available
Key reference	Metzger et al., 2005 (Int J Appl Earth Observ Geoinf 7, 253-267), Metzger et al., 2006 (Agric Ecosyst Environ 114, 69-85), Metzger et al., 2008 (Reg Environ Change 8, 91-107),
Level of integration	Different models were included in this work, the level of integration between thos is unknown.
Links to other models	IMAGE outputs were used for land use change and driving forces for different scenarios, LPJ was used for water and carbon
Ease of use/accessibility	The ATEAM vulnerability-mapping tool can be downloaded from: http://www.pik-potsdam.de/ateam/.
Website	http://www.pik-potsdam.de/ateam/
Model structure	**Fig. 1** The structure of the ATEAM project with the specific interactions between scientists and stakeholders (from Schröter et al. 2004) 

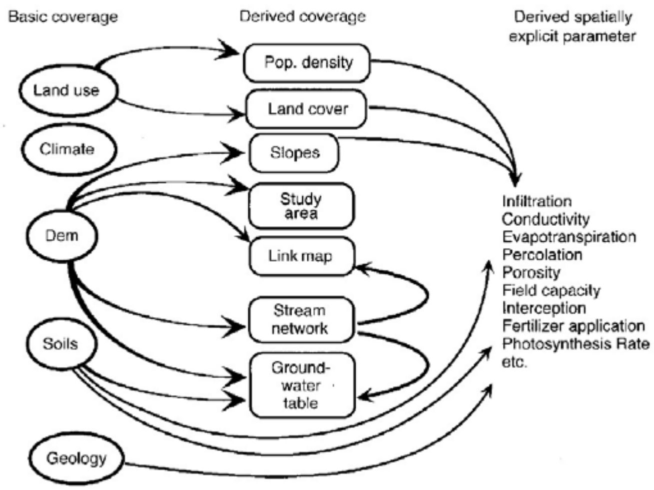
Model name	**InVEST**
Full model name	integrated valuation of ecosystem services and tradeoffs
Model type	regional assessment
Subtype	
Thematic coverage	ecosystem services, biodiversity conservation, commodity production and tradeoffs
Input (key drivers and pressures)	drivers: market conditions and incentive-based conservation payments (policies), inputs: land use maps; basic information about the landscape, land quality, management practices, infrastructure and governance (simple or complex model, depending on data availability)
Output (key variables)	future land use, potential water yield, carbon sequestration, agricultural production, biodiversity, balance sheets for trade-offs between ecosystem services, optimal land allocation for different services
Geographical coverage and resolution	regional, resolution flexible; case studies: Willamette Basin, Oregon, USA (30 m x 30 m grid, for results: 500 ha units); Amazon basin. Currently a global assessment of ecosystem services is done with InVEST. Results have not been published yet.
Temporal coverage and resolution	Calibration depending on land use maps available; 50 year projections, results on annual basis
Analytical technique	empirical-statistical models
Model developers and/or owners	Natural Capital Project (Stanford University), The Nature Conservancy, and World Wildlife Fund
Model development history	published: 2008
Target Group/users	Local managers and stakeholders. The aim of the Natural Capital Project is to align economic forces with conservation.
Calibration	Model was calibrated based on historical data on land use change, calibration data needed for each regional application.
Validation	Not available
Uncertainty analysis	Not available
Key reference	Nelson et al. 2009 (Frontiers in Ecology and Evolution 7, 4-11) Nelson et al. 2008 (PNAS 105, 9471-9476)
Level of integration	Low integration between different submodels: land use model predicts land use based on economic considerations and policies, after that changes in ecosystem services and biodiversity are calculated; no feedback between ecosystem services and land use change incorporated yet
Links to other models	unknown
Ease of use/accessibility	Available at: http://www.naturalcapitalproject.org/InVEST.html, Model equations are given in Nelson et al., 2009 (supplement) Running InVEST effectively does not require knowledge of Python programming, but it does require basic to intermediate skills in ArcGIS.
Website	http://www.naturalcapitalproject.org/InVEST.html
Comments/remarks	Global assessment with InVEST is forthcoming.

Model structure	 *Figure 1: The InVEST Process*

Model name	**Naidoo et al., 2008**
Full model name	
Model type	global assessment (mapping)
Subtype	
Thematic coverage	mapping of ecosystem services, partly based on biophysical models, synergies with biodiversity conservation
Input (key drivers and pressures)	land cover, climate, soil
Output (key variables)	carbon sequestration, carbon storage livestock production, water supply, species distribution
Geographical coverage and resolution	global, maximum resolution 0.5°
Temporal coverage and resolution	No future predictions, current situation only
Analytical technique	linear optimalization approach for habitat protection
Model developers and/or owners	see reference
Model development history	
Target Group/users	For exploratory purposes only, scientists
Calibration	Not applicable
Validation	Not applicable
Uncertainty analysis	Not applicable
Key reference	Naidoo et al., 2008 (PNAS 105, 9495-9500)
Level of integration	The different models/methods used are not integrated. They were used for mapping of present situation only and not for predictions.
Links to other models	TEM (terrestrial ecosystem model) was used to estimate annual carbon exchange rates, water provision was estimated using WaterGAP.
Ease of use/accessibility	The approach and input data have been described (Naidoo et al, 2008) and could be repeated

Website	Not applicable
Model structure	Not available

Model name	**PLM**
Full model name	Patuxent landscape model
Model type	Integrated assessment model
Subtype	regional assessment
Thematic coverage	land use effects on ecosystem services (linked ecological economic model)
Input (key drivers and pressures)	human land use policies (socio-economic), land management (N input), climate
Output (key variables)	land use pattern, water quality, NPP, water cycle, soil nutrients, land prices based on surroundings
Geographical coverage and resolution	Patuxent River watershed, Maryland, USA; variable resolution, maximum resolution: 200 by 200m
Temporal coverage and resolution	baseline: 1990, historial data (from 1650) and future projections, time steps differ between model components: daily (hydrology) to annual (economics)
Analytical technique	
Model developers and/or owners	R. Costanza
Model development history	software: STELLA
Target Group/users	Local managers
Calibration	A modular, multiscale approach was used to calibrate and test the model. Model results showed good agreement with data for several components of the model at several scales. Calibration was done against field data sets for forest growth and hydrological parameters and against results from EPIC for crop yields.
Validation	Historical validation (time series data).
Uncertainty analysis	sensitivity analysis done for different modules
Key reference	Costanza et al., 2002 (Ecol. Monogr. 72, 203-231)
Level of integration	Socio-economic component and general ecosystem model with modules for hydrology, nutrient, plant, consumers and human-dominated systems
Links to other models	Unknown (PLM formed the basis for GUMBO)
Ease of use/accessibility	Not available online
Website	http://www.uvm.edu/giee/PLM/home.html

Model structure	210 ROBERT COSTANZA ET AL. Ecological Monographs Vol. 72, No. 2  FIG. 4.. Patuxent landscape model (PLM) spatial coverages. There are six basic coverages: land use, climate, digital elevation model (DEM), soils, and geology. The arrows connect basic coverages with derived coverages. Additional maps are created during preprocessing and model initialization. Other spatial parameters and variables are calculated and updated during model runs.

Model name	**Swallow et al., 2009**
Full model name	
Model type	regional assessment
Subtype	
Thematic coverage	tradeoffs and synergies among ecosystem services
Input (key drivers and pressures)	land use change, agricultural production
Output (key variables)	water yield and reguation, erosion control
Geographical coverage and resolution	Lake Victory basin; multiple spatial scales, smallest: 5km by 2.5km (arial photograph), sub-basin, country division, river basin
Temporal coverage and resolution	no predictive modeling, current and past situation only
Analytical technique	empirical-statistical
Model developers and/or owners	See reference
Model development history	Not applicable
Target Group/users	Results from the study are meant for agencies, both state and non-state, concerned with rural development and environmental conservation in the Kenya portion of the Lake Victoria basin
Calibration	SWAT-model was calibrated for the Vicotria basin.
Validation	Not available
Uncertainty analysis	Not available
Key reference	Swallow *et al.*, 2009
Level of integration	The SWAT model and the agricultural data were not integrated.
Links to other models	SWAT was used to model water and sediment yield
Ease of use/accessibility	Methodology has been described and could be repeated.
Website	Not applicable
Model structure	Not applicable

1.2 Can the model results be interpreted in terms of ecosystem goods and services?

1.2.1 Integrated assessment models

	Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA models**	**IMAGE**	**MIMES**
Ecosystem services	**Provisioning services**	water supply, food and timber production	harvested organic matter, water supply, mined ores, and extracted fossil fuel	Agricultural production, including marine fishing and aquaculture	agricultural production (can be separated into crops, livestock and forestry)	timber production, agricultural food production, renewable water resources	Agricultural production, including grass/fodder production and livestock/milk production, demand for wood products, timber, fuelwood	Food production, production of raw materials
	Supporting services	Not available	Soil formation (decomposition), nutrient (N) cycling, disturbance regulation	Not available	SOC (soil organic carbon)	Not available	Soil fertility	Soil formation, nutrient cycling
	Regulating services	greenhouse gas emissions, air pollution, carbon sequestration, human health (malaria	gas regulation (C flux), climate regulation (temperature), waste assimilation, disturbance regulation	Human health, CO_2 emissions	human health impacts, sea level, air pollution, carbon emissions	carbon sequestration	Carbon flux, carbon plantations, ocean carbon model, water-erosion sensitivity, air pollution, soil	climate regulation, waste assimilation , disturbance regulation

	Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA models**	**IMAGE**	**MIMES**
		distribution), flood damage	(variation in total biomass)		and stocks		moisture	
	Cultural services	Not available	recreation, cultural (positively related to total biomass and density of social network, negatively related to human population size)	Not available	Not available	Not available	Not available	recreation, cultural
biodiversity	**Species diversity**	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	MSA via GLOBIO	Not applicable
	Genetic diversity	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable
	Ecosystem diversity	Vegetation distribution	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable

1.2.2 Economic models, scenario-building tools, IMPACT-WATER and CLUE

	Model name	**PoleStar**	**Treshold 21**	**GTAP**	**ENV-Linkages**	**IMPACT-WATER**	**CLUE**
Ecosystem services	**Provisioning services**	water resources, raw materials and agriculture	agriculture, consumption of natural resources (renewable and nonrenewable), resource depletion (e.g. forests)	agricultural food production	timber production, agricultural production (crops and livestock, intensive and extensive production)	agricultural food production (crops and livestock), water supply	None (but land used for agriculture, grazing, forestry)

	Supporting services	Not available	land degradation	Not available	Not available	Not available	Not available
	Regulating services	solid waste management, environmental loadings	soil erosion, greenhouse gas emissions, air and water quality (pollution)	Not available	Not available	Not available	Not available
	Cultural services	Not available	Not available	Not available	Not available	Not available	Not available
biodiversity	**Species diversity**	Not available	Not available	Not available	Not available	Not available	Not available
	Genetic diversity	Not available	Not available	Not available	Not available	Not available	Not available
	Ecosystem diversity	Not available	Not available	Not available	Not available	Not available	Land cover diversity explicit

1.2.3 Biogeochemical models

	Model name	**IBIS**	**Agro-IBIS**	**CENTURY**	**LPJmL**	**PICUS**	**SAVANNA**
Ecosystem services	**Provisioning services**	water runoff	water supply, crop production	grass, tree and crop production, water supply (stream discharge)	runoff volumes, crop production	timber production	livestock production, grass and timber production, water supply (runoff, deep drainage)
	Supporting services	NPP, SOC, N balance	NPP, SOC, N balance	N, P and S balance, SOC	annual NPP	nitrogen cycling in forests	NPP, nutrient cycling
	Regulating services	carbon balance (carbon fluxes, SOC), water regulation	carbon flux, N leaching, water regulation	Water balance, decomposition, CO_2 flux, erosion	CO_2 exchange, water balance	carbon sequestration, soil moisture (water cycling)	water balance
	Cultural services	Not available	Not available	Not available	Not available	Not available	Not available
bi	**Species**	Vegetation	Vegetation	Not available	vegetation cover	forest species	Species distribution

	diversity	composition (functional types)	composition (functional types)		(fraction of different plant functional types per grid cell),	composition (diversity, naturalness indicators)	and abundance (plants + animals)
	Genetic diversity	Not available	Not available	Not available	Not available	Not available	Not available
	Ecosystem diversity	Vegetation composition	Vegetation composition	Not available	Vegetation composition	forest species composition	community composition

1.2.4 Hydrological models

	Model name	**WaterGAP**	**E-SWAT**	**WBM**
Ecosystem services	**Provisioning services**	water supply	water supply	water supply, livestock production
	Supporting services	Not available	Not available	Not available
	Regulating services	Not available	erosion control	soil water content
	Cultural services	Not available	Not available	Not available
biodiversity	**Species diversity**	not applicable	not applicable	not applicable
	Genetic diversity	not applicable	not applicable	not applicable
	Ecosystem diversity	not applicable	not applicable	not applicable

1.2.5 Biodiversity models

model name	**GLOBIO**	**MIRABEL**	**Biodiversity**	**SAR species**	**GARP-type**	**EUROMOVE**

				intactness index	**area relationship**	**models**	
Ecosystem	**provisioning**	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable
	supporting	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable
	regulating	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable
	cultural and spiritual	not applicable	not applicable	not applicable	not applicable	not applicable	not applicable
biodiversity	**species diversity**	mean species abundance (MSA)	Not available	biodiversity intactness index	number of species	number of species	number of species
	genetic diversity	Not available	Not available	Not available	Not available	Not available	Not available
	ecosystem diversity	Not available	habitats at risk	Not available	Not available	Vegetation composition/species distribution	Vegetation composition/species distribution

7.1.6 Ocean models I

	Model name	**ASSETS**	**Atlantis**	**Aus-Connie - Australian Connectivity Interface**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM**
Ecosystem services	**Provisioning services**	Estuarine fisheries/aquaculture	Fisheries (inc. their ecosystem effects).	Ecosystem connectivity through genetic diversification (partial match to provisioning services)	Impacts on fisheries/aquaculture; ability of ecosystems to provide non-living resources.	Fisheries (inc. their ecosystem effects).	Fisheries (inc. their ecosystem effects).
	Supporting services	Primary production, nutrient cycling	Population dynamics (Trophic controls); changes	Nutrient cycling; Larval recruitment to fisheries	Reduction in nutrient cycling ability (e.g. through dead	Population dynamics (Trophic	Population dynamics (trophic

	Model name	**ASSETS**	**Atlantis**	**Aus-Connie - Australian Connectivity Interface**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM**
			to ecosystem community structure may impact on other ecosystem services; Ecological fluxes (biomass and nutrient limitations)		zones/pollution); Impacts on habitats and their services.	controls); Biomass and Fluxes.	controls); biological maintenance of resilience; changes to ecosystem community structure may impact on other ecosystem services;
	Regulating services	water quality	Not applicable	Not applicable	Impact ability of ecosystem to provide regulating services generally.	Not applicable	Not applicable
	Cultural services	Recreation	Economic valuation of resources	Not applicable	Impacts on recreation, aesthetic values and experience, spiritual enrichment etc.	Economic valuation of resources	Not applicable
biodiversity	**Species diversity**	dominance by most prolific algal species out-competes all others leading to a loss of species diversity overall. Also, localised dead zones.	Population dynamics and trophic structure.	larval dispersal and recruitment	Not applicable	Population dynamics and trophic structure.	Population dynamics and trophic structure
	Genetic diversity	dominance by most prolific algal	Not applicable	genetic connectivity	Not applicable	Not applicable	Not applicable

	Model name	ASSETS	Atlantis	Aus-Connie - Australian Connectivity Interface	Cumulative Threat Model for the global ocean	EwE, EcoSpace & EcoOcean	GEEM
		species, reducing genetic diversity of system.		between ecosystems			
	Ecosystem diversity	eutrophication leading to dead zones	'within ecosystem' diversity based primarily around trophic links and potential fisheries impacts on these.	ecosystem connectivity, dispersion of contaminants between ecosystems	Cumulative human impact scores for 20 marine ecosystems.	'within ecosystem' diversity based primarily around trophic links (EwE) and movement of species (Ecospace).	'within ecosystem' diversity based primarily around trophic links and potential human impacts on these.

1.2.7 Ocean models II

	Model name	Impact of Climate Change on Global Biodiversity	RamCo	Reefs at Risk	ERSEM II	ICTHYOP
Ecosystem services	**Provisioning services**	Fisheries (commercial and artisanal).	Food security of coastal systems; Water provisioning/water quality; commercial	Coral reef fisheries; Raw materials for medicines; Other raw materials	Fisheries (understanding environmental drivers and bottom-up processes	Ecosystem connectivity i.e. Genetic diversification (partial match to provisioning

	Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
			products provided by coastal zones.	(seaweed and algae for agar, manure etc.); Curio and jewellry; Live fish and coral collected for aquarium trade.	impacting fish populations; impacts of fisheries).	services)
	Supporting services	Changes to ecosystem community structure may impact on other ecosystem services.	Supporting services related to coastal zones generally, e.g. Primary production, nutrient cycling, maintenance of habitats, population dynamics etc.	Maintenance of habitats; maintenance of biodiversity and genetic library; biological maintenance of resilience; mobile links between ecosystems; export of organic production between ecosystems; protection of adjacent shorelines - in doing so supporting wetlands,	Ecological fluxes (biomass and nutrient limitations); Lower trophic level habitat modelling for pelagic and benthic systems;	Larval dispersal and recruitment to fisheries; Nutrient cycling; Bottom-up support of food webs.

	Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
				seagrass beds, mangrove fisheries, population centres etc.; generation of coral sand; build up of land; Nitrogen fixation; CO2/Ca budget control		
	Regulating services	Not applicable	Ability of coastal zone to provide regulating services generally; Water provisioning/water quality;	Waste assimilation.	Not applicable	Not applicable
	Cultural services	Artisanal fishing practices	Ability of coastal zone to provide cultural and spiritual services generally.	Recreational Value; ecotourism; sustaining livelihoods of local communities; aesthetic value; support of cultural, religious and spiritual values.	Not applicable	Not applicable

	Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
biodiversity	**Species diversity**	shifts in species distributions, invasions and extinctions.	impacts of socioeconomic drivers on species diversity in the coastal zone.	Threats to species diversity	lower trophic species (phytoplankton, zooplankton etc.) of pelagic and benthic systems.	larval dispersal and recruitment
	Genetic diversity	Not applicable	Not applicable	Threats to genetic diversity	Not applicable	genetic connectivity between ecosystems
	Ecosystem diversity	community shifts in ecosystems.	impacts of socioeconomic drivers on ecosystem diversity in the coastal zone.	Threats to ecosystem (the coral reef) diversity	Ecological fluxes within ecosystems, dynamics of viruses, marine trophodynamics.	ecosystem connectivity

1.2.8 Regional models/assessments

	Model name	**ATEAM**	**InVEST**	**Naidoo et al.**	**Swallow et al.**	**Costanza et al.**
Ecosyste	**Provisioning services**	food production, wood production,	drinking water, irrigation water, food production,	grassland production of livestock, water	food production, (water supply)	water supply, primary production of

	Model name	**ATEAM**	**InVEST**	**Naidoo et al.**	**Swallow et al.**	**Costanza et al.**
		energy production, water supply	timber production, non-timber forest products	supply		natural vegetation, plantations, grasslands, agriculture
	Supporting services	soil fertility maintenance (soil organic carbon), pollination	pollination (contribution to yield)	Not available	Not available	soil nutrients
	Regulating services	carbon storage (LPJ model), drought and flood prevention, water quality	flood mitigation, carbon sequestration, erosion control, water quality	carbon sequestration and carbon storage	erosion control, (flood mitigation, water quality)	water quality
	Cultural services	recreation, sense of place, beauty	recreation and tourism, cultural and aethetic values, real estate prices as indicator of valuation of nature	Not available	Not available	land prices based on surroundings
biodiversity	**Species diversity**	statistical niche modelling	species richness (feeding and breeding habitat regquirements of 37 terrestrial vertebrate species, dispersal ability)	mammal, bird, reptile, and amphibian species distribution	Not available	Not available

	Model name	**ATEAM**	**InVEST**	**Naidoo et al.**	**Swallow et al.**	**Costanza et al.**
	Genetic diversity	Not available	Not available	Not available	Not available	Not available
	Ecosystem diversity	Not available	Not available	Not available	Not available	Not available

1.3 Usability of selected models for TEEB

1.3.1 Integrated assessment models

Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA Integrated Assessment Modeling Framework**	**IMAGE**	**MIMES**
International acknowledgement	Has been used in many assessments (IPCC, GEO), widely accepted (esp. in Asia), little scientific literature.	One peer-reviewed article, widely cited, large number of collaborators	widely accepted, broad range of users, many assessments	widely accepted, many publications	Widely accepted, used in IIASA assessments	widely accepted, publications: 2 books, > 100 papers, used in MA, IPCC, OECD outlook, GEO, GBO	not published yet, large number of collaborators, high level of publicity, including politics (see website)
width of spectrum of drivers	broad range of socio-economic drivers	Key drivers are human population development and investment	broad range of socio-economic drivers, including socio-political	broad range of socio-economic drivers	broad range of socio-economic drivers	broad range of socio-economic drivers	Key drivers are human population development and investment
width of spectrum of goods and services covered	Provisioning (water, timber, food), and regulating (climate regulation, air quality, human health, flood damage)	The dynamics of eleven major ecosystem goods and services for each of the biomes are simulated and evaluated: provisioning,	Only provisioning services including fisheries, carbon emissions, water use, human health	agriculture, climate regulation , air quality, human health, sea level	provisioning, climate regualation	provisioning (crop + livestock production), regulating (carbon) supporting (nitrogen cycling)	very large, all areas covered

Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA Integrated Assessment Modeling Framework**	**IMAGE**	**MIMES**
		supporting, regulating, cultural, biodiversity.					
richness of detail including sectoral detail	high	high number of parameters and variables in the socio-economic as well as the biophysical sub-models (economic sectors are aggregated into one, diverse energy resources, simple food demand and land use sub-model)	High, six economic sectors: (agriculture, materials, energy, industry, services, and information/communications technology or ICT), eduction, healt, socio-political,	High amount of sectoral detail, especially in the energy sector (different energy sources), agriculture, transport, plus biogeochemical modelling	high	high	very high: large number of variables and parameters
Possibility of upscaling/ downscaling	5º by 5º resolution, application on scale close to this or lower does not provide useful results	Not spatially explicit, 11 biome types	Not spatially explicit, not below country-level	0.5º by 0.5º resolution, application on scale close to this or lower does not provide useful results	5’ by 5’ 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 results	The MIMES at this stage represented a general model scalable in time and space to be applied in global, regional and local models
effects of European	Yes	Not known	Yes- Model is focussed on	Yes	Yes	Yes – several studies already on	Not known

Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA Integrated Assessment Modeling Framework**	**IMAGE**	**MIMES**
policies on global level?			estimating direct and indirect effects of different policies, interactions between different policies.			effects of national and multinational policies	
operational access for TEEB	Model not available online	The model can be downloaded and run on the average PC to allow users to explore for themselves the complex dynamics of the system and the full range of policy assumptions and scenarios. Commercial and consultancy uses have to be coordinated with developers/University of Vermont.	Model is available online: www.ifs.du.edu	Model not available online	Models not available online	model not available, requires a well-trained multidisciplinary team	Model is available for download: http://www.uvm.edu/giee/mimes2/downloads.html
known plans for	Improvement of	calculate the	Enhancement	Improvements on	Various	by 2010 the	The different

Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA Integrated Assessment Modeling Framework**	**IMAGE**	**MIMES**
maintenance and development	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	'shadow prices' of ecological resources based on 'optimal' (rather than 'actual') levels of resource use.	aiming at better scenario-testing and policy analysis	the resolution of the climate submodel	activities are ongoing related to bio-energy production, REDD-related carbon trade options, analysis of organic and precision farming and natural hazard mitigation strategies	incorporation of a biophysical water and vegetation module (LPJ) is planned	submodels for the ecosystem services are constantly improved by the users, including marine

1.3.2 Economic models, scenario building tools and others

Model name	**PoleStar**	**Treshold 21**	**GTAP**	**ENV-Linkages**	**IMPACT-WATER**	**CLUE**
International acknowledgement	Widely accepted, used in GEO assessment	Used for national application mainly	widely accepted, many publications, used in several assessments	Specially developed for assessments, used by World bank	widely used	widely used, many peer-reviewed publications
width of spectrum of drivers	high: socio-economic as well as environmental, users may define extra drivers	broad range of socio-economic drivers	range of economic drivers	broad range of socio-economic drivers	broad range of socio-economic drivers	covers a wide range of biophysical and human drivers at different temporal and spatial scales
width of spectrum of goods and services covered	Provisioning services (water, raw materials, agriculture)	Provisioning services (agriculture)	Provisioning services (agriculture)	Provisioning services (crops, livestock timber)	Provisioning services (crops, livestock, water)	none
richness of detail including sectoral detail	high, data can be disaggregated into regions, subsectors and processes	high	high	26 economic sectors considered, different types of agriculture (intensive, extensive)	IMPACT covers 32 commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, meals, vegetables, fruits, sugar and sweeteners, and fish in a partial equilibrium framework. It is specified as a set of country-level supply and demand equations where each country model is linked to the rest	limited consideration of economic variables

Model name	**PoleStar**	**Treshold 21**	**GTAP**	**ENV-Linkages**	**IMPACT-WATER**	**CLUE**
					of the world through trade.	
Possibility of upscaling/downscaling	applicable at national, regional and global scales; own data sources can be incorporated into basic model structure	National and global level only	Global or country level	Global or country level	281 spatial units	CLUE an be scaled up or down, CLUE-S for regional modelling purposes
effects of European policies on global level?	Via drivers, can be specified explicitly	Via drivers, can be specified explicitly	yes, diverse policy options	yes, diverse policy options	yes, diverse policy options	yes
operational access for TEEB	easy to use software tool for sustainability studies, both scenario-building tool and database of current indicators, flexible and user-friendly framework for building and assessing alternative development scenarios, user manual (http://www.seib.org/polestar)	PC-based, user-friendly tool , open source, library for download, requires active role of user in the definition of the model structure.	GTAP6.2a can be downloaded at: https://www.gtap.agecon.purdue.edu/models/current.asp	Model not available online.	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).	Full version with technical support of the model is only available for collaborative projects. Others may use the model signing a memorandum of understanding excluding the commercial use of the model and requirement of proper referencing.
known plans for maintenance and development	unknown	unknown	There is a project to extend the GTAP Model for the analysis of poverty issues, inclusion of bio-fuel as energy	Carbon sequestration and storage will be included, as well as greenhouse gas emissions due to changes in land use. The energy sector is going to be	Ongoing developments aim at integrating various models of food supply and demand at the	Future developments of the model include a crop (management)-specific approach and the application of

Model name	**PoleStar**	**Treshold 21**	**GTAP**	**ENV-Linkages**	**IMPACT-WATER**	**CLUE**
			source (production, consumption and trade)	disaggregated into nuclear, fossil fuel, hydro-energy and various renewable energy sources.	macro- and micro-level, both from the socio-economic as well as the biophysical modelling side. Interaction between both components will be incorporated. Interfaces with national and global level general equilibrium models are developed.	spatially specific attainable yields. Other planned developments are the modelling of biophysical landscape processes, further implementation of socio-economic processes, and the use of remote sensing images.

1.3.3 Biogeochemical models

Model name	**IBIS**	**Agro-IBIS**	**CENTURY**	**LPJmL**	**PICUS**	**SAVANNA**
International acknowledgement	widely used, many peer-reviewed publications	widely used, many peer-reviewed publications	widely used, many peer-reviewed publications	widely used, many peer-reviewed publications	several peer-reviewed publications	widely used, many peer-reviewed publications
width of spectrum of drivers	environmental drivers	environmental drivers and land use	environmental drivers and land use	environmental drivers and land use	climate and human management (flexible at individual tree level)	Climate, disturbance and human management
width of spectrum of goods and services covered	water, plant production, carbon flux, N balance	water, plant production, carbon flux, N balance	water, plant production, carbon flux	Water balance, plant production, carbon flux	good coverage of all forest-related services: timber production, nutrient, water cycling, carbon	plant production, animal production, water supply

Model name	IBIS	Agro-IBIS	CENTURY	LPJmL	PICUS	SAVANNA
					sequestration	
richness of detail including sectoral detail	no economics, detailed biogeochemical model	no economics, detailed but biogeochemical model	no economics, detailed biogeochemical model	no economics, detailed biogeochemical model	limited to forestry sector, detailed biological processes	plant and animal dynamics are modelled based on nutrient supply
Possibility of upscaling/ downscaling	unknown	Precision agricultural version PALMS for $5m^2$	Not applicable: not spatially explicit	GUESS for regional modeling	Upscaling possible	Scale-independent (dependent on input), limited number of grid-cells
effects of European policies on global level?	No policy options	No policy options (via land use maps only)	No policy options, but possible via different land management practices	No policy options, only via land use change	Not specified, but possible via forest management	Yes, via land management options, economics
operational access for TEEB	can be downloaded but not modified, http://www.sage.wisc.edu/download/IBIS/ibis.html	model and input files can be downloaded, but no help is provided, listserve and user discussions exist, http://daac.ornl.gov/MODELS/guides/IBIS_Guide.html	Century 5 is a research version of the model, it can be obtained upon request, Century 4 is freely available at: http://www.nrel.colostate.edu/projects/century/	open and unrestricted access, LPJ can be downloaded (upon request) at http://www.pik-potsdam.de/research/cooperations/lpjweb/lpj-lpjml-versions	can be acquired from the authors	available at http://www.nrel.colostate.edu/ftp/coughenour/pubs_lock/index.php?Directory=Manual_1993
known plans for maintenance and development	unknown	Smaller scale resolution, more detailed management	Develop a spatially explicit version, improve model details	Inclusion of forestry, furthermore LPJmL is linked with MAgPIE (land use model) and REMIND (macro-economic model) to model food production, land use	unknown	unknown

Model name	IBIS	Agro-IBIS	CENTURY	LPJmL	PICUS	SAVANNA
				change and water constraints.		

1.3.4 Hydrological models

Model name	WaterGAP	(E-) SWAT	WBM
International acknowledgement	high, several peer reviewed publications, used in many global and national assessments	widely used, many peer-reviewed publications	widely used, many peer-reviewed publications
width of spectrum of drivers	WaterGAP simulates the impact of demographic, socioeconomic and technological change on water use as well as the impact of climate change and variability on water availability and irrigation water use	environmental drivers only	environmental drivers
width of spectrum of goods and services covered	focussed on water (quantity)	water-related	water-related, livestock production
richness of detail including sectoral detail	high, the only comprehensive global water use model which computes sectoral water uses in grid cells	no economics, detailed biophysical model	no economics, detailed biophysical model
Possibility of upscaling/downscaling	Basic level is river basin, so it is rather-small-scaled and results can be integrated to global-level. It is not advisable to use model results for developing a water management plan for a particular river basin. But different basins can be compared.	Large amount of data necessary for calibration, high detail of land use/management	0.5° by 0.5° resolution, can not be used for smaller scales
effects of European policies on global level?	Via socio-economic drivers or climate input	Via climate input or land use input	Via socio-economic drivers or climate input
operational access for TEEB	Not available	SWAT can be downloaded at: http://www.brc.tamus.edu/swat/	Detailed descirption available at http://www.asb.cgiar.org/BNPP/phase2/ifpri/description_water_balance_model_10jul2003.

Model name	**WaterGAP**	**(E-) SWAT**	**WBM**
			doc
known plans for maintenance and development	water quality module is currently under development; for WaterGAP3: increase of spatial resolution	unknown	unknown

1.3.5 Biodiversity models

Model name	**GLOBIO**	**MIRABEL**	**Biodiversity intactness index**	**SAR species area relationship**	**GARP**	**EUROMOVE**
International acknowledgement	recently published, used in global assessments	one publication	several peer-reviewed publications	widely accepted, many peer-reviewed publications, widely cited, used for MA	application still discussed in scientific literature	two peer-reviewed publications, widely cited
width of spectrum of drivers	land use, pollution, infrastructure and fragmentation, other drivers via IMAGE	land use, pollution	land use	climate change	climate change	climate only driver, via IMAGE policy options on climate can be used as impact, no effects of land use
width of spectrum of goods and services covered	biodiversity only	biodiversity only	biodiversity only	biodiversity only	biodiversity only	biodiversity only
richness of detail including sectoral detail	limited	limited	limited	limited	limited	limited
Possibility of upscaling/downscaling	Can be applied to smaller areas	Can be applied to smaller areas	The Biodiversity Intactness Index (BII) can be applied at scales at least down to 500 km^2 (*i.e.* to the level of local	scale-independent	Scale-independent	presence data for large number of species needed as input

Model name	**GLOBIO**	**MIRABEL**	**Biodiversity intactness index**	**SAR species area relationship**	**GARP**	**EUROMOVE**
			government) while retaining its intuitive meaning.			
effects of European policies on global level?	yes, via IMAGE	Via drivers (pollution, land use)	Via land use input	Via land use input	Via climate change inputs	yes, via effects on global climate change (IMAGE) (Europe only)
operational access for TEEB	not available	Not available	Methodology described in Scholes & Biggs, 2004	Methodology described in Pimm et al., 1995	methodology is available online: www.lifemapper.org/desktopgarp	Model not available online.
known plans for maintenance and development	Improvement of infrastructure module, refinement and inclusion of other pressures	No further development	unknown	unknown	unknown	Unknown!?!/none

1.3.6 *Ocean models I*

Model name	**ASSETS**	**Atlantis**	**Aus- Connie**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM**
International acknowledgement	International collaborations are being/have been forged in: 13 North and Mid-Atlantic systems through a partnership with the UMD, UNH, UMASS, Maine State Planning	Methodology has been accepted through the peer-review process. The model has been applied to upwards of 15 ecosystems and the UN Food and Agriculture	Methodology has been accepted through the peer-review process.	Published paper has been widely cited and used by many organisations including UNEP-WCMC.	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. The	Methodology has been accepted through the peer-review process and has since been applied and built upon by the scientific community.

Model name	**ASSETS**	**Atlantis**	**Aus- Connie**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM**
	Office, and EPA (funding through CICEET); NEEA/ASSETS has been applied to 10 estuarine and coastal systems in the European Union; ASSETS scores have been developed for systems from the US, EU, and China; Possible harmonization is being investigated between OSPAR-COMPP and ASSETS (COMPASS Initiative); A joint US-EU-China Initiative is being prepared.	Organisation (FAO) has rated the model 'best in the world'.			approach is thoroughly documented in the scientific literature.	
width of spectrum of drivers	Good - ASSETS takes into account human pressures and biological parameters.	Excellent - takes into account chemical, biological, ecological and physical data as well as socioeconomic data in the form of fisheries fleet statistics.	Limited - Aus-ConnIe takes into account only those drivers based on ocean circulation and connectivity.	Good - 17 different drivers are used that fall into categories such as demersal and pelagic fisheries, climate change, pollution, and invasive species.	Good - The models take into account biological information from stock assessment data, including time series data. They build in dynamic population data linking to the ecosystem level, management regimes such as MPAs can be incorporated in Ecospace, and economic	Limited - GEEM takes into account energy (biomass) transfer between trophic levels in the food web and how these can be altered through human impacts.

Model name	**ASSETS**	**Atlantis**	**Aus- Connie**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM**
					and fisheries data for resource valuation are considered through EcoOcean.	
width of spectrum of goods and services covered	Provisioning (estuarine fisheries/aquaculture), Regulating (Water quality), Supporting (Nutrient cycling, Primary Production), Cultural and Spiritual (Recreation).	Provisioning (Fisheries (inc. their ecosystem effects); Supporting (Population dynamics (Trophic controls); changes to ecosystem community structure may impact on other ecosystem services; Ecological fluxes (biomass and nutrient limitations)); Cultural (Economic valuation of resources).	Provisioning (larval recruitment for fisheries); Regulating (ecossytem connectivity (inc. Genetic and Nutrient flows); Larval dispersal and recruitment); Supporting (nutrient cycling).	All types of goods and services provided by the marine environment can be related to this model.	Provisioning (fisheries and their effects on ecosystems); Supporting (population dynamics); Cultural and Spiritual (valuation of ecosystem resources).	Provisioning (fisheries); Regulating (biomass and fluxes); and Supporting (Population dynamics (trophic controls); biological maintenance of resilience; changes to ecosystem community structure may impact on other ecosystem services).
richness of detail including sectoral detail	Not applicable	Good level of ecosystem detail. Sectoral aspect is currently limited to fisheries applications.	Limited detail - a number of applications are mentioned but not discussed.	Although not described in depth, this model is applicable multiple sectors and it provides a framework that can be developed and adapted for use by other sectors, e.g. by adding biodiversity information.	Although a suite of ecosystem models, the models are most applicable to commercial fisheries whereas other sectors have only limited detail.	Limited detail - some applications are described briefly which include the agricultural and fishing/hunting sectors.
Possibility of upscaling/downs	Applicable to any scale of estuary.	An advantage of the Atlantis modelling	Aus-ConnIe is for use in the Australian	A global model which can be applied at the local-	The models are applicable at multiple	GEEM is applicable at multiple, ecosystem

Model name	ASSETS	Atlantis	Aus- Connie	Cumulative Threat Model for the global ocean	EwE, EcoSpace & EcoOcean	GEEM
caling		approach is that it can easily be modified to nest fine-scale models within a coarser coast-wide model.	region. Due to its fairly coarse resolution it is advised not to be used at too fine a scale.	and regional-scale	scales.	scales as it is based on food webs.
effects of European policies on global level?	Categories are colour-coded following the convention of the EU Water Framework Directive (2000/60/EC), and aims to contribute to the classification systems which are a requirement of the E.U. Water Framework Directive, providing a scale for setting eutrophication related reference conditions for different types of transitional waters.	Unknown.	Not applicable.	Unknown.	Application to FAO fisheries policies.	Application to FAO fisheries policies.
operational access for TEEB	ASSETS application is available for download at: http://www.eutro.org/register/. It is free and is available in four languages including Chinese.	Model descriptions are available in peer-reviewed published papers that can be accessed online. Technical documents are less easily available and the	Aus-Connie is freely available through the website at: http://www.per.marine.csiro.au/aus-connie/interface. Model is available through either an	All data sets and the model are freely available to download online at: http://www.nceas.ucsb.edu/GlobalMarine	Model descriptions are available in peer-reviewed published papers that can be accessed online. EwE is freely available for use and downloadable from www.ecopath.org	Modelling process is complex and would need to be carried out by a specialist. However, all methods and results are fully and transparently published and discussed in the scientific literature.

Model name	**ASSETS**	**Atlantis**	**Aus- Connie**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM**
		model is not freely available for use. Contact Beth Fulton at Beth.Fulton@csiro.au for more information.	anonymous log-in with restricted access or through a registered users portal.			The model cannot be downloaded.
known plans for maintenance and development	NEEA/ASSETS Update Program is in operation. Type specific indicator variables and thresholds are being considered to improve the accuracy and management implications of the model.	Not specified. Developments may vary depending on the study area to which the model is applied.	Not specified, although the website does have a feedback form for the website itself and the model which indicates future development will take place.	Next key research step will be to compile regional and global databases of empirical measurements of ecosystem condition to further validate the efficiency of the approach.	Facilities are currently being implemented in EwE6 for using spatial drivers and reference data, e.g. Primary production, Salinity, Temperature, Nutrients, Advection, Fish distributions, and Survey data. EcoOcean is planned to be developed to a 0.5km grid cell resolution. The Depletion Index provided by EcoOcean is also being developed to represent a marine equivalent of the MSA used in the GLOBIO project.	Not specified.

1.3.7 Ocean models II

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
International acknowledgement	Model recently (2008/2009) published in peer-reviewed journals by an internationally recognised team of scientists and has recieved wide media interest.	RamCo has been applied to the south-west Sulu-Sulawesi region and this methodology has been published in two peer-reviewed scientific papers.	The Reefs at Risk series created high impact in the global media and are considered high profile documents internationally. The methodology has been applied internationally to help inform decision making regarding the management of coral reefs.	The ERSEM II methodologies and applications were published in a special edition of the Journal of Sea Research - an internationally renowned, peer-reviewed publication. The fact that ERSEM was an EU funded project also emphasises the international buy-in of the product.	Methodology has been accepted through the peer-review process.
width of spectrum of drivers	Good - Takes into account 1066 commercial fish species and includes habitat preferences, dynamic population measures, climate scenarios, and oceanographic variables.	Excellent - Integrated model taking into account socioeconomic data as well as environmental and physical components.	Good - takes into account four component indicators (Coastal development; Marine Pollution; Overexploitation and destructive fishing; Inland pollution and erosion). However the model does not take into account future threats of climate change or population growth, nor does it consider threats resulting from coral disease, bleaching, and other factors considered largely natural in origin.	Good - takes into account both biological data on the lower trophic levels of pelagic and benthic systems and the physical parameters that are affected by these communities, e.g. Carbon and nutrient dynamics of Microzooplankton. The data in this model can then be linked to physical models thus increasing the range of drivers.	Limited - Icthyop takes into account biological propoerties of icthyoplankton and the key physical variable that influence their dynamics.
width of spectrum of goods and services covered	Provisioning (commercial and artisanal); Supporting (changes to ecosystem	All types of goods and services provided by the coastal zone can be related to this model.	All types of goods and services provided by coral reefs can be related to this model.	Provisioning (fisheries through bottom up controls of fisheries populations; impacts of fisheries);	Provisioning (larval recruitment for fisheries); Regulating (ecosystem connectivity; Larval dispersal

Model name	Impact of Climate Change on Global Biodiversity	RamCo	Reefs at Risk	ERSEM II	ICTHYOP
	community structure); and Cultural and Spiritual (impacts on artisanal fishing practices.			Regulating (ecological fluxes; nutrient limitations); Supporting (Lower trophic level habitat modelling for pelagic and benthic systems).	and recruitment); Supporting (bottom-up support of food webs).
richness of detail including sectoral detail	Limited detail - main application described is to fisheries and only commercial fish species are used in the model.	Good richness of detail regarding the economic impacts on coastal systems. This is based primarily around agriculture and direct use of resources, however also considers the tourism and transport sectors.	Good richness of detail of data used in technical notes, a number of sectors are considered in the model including fisheries, fuel, transport, and tourism.	Limited detail - a number of previous applications to sectors are briefly described, however the majority of information is provided through the ecosystem modelling of regional examples.	Not applicable
Possibility of upscaling/downscaling	The global model can be downscaled to regional and local scales with the aim of improving understanding of potential climate change impactsat finer spatial and temporal scales. The next step would be to obtain physical and biological data in finer resolution for regional scale studies, particularly in climate	RamCo is the first prototype of an information system, which is to evolve eventually into a Generic Decision Support System for the Integrated Assessment of Sustainable Coastal Zone Management problems. The ultimate aim is to develop a system that will be applicable for the purpose of (1) rapid assessment, to (2) a wide range of coastal zone	The Reefs at Risk model is relevant, and has been applied at, global, regional and national scales.	Several studies have shown that the model is equally applicable in warm temperate (e.g. Mediterranean) systems and tropical situations (such as the Arabian Sea). The versatility of ERSEM is demonstrated by the range of subjects to which it has been applied. Studies of land-ocean interaction have ranged from shallow coastal lagoons to an assessment of riverine influence on the North Sea basin. Basin scale	Though it has been historically developed to study the dynamics of small pelagic fish ichthyoplankton in upwelling systems, Ichthyop is a generic tool in the sense that it incorporates the most important processes involved in ichthyoplankton dynamics. Using Ichthyop for other species in other systems may imply a few changes in the source code (e.g., changing the growth function, implementing a specific larval vertical migration scheme, etc.).

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
	sensitive areas.	management problems, in (3) most of the coastal zones of the world.		and open ocean applications in 1, 2 and 3 dimensions have addressed issues varying from the dynamics of viruses to the influence of weather and climate on marine trophodynamics. ERSEM also provides a model mesocosm environment that can be expected to react in a qualitatively correct manner to seasonal, regional and inter-annual variations.	
effects of European policies on global level?	Unknown.	Not applicable.	Unknown.	Unknown.	Unknown.
operational access for TEEB	Model descriptions are available in peer-reviewed published papers that can be accessed online. The model is not available for use, however, Sea Around Us have an excellent collaborative history, making products available from their models for use by other organisations.	Demos of the model and the user's guide are available through the RIKS website (http://www.riks.nl/projects/RamCo). Neither software development with the tools provided in the RAMCO package nor the application of the RAMCO package to a case study is permitted. Software or application development and further usage or marketing of the	Details of the model and methodology are available in the Reefs at Risk publications available through the WRI website. CDROMs containing all the GIS data and models used in the analysis are available upon request. Contact Lauretta Burke for more information: lauretta@wri.org .	Details of the model and methodology are available through the ERSEM PML website (http://web.pml.ac.uk/ecomodels/ersem.htm). The model is not available for download and some of the website is still under development therefore there is instruction to contact modelling@pml.ac.uk for more information.	The software is freely available for download and a user manual is available at http://www.ur097.ird.fr/projects/icthyop/. Output files are in netcdf format and can be post-processed easily. This code is organized simply, commented and documented, which should make it easy to modify by a user with basic programming skills.

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
		RAMCO package will only be accepted following the purchase of a full version of the package.			
known plans for maintenance and development	Plans are in place to: include the effects of salinity on species distribution in the model; to incorporate coastal upwelling as a factor to determine present and future distributions of marine species; to predict global maps of kelp forests and simulate how climate change may affect the distribution of kelp forests and their associated fauna; to use the model to investigate climate-induced changes in physiology and population dynamics; to account for the affects of ocean chemistry.	Building of the MBB building blocks into MBB-libraries, adding to and developing these as necessary; development of scenarios, policy options and policy impacts through input from policy makers; analysts will further develop and refine the model through calibration and parameterisation based on knowledge of coastal zone processes. Through this process, RAMCO could evolve into a storage tank of coastal management knowledge, from this specfic Libraries could be developed which will group the MBBs required for specific coasts.	WRI and ICRAN are leading a update of the 1998 analysis (Reefs at Risk + 10), which will provide a detailed examination of human pressures on coral reefs, implication for reef condition, and projections of associated economic impacts in coastal communities. WRI and ICRAN, in collaboration with a number of other partners, aim to raise public awareness to the location and severity of threats to coral reefs, and catalyse targeted, responsible, and informed decisions that protect coral reefs and the broad range of benefits they provide for people.	Ongoing work is investigating data assimilation as a technique for producing robust forecasts of ecosystem response to short term climatic influences.	Not specified

1.3.8 Regional models/assessments

Model name	**ATEAM**	**InVEST**	**Naidoo et al., 2008**	**Swallow et al., 2009**	**Costanza et al. 2002**
International acknowledgement	several peer-reviewed articles, widely cited	recent project, first publications	peer-reviewed article recently published	peer-reviewed article recently published	peer-reviewed article, widely cited
width of spectrum of drivers	policy scenarios, climate change, socio-economic development	only land use change based on scenarios (others will be incorporated)	species conservation strategies	only land use change	land use effects on ecosystem services (linked ecological economic model)
width of spectrum of goods and services covered	provisioning (agriculture, forestry, water), regulating (water, carbon), supporting (soil fertility, pollination), cultural (recreation), biodiversity	all areas of services covered: provisioning (food, timer, non-timer forest products, water supply), regulating (water, erosion, carbon sequestration), supporting (pollination), cultural (recreation) and biodiversity	provisioning (livestock, water), regulating (carbon storage and sequestration), biodiversity	Provisioning (food and water), regulating (water quality, erosion control)	Provisioning (water), supporting (soil nutrients, NPP), regulating (water quality), cultural (house prices)
richness of detail including sectoral detail	limited, detailed biogechemical models	limited	no economics, only ecosystem processes	Detailed water model (SWAT), and agicultural production	Combined ecological and economic modelling
Possibility of upscaling/downscaling		possible, input: land cover maps; model has both a simple and a complex (more data needed) version	used on global scale as well as regional (California ecoregion)		Resolution variable
effects of European policies on global level?	Yes (European level only)	if speficied within scenarios	Not applicable (mapping, no modelling)	Not applicable	Not applicable
operational access for TEEB	yes	model is available at: http://www.naturalcapitalproject.org/InVEST.html	no	no	No
known plans for maintenance and	Unknown/none	Ongoing development on the different submodels (tiers 1	unknown	unknown	unknown

Model name	**ATEAM**	**InVEST**	**Naidoo et al., 2008**	**Swallow et al., 2009**	**Costanza et al. 2002**
development		to 3)			

1.4 Description of selected scenarios

Scenario name	**GSG: conventional worlds: market forces**
Description	gradual convergence in incomes and culture toward dominant market model, market-driven globalization, trade liberalization, institutional modernization
Correspondence with other scenarios	SRES A1, OECD baseline, MA global orchestration, GEO markets first, WWV business as usual, WBSCD FROG!
Type of scenario	normative
Policies specified	none, economical development shapes future
Purpose	A central theme the scenarios the identification of policies, actions and human choices required for a transition to a more sustainable and equitable future. The diversity and continuity of the GSG offers a unique resource to researchers, decision-makers and the general public.
Authorizing environment	GSG- global scenario group: Convened in 1995 by the Stockholm Environment Institute, the Global Scenario Group is an independent, international, interdisciplinary body that has been developing integrated global and regional scenarios (Raskin et al. 1998, 2002; Gallopı´n et al. 1997). The GSG scenario narratives are quantified with the use of the PoleStar System, a transparent tool for synthesizing global data sets, organizing sectoral linkages, and introducing assumptions (Raskin et al. 1999). This work has been used by a number of international assessments. Rsults are aimed at a global citizens movement.
Stakeholders involved in the development	no stakeholders involved
Time horizon and resolution	1995-2050
Spatial coverage and resolution	global
Domains mainly considered	population development, economics, government, individual lifestyle, sustainability
Main actors	economy, markets
comments	The normative GSG scenarios stood at the basis for many other, explorative scenarios (SRES, MA, GEO 4).

Scenario name	**GSG: Barbarization: breakdown**
Description	social and environmental problems overwhelm market and policy response, unbridled conflict, institutional disintegration, and economic collapse
Correspondence with other scenarios	none
Type of scenario	normative
Policies specified	None, no stable political regime
Purpose	A central theme the scenarios the identification of policies, actions and human choices required for a transition to a more sustainable and equitable future. The diversity and continuity of the GSG offers a unique resource to researchers, decision-makers and the general public.
Authorizing environment	GSG- global scenario group: Convened in 1995 by the Stockholm Environment Institute, the Global Scenario Group is an independent, international, interdisciplinary body that has been developing integrated global and regional scenarios (Raskin et al. 1998, 2002; Gallopı´n et al. 1997). The GSG scenario narratives are quantified with the use of the PoleStar System, a transparent tool for

	synthesizing global data sets, organizing sectoral linkages, and introducing assumptions (Raskin et al. 1999). This work has been used by a number of international assessments. Rsults are aimed at a global citizens movement.
Stakeholders involved in the development	no stakeholders involved
Time horizon and resolution	1995-2050
Spatial coverage and resolution	global
Domains mainly considered	population development, economics, government, individual lifestyle, sustainability
Main actors	economy, individuals
comments	

Scenario name	**GSG: great transitions: eco-communalism**
Description	fundamental changes in values, lifestyles, and institutions, local focus and a bio-regional perspective
Correspondence with other scenarios	SRES B2
Type of scenario	normative
Policies specified	retreat into localism
Purpose	A central theme the scenarios the identification of policies, actions and human choices required for a transition to a more sustainable and equitable future. The diversity and continuity of the GSG offers a unique resource to researchers, decision-makers and the general public.
Authorizing environment	GSG- global scenario group: Convened in 1995 by the Stockholm Environment Institute, the Global Scenario Group is an independent, international, interdisciplinary body that has been developing integrated global and regional scenarios (Raskin et al. 1998, 2002; Gallopı´n et al. 1997). The GSG scenario narratives are quantified with the use of the PoleStar System, a transparent tool for synthesizing global data sets, organizing sectoral linkages, and introducing assumptions (Raskin et al. 1999). This work has been used by a number of international assessments. Rsults are aimed at a global citizens movement.
Stakeholders involved in the development	no stakeholders involved
Time horizon and resolution	1995-2050
Spatial coverage and resolution	global
Domains mainly considered	population development, economics, government, individual lifestyle, sustainability
Main actors	lifestyle change, individuals
comments	

Scenario name	**GSG: conventional worlds: policy reform**
Description	gradual convergence in incomes and culture toward dominant market model, strong policy focus on meeting social and environmental sustainability goals
Correspondence with other scenarios	MA techno garden, GEO policy first, OECD policy variants, WWV technology, WBSCD GEOpolity,
Type of scenario	normative
Policies specified	strong policies towards sustainability, social equity and environmental protection
Purpose	A central theme the scenarios the identification of policies, actions

	and human choices required for a transition to a more sustainable and equitable future. The diversity and continuity of the GSG offers a unique resource to researchers, decision-makers and the general public.
Authorizing environment	GSG- global scenario group: Convened in 1995 by the Stockholm Environment Institute, the Global Scenario Group is an independent, international, interdisciplinary body that has been developing integrated global and regional scenarios (Raskin et al. 1998, 2002; Gallopı´n et al. 1997). The GSG scenario narratives are quantified with the use of the PoleStar System, a transparent tool for synthesizing global data sets, organizing sectoral linkages, and introducing assumptions (Raskin et al. 1999). This work has been used by a number of international assessments. Rsults are aimed at a global citizens movement.
Stakeholders involved in the development	no stakeholders involved
Time horizon and resolution	1995-2050
Spatial coverage and resolution	global
Domains mainly considered	population development, economics, government, individual lifestyle, sustainability
Main actors	global policies
comments	

Scenario name	**GSG: Barbarization: fortress world**
Description	social and environmental problems overwhelm market and policy response, authoritarian rule with elites in "fortresses", poverty and repression outside
Correspondence with other scenarios	SRES A2, MA order from strength, GEO security first,
Type of scenario	normative
Policies specified	strong policies towards regional security, trade barriers
Purpose	A central theme the scenarios the identification of policies, actions and human choices required for a transition to a more sustainable and equitable future. The diversity and continuity of the GSG offers a unique resource to researchers, decision-makers and the general public.
Authorizing environment	GSG- global scenario group: Convened in 1995 by the Stockholm Environment Institute, the Global Scenario Group is an independent, international, interdisciplinary body that has been developing integrated global and regional scenarios (Raskin et al. 1998, 2002; Gallopin et al. 1997). The GSG scenario narratives are quantified with the use of the PoleStar System, a transparent tool for synthesizing global data sets, organizing sectoral linkages, and introducing assumptions (Raskin et al. 1999). This work has been used by a number of international assessments. Rsults are aimed at a global citizens movement.
Stakeholders involved in the development	no stakeholders involved
Time horizon and resolution	1995-2050
Spatial coverage and resolution	global
Domains mainly considered	population development, economics, government, individual lifestyle, sustainability
Main actors	national policies, economy
comments	

Scenario name	**GSG: great transitions: new sustainability**

Description	fundamental changes in values, lifestyles, and institutions, new form of globalization that changes the character of industrial society
Correspondence with other scenarios	SRES B1, MA adapting mosaic, GEO sustainability first, WWV values and lifestyles, WBCSD Jazz
Type of scenario	normative
Policies specified	policies towards sustainability and equility
Purpose	A central theme the scenarios the identification of policies, actions and human choices required for a transition to a more sustainable and equitable future. The diversity and continuity of the GSG offers a unique resource to researchers, decision-makers and the general public.
Authorizing environment	GSG- global scenario group: Convened in 1995 by the Stockholm Environment Institute, the Global Scenario Group is an independent, international, interdisciplinary body that has been developing integrated global and regional scenarios (Raskin et al. 1998, 2002; Gallopı´n et al. 1997). The GSG scenario narratives are quantified with the use of the PoleStar System, a transparent tool for synthesizing global data sets, organizing sectoral linkages, and introducing assumptions (Raskin et al. 1999). This work has been used by a number of international assessments. Rsults are aimed at a global citizens movement.
Stakeholders involved in the development	no stakeholders involved
Time horizon and resolution	1995-2050
Spatial coverage and resolution	global
Domains mainly considered	population development, economics, government, individual lifestyle, sustainability
Main actors	lifestyle change, individuals, governments
comments	

Scenario name	**SRES A1**
Description	rapid economic growth, market-based solutions with weak governments, free trade, high technological development
Correspondence with other scenarios	GSG market forces, OECD baseline, MA global orchestration, GEO markets first, WWV business as usual, WBSCD FROG!
Type of scenario	explorative
Policies specified	open markets, no policies for greenhouse gas emissions
Purpose	climate change predictions, assessment of mitigation strategies, provide input for negotiations of possible measures/agreements
Authorizing environment	IPCC: 6 modelling groups for development from narrative to quantitative model inputs, however, there has been criticism that macro-economists were not involved in scenario development
Stakeholders involved in the development	none, scientists only
Time horizon and resolution	2100
Spatial coverage and resolution	global
Domains mainly considered	trade, transport, manufacturing, agriculture, climate
Main actors	global economy
comments	SRES scenarios have been criticised for their negative attitude towards market-based solutions

Scenario name	**SRES A2**
Description	moderate economic growth, intermediate technological development,

	self-reliance of regions
Correspondence with other scenarios	GSG fortress world, MA order from strength, GEO security first,
Type of scenario	explorative
Policies specified	trade barriers, strong national policies, no policies for greenhouse gas emissions
Purpose	climate change predictions, assessment of mitigation strategies, provide input for negotiations of possible measures/agreements
Authorizing environment	IPCC: 6 modelling groups for development from narrative to quantitative model inputs, however, there has been criticism that macro-economists were not involved in scenario development
Stakeholders involved in the development	none, scientists only
Time horizon and resolution	2100
Spatial coverage and resolution	Global
Domains mainly considered	trade, transport, manufacturing, agriculture, climate
Main actors	global policies
comments	SRES scenarios have been criticised for their negative attitude towards market-based solutions

Scenario name	**SRES B1**
Description	rapid technological change, central strong governments, restrictive policies, convergent world towards global solutions to economic, social and environmental sustainability, moderate economic growth
Correspondence with other scenarios	GSG new sustainability, MA adapting mosaic, GEO sustainability first, WWV values and lifestyles, WBCSD Jazz
Type of scenario	explorative
Policies specified	strong global management, no policies for greenhouse gas emissions
Purpose	climate change predictions, assessment of mitigation strategies, provide input for negotiations of possible measures/agreements
Authorizing environment	IPCC: 6 modelling groups for development from narrative to quantitative model inputs, however, there has been criticism that macro-economists were not involved in scenario development
Stakeholders involved in the development	none, scientists only
Time horizon and resolution	2100
Spatial coverage and resolution	global
Domains mainly considered	trade, transport, manufacturing, agriculture, climate
Main actors	local communities, "wellfare networks"
comments	SRES scenarios have been criticised for their negative attitude towards market-based solutions

Table 4: General information on scenarios

Scenario name	**SRES B2**
Description	technological change globally unevenly distributed, local solutions to economic, social and environmental sustainability, slow economic growth, decision-making on local/regional level, weak government
Correspondence with other scenarios	GSG eco-communalism
Type of scenario	explorative
Policies specified	trade barriers, local management, no policies for greenhouse gas emissions

Purpose	climate change predictions, assessment of mitigation strategies, provide input for negotiations of possible measures/agreements
Authorizing environment	IPCC: 6 modelling groups for development from narrative to quantitative model inputs, however, there has been criticism that macro-economists were not involved in scenario development
Stakeholders involved in the development	none, scientists only
Time horizon and resolution	2100
Spatial coverage and resolution	global
Domains mainly considered	trade, transport, manufacturing, agriculture, climate
Main actors	local communities
comments	SRES scenarios have been criticised for their negative attitude towards market-based solutions

Scenario name	**MA: *Global Orchestration***
Description	global economic policies are the primary approach to sustainability
Correspondence with other scenarios	GSG market forces, SRES A1, OECD baseline, GEO markets first, WWV business as usual, WBSCD FROG!
Type of scenario	mostly explorative
Policies specified	global economic policies towards sustainability
Purpose	primary aim was to draw out the consequences of several plausible future worlds for ecosystem services, we needed to provide plausible explanations that considered social and economic drivers of change.
Authorizing environment	Scenario guidance teams
Stakeholders involved in the development	The scenario guidance team conducted a series of interviews with potential users of the scenarios to obtain their input for developing the goals and focus of the scenarios. This effort included directly asking various users what questions they wanted the MA to address. Users who responded included representatives from the Convention on Biological Diversity, the Convention to Combat Desertification, Ramsar, and other national government representatives; individuals from the private sector; and members of international nongovernmental organizations, civil society, and indigenous groups. This effort led to a greater understanding of what the active stakeholders hoped to gain from the MA scenarios. Final scenarios were developed with interviews of 59 leaders in NGOs, governments, and business from five continents.
Time horizon and resolution	2050, for some variables 2100
Spatial coverage and resolution	global
Domains mainly considered	focus on social policy, policy reforms focus on global trade and economic liberalization
Main actors	global policies, transnational companies, NGOs, multilateral organisations
comments	

Scenario name	**MA: *Order From Strength***
Description	
Correspondence with other scenarios	GSG fortress world, SRES A2, GEO security first,
Type of scenario	mostly explorative
Policies specified	national policies for nature conservation (parks and reserves), trade barriers
Purpose	primary aim was to draw out the consequences of several plausible

	future worlds for ecosystem services, we needed to provide plausible explanations that considered social and economic drivers of change.
Authorizing environment	Scenario guidance teams
Stakeholders involved in the development	The scenario guidance team conducted a series of interviews with potential users of the scenarios to obtain their input for developing the goals and focus of the scenarios. This effort included directly asking various users what questions they wanted the MA to address. Users who responded included representatives from the Convention on Biological Diversity, the Convention to Combat Desertification, Ramsar, and other national government representatives; individuals from the private sector; and members of international nongovernmental organizations, civil society, and indigenous groups. This effort led to a greater understanding of what the active stakeholders hoped to gain from the MA scenarios. Final scenarios were developed with interviews of 59 leaders in NGOs, governments, and business from five continents.
Time horizon and resolution	2050, for some variables 2100
Spatial coverage and resolution	global
Domains mainly considered	focus on self interest, regionalized and fragmented world, concerned with security and protection
Main actors	national policies, multinational companies
comments	

Scenario name	**MA:** ***Adapting Mosaic***
Description	
Correspondence with other scenarios	GSG new sustainability, SRES B1, GEO sustainability first, WWV values and lifestyles, WBCSD Jazz
Type of scenario	mostly explorative
Policies specified	local policies
Purpose	primary aim was to draw out the consequences of several plausible future worlds for ecosystem services, we needed to provide plausible explanations that considered social and economic drivers of change.
Authorizing environment	Scenario guidance teams
Stakeholders involved in the development	The scenario guidance team conducted a series of interviews with potential users of the scenarios to obtain their input for developing the goals and focus of the scenarios. This effort included directly asking various users what questions they wanted the MA to address. Users who responded included representatives from the Convention on Biological Diversity, the Convention to Combat Desertification, Ramsar, and other national government representatives; individuals from the private sector; and members of international nongovernmental organizations, civil society, and indigenous groups. This effort led to a greater understanding of what the active stakeholders hoped to gain from the MA scenarios. Final scenarios were developed with interviews of 59 leaders in NGOs, governments, and business from five continents.
Time horizon and resolution	2050, for some variables 2100
Spatial coverage and resolution	global
Domains mainly considered	focus on active learning, political and economic activity, local management
Main actors	local management, cooperatives, global organisations
comments	

Scenario name	**MA:** ***TechnoGarden***
Description	
Correspondence with other scenarios	GSG policy reform, GEO policy first, OECD policy variants, WWV technology, WBSCD GEOpolity,
Type of scenario	mostly explorative
Policies specified	proactive, global management
Purpose	primary aim was to draw out the consequences of several plausible future worlds for ecosystem services, we needed to provide plausible explanations that considered social and economic drivers of change.
Authorizing environment	Scenario guidance teams
Stakeholders involved in the development	The scenario guidance team conducted a series of interviews with potential users of the scenarios to obtain their input for developing the goals and focus of the scenarios. This effort included directly asking various users what questions they wanted the MA to address. Users who responded included representatives from the Convention on Biological Diversity, the Convention to Combat Desertification, Ramsar, and other national government representatives; individuals from the private sector; and members of international nongovernmental organizations, civil society, and indigenous groups. This effort led to a greater understanding of what the active stakeholders hoped to gain from the MA scenarios. Final scenarios were developed with interviews of 59 leaders in NGOs, governments, and business from five continents.
Time horizon and resolution	2050, for some variables 2100
Spatial coverage and resolution	global
Domains mainly considered	focus on environmental technology, multifunctional agriculture, reduction of trade barriers and subsidies
Main actors	technological development, NGOs, professional associations
comments	Multi-functional aspects of agriculture and a global reduction of agricultural subsidies and trade barriers.

Scenario name	**GEO4:** ***Markets First***
Description	Markets First pays lip service to sustainable development in terms of the ideals of the Brundtland Commission, Agenda 21 and other major policy decisions. There is a narrow focus on the sustainability of markets rather than in the context of the broader human-environment system
Correspondence with other scenarios	GSG market forces, SRES A1, OECD baseline, MA global orchestration, WWV business as usual, WBSCD FROG!
Type of scenario	explorative
Policies specified	open markets, environmental policies of national governments (air pollution), ideals of the Brundtland Commission, Agenda 21 and other major policy decisions
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 modelling teams elaborated on different

	aspects of the scenarios (Potting and Bakkes 2004).
Stakeholders involved in the development	Expert Group Meeting (Governments and relevant international organisations)
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	economic sector
comments	

Scenario name	**GEO-4: *Policy First***
Description	Policy First introduces some measures aimed at promoting sustainable development, but the tensions between environment and economic policies are biased towards social and economic considerations
Correspondence with other scenarios	GSG policy reforms, MA techno garden, OECD policy variants, WWV technology, WBSCD GEOpolity,
Type of scenario	explorative
Policies specified	policy limits market failure, climate change 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 modelling teams elaborated on different aspects of the scenarios (Potting and Bakkes 2004).
Stakeholders involved in the development	Expert Group Meeting (Governments and relevant international organisations)
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	governmental policies
comments	

Scenario name	**GEO-4: *Security First***
Description	Security First focuses on the interests of a minority: rich, national and regional. It emphasizes sustainable development only in the context of maximizing access to and use of the environment by the powerful
Correspondence with other scenarios	GSG fortress world, SRES A2, MA order from strength
Type of scenario	explorative
Policies specified	trade barrier, strong national policy, no environmental policies except for air pollution

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 modelling teams elaborated on different aspects of the scenarios (Potting and Bakkes 2004).
Stakeholders involved in the development	Expert Group Meeting (Governments and relevant international organisations)
Time horizon and resolution	2050
Spatial coverage and resolution	global
Domains mainly considered	population, economic activity, governemtn (energy prices, taxes, environmental policies), lifestyle, technology, land use limitations
Main actors	governmental policies, partly economic
comments	

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 (Governments and relevant international organisations)
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 baseline scenario**
Description	
Correspondence with other scenarios	GSG market forces, SRES A1, MA global orchestration, GEO markets first, WWV business as usual, WBSCD FROG!
Type of scenario	trend
Policies specified	business-as-usual: no new policies
Purpose	The focus of the Outlook is the critical environmental concerns facing OECD countries, but the study is global in scope, aim is the exploration of options to reduce climate change and greenhouse gas emissions
Authorizing environment	OECD
Stakeholders involved in the development	
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: 0.5° grid
Domains mainly considered	agricultural production and trade, energy sector (mitigation of climate change, control of urban air pollution), sewage treatment
Main actors	
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 modelled 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.

Scenario name	**OECD- ppOECD**
Description	This policy variant implies a broad range of policies for a reduction of greenhouse gas emissions, including a carbon tax, are only implemented in the OECD countries starting in 2012.
Correspondence with other scenarios	GSG policy reform, MA techno garden, GEO policy first, WWV technology, WBSCD GEOpolity,
Type of scenario	trend (explorative)
Policies specified	broad policy package, including phased carbon tax in OECD countries (starting 2012 with US$ 25/tC), development towards maximum feasible reductions of air pollution, installing and updrading sewage treatment systems
Purpose	The focus of the Outlook is the critical environmental concerns facing OECD countries, but the study is global in scope, aim is the exploration of options to reduce climate changeand greenhouse gas emissions
Authorizing environment	OECD
Stakeholders involved in the development	
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: 0.5° grid
Domains mainly considered	agricultural production and trade, energy sector (mitigation of climate change, control of urban air pollution), sewage treatment

Main actors	OECD 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.

Scenario name	**OECD- 450ppm multigas**
Description	A policy variant with carbon taxes. The price for carbon is not fixed, but dependent on the greenhouse gas emissions with the goal to stabilize the CO_2 equivalent concentration at 450 ppm.
Correspondence with other scenarios	GSG policy reform, MA techno garden, GEO policy first, WWV technology, WBSCD GEOpolity,
Type of scenario	trend (normative)
Policies specified	Climate policy aimed at stabilizing the concentration of the six Kyoto gases at 450 ppm carbon dioxide equivalents
Purpose	The focus of the Outlook is the critical environmental concerns facing OECD countries, but the study is global in scope, aim is the exploration of options to reduce climate changeand greenhouse gas emissions
Authorizing environment	OECD
Stakeholders involved in the development	
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.

Scenario name	**OECD-ccglobal2008**
Description	This policy variant implies an immediate implementation of carbon taxes worldwide.
Correspondence with other scenarios	GSG policy reform, MA techno garden, 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, aim is the exploration of options to reduce climate changeand greenhouse gas emissions

Authorizing environment	OECD
Stakeholders involved in the development	
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: 0.5° 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.

Scenario name	**IAASTD baseline scenario**
Description	
Correspondence with other scenarios	
Type of scenario	trend
Policies specified	no new policies (national and international agricultural policy)
Purpose	
Authorizing environment	IAASTD
Stakeholders involved in the development	Private and public sector participation in writing teams
Time horizon and resolution	50 years backward and forward
Spatial coverage and resolution	global
Domains mainly considered	food production, water supply, energy production and use, land use change, climate, trade policies and markets
Main actors	economy
comments	

Scenario name	**MIMES/GUMBO: baseline**
Description	
Correspondence with other scenarios	OECD baseline
Type of scenario	trend
Policies specified	no new policies
Purpose	
Authorizing environment	
Stakeholders involved in the development	
Time horizon and resolution	
Spatial coverage and resolution	global
Domains mainly considered	
Main actors	
comments	

Scenario name	**MIMES/GUMBO: star trek**
Description	higher rates of consumption and investment in built capital, lower investment in human, social and natural capital and the real state of the world corresponds to the optimistic parameter assumption set (new alternative energy comes on line, etc.)
Correspondence with other scenarios	
Type of scenario	explorative
Policies specified	higher rates of consumption and investment in built capital, lower investment in human, social and natural capital
Purpose	
Authorizing environment	
Stakeholders involved in the development	
Time horizon and resolution	
Spatial coverage and resolution	global
Domains mainly considered	
Main actors	
comments	

Scenario name	**MIMES/GUMBO: big government**
Description	set of technologically sceptical policies (lower rates of consumption and investment in built capital, higher rates of investment in human, social and natural capital) and the real state of the world corresponds to the optimistic parameter assumption set
Correspondence with other scenarios	
Type of scenario	explorative
Policies specified	technologically sceptical policies (lower rates of consumption and investment in built capital, higher rates of investment in human, social and natural capital)
Purpose	
Authorizing environment	
Stakeholders involved in the development	
Time horizon and resolution	
Spatial coverage and resolution	global
Domains mainly considered	
Main actors	
comments	

Scenario name	**MIMES/GUMBO: mad max**
Description	higher rates of consumption and investment in built capital, lower investment in human, social and natural capital) and the real state of the world corresponds to the sceptical parameter assumption set (no new energy forms come on line, etc.)
Correspondence with other scenarios	
Type of scenario	explorative

Policies specified	higher rates of consumption and investment in built capital, lower investment in human, social and natural capital
Purpose	
Authorizing environment	
Stakeholders involved in the development	
Time horizon and resolution	
Spatial coverage and resolution	global
Domains mainly considered	
Main actors	
comments	

Scenario name	**MIMES/GUMBO: ecotopia**
Description	technologically sceptical policies and the real state of the world corresponds to the sceptical parameter assumption set
Correspondence with other scenarios	
Type of scenario	explorative
Policies specified	technologically sceptical policies (lower rates of consumption and investment in built capital, higher rates of investment in human, social and natural capital)
Purpose	
Authorizing environment	
Stakeholders involved in the development	
Time horizon and resolution	
Spatial coverage and resolution	global
Domains mainly considered	
Main actors	
comments	

Scenario name	**WWV: business as usual**
Description	current water policies continue, high inequity
Correspondence with other scenarios	GSG market forces, SRES A1, OECD baseline, MA global orchestration, GEO markets first, WBSCD FROG!
Type of scenario	explorative
Policies specified	no, focus on demographic, technoloigcal and lifestyle development
Purpose	To increase awareness of a rising global water crisis.
Authorizing environment	Word Water Counsil
Stakeholders involved in the development	
Time horizon and resolution	2025
Spatial coverage and resolution	global
Domains mainly considered	lifestyle choice, technology development, demographics, economics
Main actors	institution and economy
comments	(focus on water, agricultural use, storage, scarcety, distribution)

Scenario name	**WWV: technology, economic and the private sector**

Description	market-based mechanisms, better technology
Correspondence with other scenarios	GSG policy reforms, MA techno garden, GEO policy first, OECD policy variants, WBSCD GEOpolity,
Type of scenario	explorative
Policies specified	no, focus on demographic, technological and lifestyle development
Purpose	To increase awareness of a rising global water crisis.
Authorizing environment	Word Water Counsil
Stakeholders involved in the development	
Time horizon and resolution	2025
Spatial coverage and resolution	global
Domains mainly considered	lifestyle choice, technology development, demographics, economics
Main actors	economy (private sector)
comments	(focus on water, agricultural use, storage, scarcety, distribution)

Scenario name	**WWV: values and lifestyles**
Description	less water intensive activities, ecological preservation
Correspondence with other scenarios	GSG new sustainability, SRES B1, MA adapting mosaic, GEO sustainability first, WBCSD Jazz
Type of scenario	explorative
Policies specified	no, focus on demographic, technological and lifestyle development
Purpose	To increase awareness of a rising global water crisis.
Authorizing environment	Word Water Counsil
Stakeholders involved in the development	
Time horizon and resolution	2025
Spatial coverage and resolution	global
Domains mainly considered	lifestyle choice, technology development, demographics, economics
Main actors	lifestyle choices (individual citizens, consumers)
comments	(focus on water, agricultural use, storage, scarcety, distribution)

Scenario name	**WBCSD: FROG!**
Description	market-driven growth, economic globalization
Correspondence with other scenarios	GSG market forces, SRES A1, OECD baseline, MA global orchestration, GEO markets first, WWV business as usual
Type of scenario	explorative
Policies specified	open markets
Purpose	to engage the business community in the debate on sustainable development
Authorizing environment	World Business Council for Sustainable Development; the scenarios were developed in an open process involving representatives from 35 organizations.
Stakeholders involved in the development	representatives from 35 organizations
Time horizon and resolution	2000-2050
Spatial coverage and resolution	global
Domains mainly considered	ecosystem sustainability, economy, technology
Main actors	economy
comments	

Scenario name	**WBCSD: GEOpolity**
Description	top-down approach to sustainability
Correspondence with other scenarios	GSG policy reforms, MA techno garden, GEO policy first, OECD policy variants, WWV technology
Type of scenario	explorative
Policies specified	global policies aiming at sustainable development
Purpose	to engage the business community in the debate on sustainable development
Authorizing environment	World Business Council for Sustainable Development; the scenarios were developed in an open process involving representatives from 35 organizations.
Stakeholders involved in the development	representatives from 35 organizations
Time horizon and resolution	2000-2050
Spatial coverage and resolution	global
Domains mainly considered	ecosystem sustainability, economy, technology
Main actors	global policies
comments	

Scenario name	**WBCSD: JAZZ**
Description	bottom-up approach to sustainability, ad hoc alliances, innovation
Correspondence with other scenarios	GSG new sustainability, SRES B1, MA adapting mosaic, GEO sustainability first, WWV values and lifestyles
Type of scenario	explorative
Policies specified	governmental activity limitd to local level
Purpose	to engage the business community in the debate on sustainable development
Authorizing environment	World Business Council for Sustainable Development; the scenarios were developed in an open process involving representatives from 35 organizations.
Stakeholders involved in the development	representatives from 35 organizations
Time horizon and resolution	2000-2050
Spatial coverage and resolution	global
Domains mainly considered	ecosystem sustainability, economy, technology
Main actors	Lifestyle (individual citizens, consumers)
comments	

Table 4: General information on scenarios

Scenario name	**EURuralis: global economy**
Description	Societies in the Global economy scenario are predominantly driven by market-based solutions. Trade barriers are gradually eliminated; CAP subsidies are phased out, and so are transfers of capital to support EU regions lagging behind economically. Government roles are limited to core responsibilities, like basic education, security and law enforcement (Westhoek *et al*., 2006)
Correspondence with other scenarios	SRES A1
Type of scenario	explorative with extra policy options
Policies specified	agricultural subsidies abolished,

Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	economy, multilateral cooperation, strong technology development
comments	

Scenario name	**EURuralis: global cooperation**
Description	The Global co-operation scenario assumes intensive multilateral international co-operation on many issues. Tariff barriers restricting market access are gradually removed but international food safety standards are raised and new mechanisms are introduced to ensure high social and environmental production standards of traded goods (Westhoek *et al*., 2006).
Correspondence with other scenarios	SRES A2
Type of scenario	explorative with extra policy options
Policies specified	some agricultural subsidies,
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	economy, multilateral cooperation for sustainability, nature conservation and equity, strong technology development
comments	

Scenario name	**EURuralis: continental markets**
Description	The Continental markets scenario assumes a view that social and cultural values can best be preserved in regional political alliances, within which nation states should keep as much sovereignty as possible.Agricultural protection measures to shield this market remain in place to safeguard food security (Westhoek *et al*., 2006).
Correspondence with other scenarios	SRES B1
Type of scenario	explorative with extra policy options
Policies specified	agricultural subsidies abolished,
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030

Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	economy, regional cooperation for sustainability, nature conservation and equity
comments	

Scenario name	**EURuralis: regional communities**
Description	In the Regional communities scenario, a high value is attributed to the subsidiarity principle and, in fact, many issues are addressed at a level below that of the nation-state. Few benefits are attributed to market-based solutions; shielded markets are preferred so as to address the strong environmental and socio-cultural concerns that typify this scenario (Westhoek *et al*., 2006).
Correspondence with other scenarios	SRES B2
Type of scenario	explorative with extra policy options
Policies specified	only agri-environmental payments,
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	government, regional cooperation for sustainability, nature conservation and equity
comments	

Scenario name	**EURuralis: CAP market support variants**
Description	These variants are implemented on top of one of the scenarios and related to market price supports in the EU which can be maintained or abolished.
Correspondence with other scenarios	
Type of scenario	policy variants
Policies specified	full market liberalization for agricultural products to constant price support
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy

Main actors	
comments	

Scenario name	**EURuralis: CAP income support variants**
Description	In these policy variants income support can be abolished, maintained or increased.
Correspondence with other scenarios	
Type of scenario	policy variants
Policies specified	abolishment of income support to increasing income support for farmers
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	
comments	

Scenario name	**EURuralis: biofuel variants**
Description	Different biofuel variants exist from no or low obligations for biofuels to 11.5% share of biofuels in the energy sector.
Correspondence with other scenarios	
Type of scenario	policy variants
Policies specified	no targets (no taxes and subsidies) to 11.5% obligations in 2010
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	
comments	

Scenario name	**EURuralis: less favoured area policy variants**
Description	Policy variants with abolishment of support for less favourite areas to increase/shift of areas.
Correspondence with other scenarios	
Type of scenario	policy variants

Policies specified	no special policy, current policy or new policies based on slope and altitude of land
Purpose	Support European governments on decisions about future
Authorizing environment	
Stakeholders involved in the development	Scientific advisory group and policy advisory group
Time horizon and resolution	2030
Spatial coverage and resolution	Europe
Domains mainly considered	macro-economy, demography, agro-technology, border support, income support, LFA, nature policy, spatial policy, erosion policy, energy policy
Main actors	
comments	

Table 4: General information on scenarios

Scenario name	**ATEAM A1**
Description	Rapid economic growth, little concern about environment, increase in mass-tourism
Correspondence with other scenarios	SRES A1
Type of scenario	explorative
Policies specified	recreation focus in protected areas
Purpose	Main objective is to assess the vulnerability of human sectors relying on ecosystem services with respect to global change
Authorizing environment	ATEAM is a consortium consisting of 18 scientific institutes
Stakeholders involved in the development	Scenarios were developed in intensive cooperation with stakeholders, primarily ecosystem managers and policy advisors.
Time horizon and resolution	baseline: 2000; 2020, 2050, 2080
Spatial coverage and resolution	Europe
Domains mainly considered	land use change based on economy (GDP), techological development, citizen participation, governmental policies, tourism, rural development, spatial planning
Main actors	global economy
comments	

Scenario name	**ATEAM A2**
Description	Moderate economic growth, strong EU, little concern about environment, decrease in tourism in general but increase in regional tourism
Correspondence with other scenarios	SRES A2
Type of scenario	explorative
Policies specified	weak nature conservation policies, protection declines
Purpose	Main objective is to assess the vulnerability of human sectors relying on ecosystem services with respect to global change
Authorizing environment	ATEAM is a consortium consisting of 18 scientific institutes
Stakeholders involved in the development	Scenarios were developed in intensive cooperation with stakeholders, primarily ecosystem managers and policy advisors.
Time horizon and resolution	baseline: 2000; 2020, 2050, 2080
Spatial coverage and resolution	Europe

Domains mainly considered	land use change based on economy (GDP), techological development, citizen participation, governmental policies, tourism, rural development, spatial planning
Main actors	regional economy
comments	

Scenario name	**ATEAM B1**
Description	Moderate economic growth, great concern about environment, styrong central government, increase in regional recreation, decrease in tourism
Correspondence with other scenarios	SRES B1
Type of scenario	explorative
Policies specified	strict protection and expansion of selected areas
Purpose	Main objective is to assess the vulnerability of human sectors relying on ecosystem services with respect to global change
Authorizing environment	ATEAM is a consortium consisting of 18 scientific institutes
Stakeholders involved in the development	Scenarios were developed in intensive cooperation with stakeholders, primarily ecosystem managers and policy advisors.
Time horizon and resolution	baseline: 2000; 2020, 2050, 2080
Spatial coverage and resolution	Europe
Domains mainly considered	land use change based on economy (GDP), techological development, citizen participation, governmental policies, tourism, rural development, spatial planning
Main actors	global government
comments	

Scenario name	**ATEAM B2**
Description	Low economic growth, great concern about environment, decrease in tourism, increase in eco-recreation, strong regional governments
Correspondence with other scenarios	SRES B2
Type of scenario	explorative
Policies specified	local policies for nature conservation
Purpose	Main objective is to assess the vulnerability of human sectors relying on ecosystem services with respect to global change
Authorizing environment	ATEAM is a consortium consisting of 18 scientific institutes
Stakeholders involved in the development	Scenarios were developed in intensive cooperation with stakeholders, primarily ecosystem managers and policy advisors.
Time horizon and resolution	baseline: 2000; 2020, 2050, 2080
Spatial coverage and resolution	Europe
Domains mainly considered	land use change based on economy (GDP), techological development, citizen participation, governmental policies, tourism, rural development, spatial planning
Main actors	regional government
comments	

1.5 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, EcoOcean (EwE)
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)
MIMES/GUMBO	explorative	limited	wide set of quantitative indicators	Moderate	MIMES, GUMBO
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	

1.6 Summary of models with respect to drivers, pressures and impacts

1.6.1 Integrated Assessment Models

Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA**	**IMAGE**	**MIMES**
natural drivers and environmental pressures	Climate change (as affected by emissions and policy)	climate	climate	Climate change (as affected by emissions and policy)	Climate change (as affected by emissions and policy)	Climate change (as affected by emissions and policy)	climate
human drivers and pressures	energy demand (land use change)	Human population, knowledge and social institutions (rules and norms) drive the rate of the material and energy flux.	demography, economic, agricultural, energy, socio-political, international political	capital, labour	demography, economy, energy demand	Demography, macro-ecomomy, agricultural demand and trade (from GTAP)	Human population, knowledge and social institutions (rules and norms) drive the rate of the material and energy flux.
policies	scenario-inputs	scenario inputs	international politics	scenario-inputs	scenario-inputs	Policy decision support model FAIR, scenario inputs	scenario inputs
land use	land use change model included, spatially explicit	11 biomes globally aggregated (open ocean, coastal ocean, forests, grasslands, wetlands, lakes/rivers, deserts, tundra, ice/rock,	not spatially explicit	spatially explicit	spatially explicit	geographically explicit modelling of land use/cover	spatially explicit, different types: forest, wetland, grass, urban, desert

Model name	**AIM**	**GUMBO**	**IFs**	**IGSM**	**IIASA**	**IMAGE**	**MIMES**
		croplands, urban): areal land use, not spacially explicit					
biodiversity	Vegetation distribution	Not available	Not available	Not available	Not available	MSA via GLOBIO	Not available
ecosystem function	Water balance	carbon, water and nutrient cycles, decomposition		water and carbon cycling, NPP	carbon cycle (MAGICC, DIMA)	C, N cycle, LAI, vegetation distribution	Soil formation, nutrient cycling
ecosystem services	water supply, food and timber production, greenhouse gas emissions, air pollution, carbon sequestration, human health (malaria distribution), flood damage/sea level rise	soil formation, gas regulation, climate regulation, nutrient cycling, disturbance regulation, recreation and culture, and waste assimilation, water, harvested organic matter, mined ores, and extracted fossil fuel	Agricultural production, including marine fishing and aquaculture, Human health, CO_2 emissions	agriculture, air pollution, sea level, carbon sequestration, human health impacts, air pollution, carbon stocks	timber production, agricultural food production, renewable water resources	food production, forestry module, water (forthcoming), Carbon flux, carbon plantations, ocean carbon model, water-erosion sensitivity, air pollution	Food production, production of raw materials, climate regulation, waste assimilation , disturbance regulation, cultural and recreational
economic value/human well-being	human health	valuation: marginal product of ecosystem services in both the model's production and	Human health	Health impacts, policy costs			valuation: marginal product of ecosystem services in both the model's production and welfare functions

Model name	AIM	GUMBO	IFs	IGSM	IIASA	IMAGE	MIMES
		welfare functions (food, energy, GWP and welfare per capita)					

1.6.2 *Economic models, scenario-building tools, IMPACT-WATER and CLUE*

Model name	PoleStar	Threshold 21	GTAP	ENV-Linkages	IMPACT-WATER	CLUE
natural drivers and environmental pressures	resources, pollution	Not available	Not available	Climate change (as affected by emissions and policy)	water availability, soil conditions, climate	climate, land suitability for crops, effects of past land use, impact of pests, weeds and diseases
human drivers and pressures	GDP and population development, more specified socio-economic drivers, pollution	socio-economic factors, resources, technology	production functions including capital, labour and land prices	socio-economic factors, policy instruments (carbon taxes, tradable emission permits, regulatory policies)	population development, economy, technology development	population size and density, technology level, political structure, economy
policies	policy options	policy options	policy options	policy options	policy options	Scenario inputs
land use	yes	spatially explicit	explicit different land use types (land price and suitability for crops)	spatially explicit	spatially explicit, river basin scale	geographically explicit modeling of land use/cover
biodiversity	Not available	Not available	Not available	Not available	Not available	Not available

Model name	**PoleStar**	**Threshold 21**	**GTAP**	**ENV-Linkages**	**IMPACT-WATER**	**CLUE**
ecosystem function	Not available	Not available	Not available	Not available	N, P and S balance, water cycle	Not available
ecosystem services	water resources, raw materials and agriculture, solid waste management, environmental loadings	agriculture, consumption of natural resources (renewable and non-renewable), resource depletion (e.g. forests), soil erosion, land degradation, greenhouse gas emissions, air and water quality (pollution)	agricultural food production	timber production	agricultural food production (crops and livestock), water supply	not available, except for land sused for agriculture, forestry and grazing
economic value/human well-being	income distribution and poverty	GDP			Percentage and number of malnourished preschool children, Per-capita calorie availability from Foods, prices	

1.6.3 Biogeochemical models

Model name	**PICUS**	**LPJmL**	**CENTURY**	**Agro-IBIS**	**IBIS**	**SAVANNA**
Natural drivers and environmental	climate	climate	climate	climate	climate	Climate, fire

Model name	**PICUS**	**LPJmL**	**CENTURY**	**Agro-IBIS**	**IBIS**	**SAVANNA**
pressures						
human drivers and pressures	forestry management	land use change	land use	land use, agricultural management practices (fertilization, irrigation)	Land use	land management (stocking density, fire)
policies	Via management input	Not directly, via land use only	Not directly, via land use only	Not directly, via land use only	Not possible	Yes, via land management, socio-economic factors
land use	spatially explicit	spatially explicit	not spatially explicit, detailed land management options (new ones can be defined)	spatially explicit	spatially explicit	spatially explicit (fractional cover of grid cells by different plant types)
biodiversity	forest species composition (diversity, naturalness indicators)	Vegetation composition (functional types)	No included	Vegetation composition (functional types)	Vegetation composition (functional types)	flora and fauna abundance (for defined functional groups)
ecosystem function	carbon sequestration, soil moisture (water cycling), N cycling, NPP	CO_2 exchange, water balance, annual NPP,	C, N, P, S and water balance, decomposition	Water cycling, energy balance, carbon flux, N balance, NPP, LAI, phenology	NPP, LAI, phenology, water cycle, energy balance	primary production, plant competition for water, light and nutrients, herbivory, predation, nutrient cycling
ecosystem services	timber production	Annual NPP, crop production	grass, tree and crop production, water supply	water balance, crop production	NPP, water runoff	livestock production, water budget (runoff)
economic value/human well-being	Costs and benefits of management practices	Not available	Not available	Not available	Not available	Costs and benefits of management practices

1.6.4 Hydrological models

Model name	**WaterGAP**	**(E-) SWAT**	**WBM**
natural drivers and environmental pressures	Climate, including climate change , disturbances (fire)	climate, topology	climate, topology
human drivers and pressures	Socio-economic factors (population growth, GDP): energy production, livestock numbers, area irrigated, population size	Land use/management (pollution)	demography
policies	Via scenario input	Via land use	Not available
land use	Geographically explicit modeling of land use/cover	spatially explicit	spatially explicit
biodiversity	no	no	no
ecosystem function	water cycle (runoff, discharge)	water cycle	water cycle
ecosystem services	Water supply	water supply, erision control	water supply, livestock production
economic value/human well-being	Water scarcity	Not available	Not available

1.6.5 Biodiversity models

Model name	**GLOBIO**	**MIRABEL**	**Biodiversity intactness index**	**Species area relationship (SAR)**	**GARP-based species distribution models**	**EUROMOVE**
natural drivers and environmental pressures	climate change, N deposition	climate change, N deposition	none	climate change	climate change	climate change
human drivers and pressures	land use change, N deposition, infrastructure, fragmentation	land use change, N deposition, infrastructure, fragmentation	land use	habitat loss and fragmentation (land use change), N deposition	None (via greenhouse gans emissions)	Land use
policies	Via IMAGE	Via land use, pollution	Via land use	Via land use	Via climate change	Via climate change and land use
land use	spacially explicit (input variable)	EUNIS land use classification	spatially explicit, classification: from protected to moderate use, degraded, cultivated, urban and plantation	not spatially explicit (aggregated at biogeographical units)	spatially explicit	spatially explicit
biodiversity	MSA (mean species abundance of original species)	habitats at risk	biodiversity intactness index	number of species	number of species, species distribution	number of species, species distribution
ecosystem function	Not available	habitats at risk	Not available	Not available	Not available	Not available
ecosystem services	Not available	Not available	Not available	Not available	Not available	Not available
economic value/human well-being	Not available	Not available	Not available	Not available	Not available	Not available

1.6.6 Ocean models I

Model name	**ASSETS**	**Atlantis**	**Aus-ConnIe**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM - General Equilibrium Ecosystem Model**
natural drivers and environmental pressures	Capacity of a system to flush/dilute nutrient loads	Biological, chemical, ecological and physical drivers related to the ecosystem	Sea level; Wind fields; Particle trajectories; Geostrophic currents; Wind forced components; Ocean currents;	Vulnerability/sensitivity of ecosystems	Population dynamics; Habitat preferences; Trophic interactions.	Population dynamics; trophic interactions; biomass fluxes.
human drivers and pressures	Input of Nitrogen and Phosphorous; Poor management of watersheds.	Fisheries	Not applicable	17 different anthropogenic drivers covering pelagic and demersal,fishing, climate change, pollution, transport, and invasive species.	Fisheries	Human impacts on the energy/biomass flows within a food web, e.g. culling fish species through fisheries or habitat modification.
policies	Related policies are: Clean Water Act of 1972 (US); Air Pollution Prevention and Control Act of 1977 (US); Coastal Zone Management of 1972 (US); Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (US); EU Water Framework	Relating most closely to fisheries and environmental protection policies.	None specified	None considered but this model could be used to advise on a wide range of marine protection/use policies.	Relating most closely to fisheries and environmental protection policies.	Aim nof model is to influence more effective policy-making through providing a link between the ecosystem and its economic valuation.

Model name	**ASSETS**	**Atlantis**	**Aus-ConnIe**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM - General Equilibrium Ecosystem Model**
	Directive (EU); Urban Wastewater Treatment Directive (EU); Nitrates Directive (EU); Shellfish Directive (EU); Bivalve Transport Directive (EU); OSPAR Convention; HELCOM Convention; and Barcelona Convention.					
land use	Land-based nutrient run-off	Not applicable	Not applicable	Land-based pollution	Not applicable.	Model can be used to assess the impacts of land modification/use on the energy relationships in food webs.
biodiversity	Macroalgae, diatoms, flagellates, pelagic and benthic alage, harmful algae.	Dynamics of functional groups within a given food web (with Nitrogen as the common currency between these groups)	Larvae (dispersal and recruitment); other species influenced by ocean currents; connectivity of genetic resources.	Implicit through the focus on ecosystems.	Biodiversity impacts of fisheries, *e.g.* direct loss of biodiversity through Depeletion Index.	Impacts of human interactions on the trophic dynamics of species food-webs within an ecosystem with the view to linking economic valuation information to this.
ecosystem function	Loss of SAV; Dissolved Oxygen; Nuisance and Toxic	Fisheries impacts on ecosystem function and	Connectivity of ecosystems inc. Larval and	Implication that increased cumulative threat index would lead	Fisheries impacts on ecosystem function, e.g. Loss of functional	Negative impacts on food webs can lead to loss of functional

Model name	**ASSETS**	**Atlantis**	**Aus-ConnIe**	**Cumulative Threat Model for the global ocean**	**EwE, EcoSpace & EcoOcean**	**GEEM - General Equilibrium Ecosystem Model**
	Algal Blooms; Eutrophication leading to dead zones, thus loss of ecosystem function.	structure.	contaminant dispersal.	to loss of ecosystem function.	groups, disaggregation of communities, change in community controls (i.e. Bottom-up/top-down).	groups, trophic cascades, and a reduction of ecosystem functionality in general.
ecosystem services	Negative impact on water quality, thus affecting fisheries/aquaculture; ecosystem health; and human uses.	Unsustainable use of provisioning services; Disruption to trophic structure; Loss of connectivity/genetic resources.	Connectivity affects larval recruitment for fisheries; increases genetic diversity leading to increased redundancy and higher ecosystem resilience and functioning; Dispersal of contaminants and understanding their potentially negative effects on ecosystem services.	Approach provides a structured framework for quantifying the ecological tradeoffs associated with different human uses of marine ecosystems and for identifying locations and strategies to minimize ecological impact and maintain sustainable use	Unsustainable use of provisioning services; Destruction of supporting habitats; Loss of connectivity/genetic resources;	Trophic controls of fisheries; carbon and nutrient cycling; ecosystem reactions to impacts including loss of functionality leads to potential impact on ecosystem services;
economic value/human well-being	Negatively impact fisheries/aquaculture; revenue from recreation; Toxic algal blooms can be harmful to human health.	Food security; economic/fisheries resource value of ecosystem goods and services under different management scenarios.	Understanding sustainability of fisheries, understanding dispersal of contaminants possibly harmful to marine	Model implies that areas that are more highly impacted will not be able to provide the quality and range of ecosystem services as less impacted areas. Reduced goods and	Bioaccumulation effects; food security; economic value of ecosystem goods and services under different management scenarios;	Negatively impact fisheries; possible threats to food security; negative impacts on livelihoods if ecosystem functionaility/services

Model name	ASSETS	Atlantis	Aus-ConnIe	Cumulative Threat Model for the global ocean	EwE, EcoSpace & EcoOcean	GEEM - General Equilibrium Ecosystem Model
			resources and humans thus reducing ecosystem services, general understanding of the sustaiability and connectivity of ecosystem services.	services will have a general negative impact on human health.		are lost potentially impacting vulnerable coastal communities.

1.6.7 *Ocean model II*

Model name	Impact of Climate Change on Global Biodiversity	RamCo (Versions 1.0 and 2.0)	Reefs at Risk	ERSEM II	ICTHYOP
natural drivers and environmental pressures	Population dynamics; Species habitat preferences; Oceanographic variables (e.g. Bathymetry).	Micro-scale drivers of Sea Use Functions (seagrass and coral reefs); Land Use functions (Mangrove; Nature/forest); Land use features (Sea; Inland water); and Macro-scale drivers based around water and ecology.	Relative slope, land cover class, and precipitation are used for the Inland pollution and erosion model. Otherwise, natural drivers, such as disease and bleaching, are not considered.	Carbon dynamics; nutrient dynamics; trophodynamics; physical drivers such as climate and weather (when linked with physical models).	Biological: age (day), length (mm), stage (egg, yolk-sac larva, or feeding larva), location (longitude/latitude) and depth (m), and status (alive or dead). Physical: current velocities (m s-1), temperature (*C), and salinity. The physical inputs are

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo (Versions 1.0 and 2.0)**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
					archived from oceanic simulations of the "Regional Oceanic Modelling System" (ROMS) or the "Model for Applications at Regional Scale" (MARS).
human drivers and pressures	Anthropogenic climate change	Micro-scale functions of Land Use functions (Agriculture; Rice culture; Shrimp culture; Industry; Tourism; Urban residential; Rural residential); and Land use features (Airport; Harbour; Beach); and Macro-scale drivers based around land use and the economy.	Coastal development; Marine pollution; Overexploitation and Destructive fishing; Inland Pollution and Erosion.	Not available	Not available
policies	Not specified, however, model outputs are relevant to fisheries policies and marine	Future policy choices under the influence of climate changes, demographic	Outputs can be and have been used to inform policy making and have been	Production of accurate scenarios by the ERSEM can be used to inform	None specified

Model name	Impact of Climate Change on Global Biodiversity	RamCo (Versions 1.0 and 2.0)	Reefs at Risk	ERSEM II	ICTHYOP
	protection policies (through identification of hotspots).	growth or changing economic demand can be tested.	used to set regional and local priorities - such as in Sabah, where the Reefs at Risk analysis aided the development of legislation restricting coastal development	policy-makers on decisions relating to sectors such as fisheries management and climate change.	
land use	Not applicable	Land Use functions (Agriculture; Rice culture; Shrimp culture; Industry; Tourism; Urban residential; Rural residential; Mangrove; Nature/forest); and Land use features (Sea; Inland water; Airport; Harbour; Beach).	Land cover type and inland sources of pollution.	Not applicable	Not applicable
biodiversity	Current and future distributions of 1066 commercial fish species are modelled.	Impacts of policies and future demographic and socio-economic	Coral reef degradation is considered in terms of major changes in	Lower trophic levels of pelagic and benthic marine systems.	Larvae (dispersal and recruitment); connectivity of genetic resources.

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo (Versions 1.0 and 2.0)**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
		change on coastal zone biodiversity, in particular, pollution impacts on rivers and the coast, destruction of habitats for food production increasing erosion and sedimentation.	species composition and relative species abundance.		
ecosystem function	Disassociation of communities within an ecosystem leading to functional loss or change.	Pollution and sedimentation lead to species die-offs and alteration of current ecosystem function. Destruction of land-based habitats negatively effect ecosystem buffering functionality, increasing flooding.	Coral reef degradation is considered in terms of major change sto the productivity of coral reef communities.	Carbon and nutrient cycling; lower trophodynamic influences regarding bottom-up control.	Connectivity of ecosystems inc. Larval dispersal.
ecosystem services	Impacts on fisheries (commercial and artisanal); Potential services loss through	Increased pressures on the coastal zone will negatively impact	Considers impacts on all ecosystem services provided	Bottom-up control of fisheries; carbon and nutrient	Connectivity affects larval recruitment for fisheries; increases

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo (Versions 1.0 and 2.0)**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
	teh diassociation of functioning ecosystem communities.	biodiversity and ecosystem function, thus generally degarding teh wide variety of ecosystem services provided by coastal zone systems.	by coral reefs.	cycling; ecosystem reactions to impacts and thus potential impact to ecosystem services; Regulation of marine bacteria and viruses.	genetic diversity leading to increased redundancy and higher ecosystem resilience and functioning.
economic value/human well-being	Negatively impact fisheries economics, particularly the vulnerable coastal communities that rely on small, artisanal fisheries	Polluted water has negative impacts on human health, potential for risks to food security if coastal system functionality is lost, increased or modified flood patterns can cause direct risks to coastal communities.	Negatively impact economic benefits of coral reefs (fisheries, medicinal products, curio/jewellry, aquarium trade); Increase vulnerability of coastal communities and habitats to natural hazards; Reduce food availability impacted on human health; Negatively impact livelihood associated with coral reefs; negatively impact	Bottom-up control of fisheries; Marine bacteria and virus dynamics; Influence of weather and climate on marine ecosystem services (e.g. Food security).	Understanding sustainability of fisheries; general understanding of the sustaiability and connectivity of ecosystem services.

Model name	**Impact of Climate Change on Global Biodiversity**	**RamCo (Versions 1.0 and 2.0)**	**Reefs at Risk**	**ERSEM II**	**ICTHYOP**
			spiritural, cultural, and aesthetic values associated with coral reefs.		

1.6.8 *Regional models/asssessments*

Model name	**ATEAM**	**InVEST**	**Naidoo et al., 2008**	**Swallow et al., 2009**	**Patuxent landscape model (PLM) Costanza et al. 2002**
natural drivers and environmental pressures	climate	not yet (possible: climate change)	none (mapping only)	None (mapping only)	Climate
human drivers and pressures	socioeconomic factors and land use	management practices, infrastructure, governance	none (mapping only, potentially: land use)	land use change	land use
policies	Via scenario inputs	governance, stakeholder-defined scenarios	examined: habitat conservation policies: synergies with ecosystem services	Via land use change	Via economics
land use	14 land use types, spatially explicit	spatially explicit	spatially explicit	spatially explicit	spatially explicit, land use types: water, forest, agricultural, rural

Model name	**ATEAM**	**InVEST**	**Naidoo et al., 2008**	**Swallow et al., 2009**	**Patuxent landscape model (PLM) Costanza et al. 2002**
					residential, urban
biodiversity	yes (species richness and turnover of plants, mammals, birds, reptiles and amphibians), shifts in suitable habitats	yes (Species richness (species area realtionship), habitat area and quality)	yes (species distribution for mammals, birds, reptiles and amphibians)	Not available	Not available
ecosystem function	Water and carbon cycling, soil fertility	carbon and water cycling	carbon and water cycling	Not available	primary production, soil nutrient cycling
ecosystem services	food and timber production, water and carbon regulation, soil fertility, recreation	water quality, supply and regulation, timber and food production, carbon stocks and sequestration, recreation, species richness	carbon sequestration and storage, water supply, livestock production	Food and water supply, erosion control, water quality	water supply, aesthetic value (house prices)
economic value/human well-being	Not available	economic valuation of ecosystem services (per hectare market values)	Not available	Not available	aesthetic value (house prices)

2 APPENDICES OF CHAPTER 3: OVERVIEW OF RESULTS FROM MODELS FOR THE LOSS OF BIODIVERSITY AND ECOSYSTEMS AND THEIR SERVICES

2.1 List of relevant projections and model results made in the assessment

Biodiversity / ecosystem service	Assessment	Scenarios	Indicator	Model	Details examined?
Terrestrial biodiversity	OECD Environmental Outlook to 2030	1	Mean Species Abundance	IMAGE	Yes
Terrestrial Biodiversity	GEO 4	4	Forest cover	IMAGE	Yes
Terrestrial biodiversity	MA	4	Forest cover	IMAGE 2.2	Yes
Terrestrial biodiversity	MA	4	Global loss of vascular plant species	IMAGE 2.2	Yes
Terrestrial biodiversity	GEO 4	4	Mean Species Abundance	GLOBIO	Yes
Terrestrial biodiversity	CBD 2006	7	Mean Species Abundance	IMAGE GLOBIO 2	Yes
Terrestrial Biodiversity	MA	4	Global loss of vascular plant species through nitrogen deposition	IMAGE 2.2	No
Terrestrial biodiversity	MA	4	Global loss of vascular plant species through habitat loss	IMAGE 2.2	No
Food availability	IAASTD	1	kilocalories/day	IRPRI IMPACT	Yes

Biodiversity / ecosystem service	**Assessment**	**Scenarios**	**Indicator**	**Model**	**Details examined?**
Food availability	GEO 4	4	kilocalories/day	IMAGE	Yes
Food production	MA	4	Cereal yield (megatonnes/year)	IMPACT	Yes
Food production	IAASTD	2	Fish landings	ECO-OCEAN	Yes
Food production	IAASTD	1	cereal yield	IFPRI IMPACT	Yes
Marine biodiversity	MA	4	Biomass Diversity Index	Ecopath with Ecosim	Yes
Marine biodiversity	GEO 4	4	Change in total biomass of select fish groups	EwE	Yes
Marine biodiversity	Ecosystem based global fishing policy scenarios	4	MTI (Marine Trophic Index)	EcoOcean	Yes
Marine: Biomass Diversity Index	IAASTD	2	Biomass Diversity Index	EcoOcean	Yes
Terrestrial biodiversity	Ag Assessment	1	Mean Species Abundance	GLoBio3	Yes
Erosion control	MA	4	million km2	IMAGE 2.2	Yes
Erosion control	GEO 4	4	million km2	IMAGE	No
Food production	MEA	4	fish landings	Ecopath/Ecosim	No
Food production	GEO 4	4	cereal yield (tonnes/ha)	IMAGE	No

Biodiversity / ecosystem service	**Assessment**	**Scenarios**	**Indicator**	**Model**	**Details examined?**
Food production	GEO 4	4	Total landings from marine fisheries (billion tonnes)	EcoPath with EcoSim	No
Food production	Ecosystem based global fishing policy scenarios	4	Total landings from marine fisheries (billion tonnes)	EcoOcean	No

2.2 Projections of biodiversity and ecosystems services under different assessment scenarios.

All projections from 2000 to 2050 unless stated

	Scenario	Biodiversity / ecosystem service	Model	Projections	Pressures and trends
CBD - Global Biodiversity Outlook	Baseline	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global losses of 7.5%. Sub-Saharan Africa, Europe show declines of greater than 11%.	Infrastructure, increasing climate change, agriculture, increasing climate change development and settlement also become increasingly important.
	Full trade liberalisation in agriculture	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global losses of 8.8%; 1.3% below the baseline.	Shift of agricultural production to Southern Africa and Latin America. Agricultural areas no longer required in developed countries potentially restored for biodiversity.
	Alleviation of extreme poverty in Sub-Saharan Africa	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global losses of 9.2%; 1.7% below the baseline. Reduces by 5.7% from the baseline in Sub-Saharan Africa.	Increased food consumption in Africa, produced predominately in the region. Potential long term benefits from reductions in demographic pressure and economic improvements.
	Climate Change mitigation policy	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global losses 8.5%; 1% below the baseline.	Biodiversity gain (+1%) from avoiding climate change and reduced nitrogen deposition. Loss (-2%) from additional land use for biofuels.
	Sustainable wood production	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 7.4%; +0.1% above the baseline.	Initial biodiversity loss through landuse. Later, reduced climate change and pressure on natural forests. Semi natural forests previously exploited left to recover.
	Sustainable meat production	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 7.2%. +0.3% above the baseline.	Increase in the cost of meat means lower demand and less area being needed for agriculture and lower nitrogen deposition.

	Scenario	**Biodiversity / ecosystem service**	**Model**	**Projections**	**Pressures and trends**
	Doubling terrestrial biomes under protection	Terrestrial Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 6.4%. +1.1% above baseline. Latin America and Africa see smallest improvements.	Nitrogen deposition, fragmentation and climate change and increased pressure on adjacent land. Partly offset by reduced land conversion and greater connectivity.
OECD Environmental Outlook to 2030	OECD baseline scenario	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 11%. Deterioration faster than 20th century.	Infrastructure, climate change, expansion of agricultural land.
	OECD policy package	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 11%. Deterioration faster than 20th century.	Infrastructure becomes an increasing source of pressure on MSA between now and 2050, from -6% to -11%. Climate change also becomes more significant. The expansion of crops and pasture accounts for the biggest loss of MSA.
	OECD 450ppm	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 10%. Biggest improvement from baseline.	Infrastructure, climate change, woody fuel, crops. Partly offset by reduced impacts of climate change.
	OECD global policy package	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 11%.Deterioration faster than 20th century.	Infrastructure, climate change, crops.
IAASTD	Baseline	Terrestrial: Mean Species Abundance	GLoBio3	Global loss of 10%. The rate of loss is faster than between 1970 - 2000.	Infrastructure, climate change and agricultural expansion.
GEO 4	*Markets first*	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 12%. 16% and 15% loss in Africa and Latin American & the Caribbean respectively.	Infrastructure to access natural resources, climate change. Agriculture exerts negative pressure in Africa and Latin America & the Caribbean. Positive impact elsewhere.

	Scenario	Biodiversity / ecosystem service	Model	Projections	Pressures and trends
	Policy first	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 7%. 10% and 8% loss in Africa and Latin American & the Caribbean respectively.	Climate change, agriculture expansion. Protected areas protect some of the most endangered species.
	Security first	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 10%. 16% and 12% loss in Africa and Latin American & the Caribbean respectively.	Infrastructure and climate change, exacerbated by large population growth and increased conflict.
	Sustainability first	Terrestrial: Mean Species Abundance	IMAGE GLOBIO 3	Global loss of 7.5%. 10.5% and 9% loss in Africa and Latin American & the Caribbean respectively.	Climate change and expanded demand of agricultural land for biofuels. Protected areas protect some of the most endangered species.
GEO 4	*Markets first*	Forest cover	IMAGE GLOBIO 3	Global forest cover projected to reduce from circa 45 million km^2 in the year 2000 to circa 40 million km^2 by 2050. N. America and Europe projected to see a slight growth in forest cover whereas Africa, Latin America and the Caribbean are all projected to have a decrease.	Loss of forest cover is not as pronounced as under the Policy First and Sustainability First scenarios since the increasing demand for land is partly compensated by developments in technology under this scenario.
	Policy first	Forest cover	IMAGE GLOBIO 3	Global forest cover projected to reduce from circa 45 million km^2 in the year 2000 to circa 35 million km^2 by 2050. Africa is projected to lose nearly the entirety of its forest cover.	Population growth, strong targets for mitigating the effects of GHG emissions under this scenario leads to added pressure to increase the area of land used for biofuel crop production.
	Security first	Forest cover	IMAGE GLOBIO 3	Global forest cover projected to reduce to circa 42 million km^2 by 2050 (from 45 million km^2 in 2000). From 2030, an increase in forest cover is projected in Asia and the Pacific, Europe and N. America. In Latin America and the Caribbean forest cover is projected to stabilise at circa 8 million km^2 between 2020 and 2050.	Under this scenario, low economic growth means agricultural land expansion is smallest out of all the scenarios. In Latin America and the Caribbean where forest is a key natural resource, key forest areas are kept well protected due to the interests of the elite in this region.
	Sustainability first	Forest cover	IMAGE GLOBIO 3	Global forest cover projected to decrease by circa 7 million km^2 (from the year 2000) to circa 38 million km^2 in 2050. Slight increase in forest cover in Latin America and the Caribbean projected between 2030 and 2050.	Strong targets for mitigating the effects of GHG emissions under this scenario, added pressure to increase the area of land used for biofuel crop production. Improvements in technology made under this scenario counterbalanced by an increased concern for food availability. In Latin America and the Caribbean,

	Scenario	Biodiversity / ecosystem service	Model	Projections	Pressures and trends
					mechanisms put in place in order to rehabilitate affected forest ecosystems.
MA	*Global Orchestration*	Forest cover	IMAGE 2.2	Rate of loss of "original forest"* unchanged. Cover increases in Industrial regions and declines in Developing regions	Rapid income growth and preference for meat. Partly offset by increased crop yields due to technological innovation. Circa 50% of Sub-Saharan forest disappears.
	Order from Strength	Forest cover	IMAGE 2.2	Rate of loss of "original forest"* globally increases from 0.4% to 0.6%. Significant reductions in Developing regions.	Increasing population and slow improvements in crop yield in low-income countries. Two thirds of Central African forest in 1995 gone.
	Adapting Mosaic	Forest cover	IMAGE 2.2	Rate of loss of "original forest"* unchanged. Cover increases in Industrial regions and declines in Developing regions	Locally successful experiments mitigate expansion of agricultural land after 2040. Lowest deforestation rates in Africa but virtual depletion of forest areas in South Asia by 2100 due to low crop yields.
	Techno Garden	Forest cover	IMAGE 2.2	Net increase in forest cover. Rate of loss of "original forest"* slightly below current rate. Significant depletion in Africa and Southeast Asia.	Assumed lower meat consumption reducing pastureland. Partly offset by increase in crops and land for biofuels to combat climate change.
MA	*Global Orchestration*	Global loss of vascular plant species	IMAGE 2.2	16.5% loss between 1970 and 2050.	Climate change main driver on savanna and cool conifers. Agricultural expansion, particularly in temperate, tropical and warm mixed forests. N deposition important driver on temperate deciduous forest.
	Order from Strength	Global loss of vascular plant species	IMAGE 2.2	18.5% loss between 1970 and 2050.	Climate change, agricultural expansion, N deposition. Expanding population and slow crop yields main driver.
	Adapting Mosaic	Global loss of vascular plant species	IMAGE 2.2	15% loss between 1970 and 2050.	Climate change, agricultural expansion. Slower development rates in developing countries slowing the increases in food demand.

	Scenario	Biodiversity / ecosystem service	Model	Projections	Pressures and trends
	Techno Garden	Global loss of vascular plant species	IMAGE 2.2	13.5% loss between 1970 and 2050.	Agricultural expansion, climate change. Higher yields and stabilising population reduce land expansion impact.
GEO 4	*Markets first*	Food availability (kilocalories/day)	IMAGE GLOBIO 3	Large increases in all regions. Consistent gaps between rich and poor.	Increased demand, greater investments in technology.
	Policy first	Food availability (kilocalories/day)	IMAGE GLOBIO 3	Large increases in all regions. Consistent gaps between rich and poor.	Increased demand, greater investments in technology, environmental stewardship.
	Security first	Food availability (kilocalories/day)	IMAGE GLOBIO 3	Food production barely keeps up with population increase after 2020 and there is a small decline after 2040.	Growing population, lack of investment in technology.
	Sustainability first	Food availability (kilocalories/day)	IMAGE GLOBIO 3	Largest increases in all regions. Significant reduction in gap between rich and poor countries.	Lower overall population growth, reduced land degradation, regional integration.
IAASTD	*Reference scenario*	Food availability (kilocalories/day)	IFPRI IMPACT	Slow improvement. Lowest in Sub-Saharan Africa and South Asia at circa 2, 7400 compared to over 3,000 elsewhere. Child malnutrition grows 11% in Sub-Saharan Africa.	Increasing food prices, inability of poor countries to increase production to match population growth.
	Reference scenario	Food production (cereal yield)	IFPRI IMPACT	Grows at a slower annual rate than 1980-2000 of 1.96% to 1.02%. Latin America and Caribbean and Sub-Saharan Africa grow 1.61% and 1.68% respectively.	Moderate technological investment. Slowed by increasing water scarcity, drought from climate change.
MA	*Global Orchestration*	Food production (cereal yield)	IMPACT	World output increases 72% , almost four-fold in Sub-Saharan Africa.	Large investments in agricultural research and supporting infrastructure. Land under irrigation increases rapidly.

	Scenario	**Biodiversity / ecosystem service**	**Model**	**Projections**	**Pressures and trends**
	Order from Strength	Food production (cereal yield)	IMPACT	World output increases 55%.	Significant crop area expansion as investments insufficient to match demand. Subsidies and barriers increase cost of procuring food, particularly for the poor.
	Adapting Mosaic	Food production (cereal yield)	IMPACT	World output increases 53%.	Food produced locally on expanded crop areas insufficient for demand. Results in pressures on food prices and increase in demand for imports.
	Techno Garden	Food production (cereal yield)	IMPACT	World output increases 57%.	Substantial improvements in crop yields and lower meat consumption diet reducing demand for crop area expansion. Medium population growth.
GEO 4	*Markets first*	Change in total biomass of select fish groups	Ecopath with Ecosim	Large demersals decrease by circa 6% and large pelagics decrease by circa 14%.	Increase in global income and improved technology. Increased fishing effort.
	Policy first	Change in total biomass of select fish groups	Ecopath with Ecosim	Large demersals increase to circa 8% while large pelagics decrease by circa 7%.	Increased fishing effort.
	Security first	Change in total biomass of select fish groups	Ecopath with Ecosim	Large demersals increase by circa 4% while large pelagics decrease by circa 11%.	Large projected population
	Sustainability first	Change in total biomass of select fish groups	Ecopath with Ecosim	Large demersals increase to 30% while large pelagics decrease by circa 8%.	Attempt to fish lower on the food chain, shifting diets and smaller increases in population.
MA	*Global Orchestration*	Marine: Biomass Diversity Index	Ecopath with Ecosim	**Gulf of Thailand** responds well to ecosystem rebuilding, but drops dramatically when focus changes to provide fishmeal for aquaculture. **Bay of Benguella** responds to ecosystem recovery after 2030. **Central North Pacific** is not much affected.	Decline in fisheries addressed once economic importance becomes apparent. High global coordination a positive.

	Scenario	**Biodiversity / ecosystem service**	**Model**	**Projections**	**Pressures and trends**
	Order from Strength	Marine: Biomass Diversity Index	Ecopath with Ecosim	Risk of fisheries collapse high worldwide. **Gulf of Thailand** decreases consistently. **Bay of Benguella** initially does well as focus on jobs results in ecosystem management. **Central North Pacific** loses biomass diversity.	Unchecked exploitation and lack of co-ordination.
	Adapting Mosaic	Marine: Biomass Diversity Index	Ecopath with Ecosim	**Gulf of Thailand** decreases consistently. **Bay of Benguella** increased due to management policy to maintain jobs. **Central North Pacific** increases slightly in response to protection but decreases in 2030 when focus returns to high-value fisheries.	Informed local management does well but is hampered by lack of co-ordination at the global level.
	Techno Garden	Marine: Biomass Diversity Index	Ecopath with Ecosim	**Gulf of Thailand** responds very well to ecosystem rebuilding, but drops dramatically when focus changes to provide fishmeal for aquaculture. **Bay of Benguella** drops initially but increases after 2030 when managed to provide fishmeal due to the favourable mix of species present. **Central North Pacific** decreases as technology improves catch rate. Not affected by development of aquaculture.	Decline in fisheries is addressed through environmental technologies and rapid development of aquaculture.
Ecosystem based global fishing policy scenarios	*Markets first*	MTI (Marine Trophic Index)	EcoOcean	General decrease in Marine Trophic Index in all oceans studied. Increased landings usually at lower trophic levels.	As most large bodied demersal fish already overexploited in 2003, landings were increased by augmenting secondary demersal fish groups and invertebrates (e.g. lobster, crab, shrimp).
	Policy first	MTI (Marine Trophic Index)	EcoOcean	General decrease in Marine Trophic Index in all oceans studied. Increased landings usually at lower trophic levels.	As most large bodied demersal fish already overexploited in 2003, landings were increased by augmenting secondary demersal fish groups and invertebrates (e.g. lobster, crab, shrimp).

	Scenario	**Biodiversity / ecosystem service**	**Model**	**Projections**	**Pressures and trends**
	Security first	MTI (Marine Trophic Index)	EcoOcean	General decrease in Marine Trophic Index in all oceans studied. Increased landings usually at lower trophic levels.	As most large bodied demersal fish already overexploited in 2003, landings were increased by augmenting secondary demersal fish groups and invertebrates (e.g. lobster, crab, shrimp).
	Sustainability first	MTI (Marine Trophic Index)	EcoOcean	Least increase in landings. Slightly higher MTI in most oceans studied than the other scenarios but a general decrease still projected in all oceans studied. Increased landings usually at lower trophic levels. In some areas under this scenario a decreased demersal fleet effort is projected.	As most large bodied demersal fish already overexploited in 2003, landings were increased by augmenting secondary demersal fish groups and invertebrates (e.g. lobster, crab, shrimp).
GEO-4	*Markets first*	Marine Trophic Index of catch	Ecopath with Ecosim	General decrease in MTI	Increased fishing effort and improved technology
	Policy first	Marine Trophic Index of catch	Ecopath with Ecosim	General decrease in MTI	
	Security first	Marine Trophic Index of catch	Ecopath with Ecosim	General decrease in MTI. Highest MTI of catch as effort is maintained on more valuable species.	Lower catches but efforts maintain on higher value fish.
	Sustainability first	Marine Trophic Index of catch	Ecopath with Ecosim	Biggest decrease in MTI	Attempt to fish lower on the food chain to maintain marine ecosystems. Lower overall catch increases due to smaller population increases and changing diets.
IAASTD	Reference Scenario	Marine Trophic Index of catch	EcoOcean	**Atlantic Ocean:** decreased trophic level of catches by 2-2.5%. **Pacific Ocean:** Unchanged. **Indian Ocean:** Unchanged. **Mediterranean:** 3% decline. All between 2003-2048.	Value of landings optimised with fishing effort as the driver, until 2010, after which only small pelagic fleet allowed to change.

	Scenario	Biodiversity / ecosystem service	Model	Projections	Pressures and trends
	Increase in small pelagic fleet	Marine Trophic Index of catch	EcoOcean	**Atlantic Ocean:** decreased trophic level of catches of 2-2.5%. **Pacific Ocean:** declines 1.3%. **Indian Ocean:** Consistent decline. **Mediterranean:** consistent decline. All between 2003-2048.	2% increase in pelagic fishing effort per year after 2010. Sustainability of Indian Ocean & Mediterranean uncertain due to constant fall in trophic level. Atlantic observes declines in large demersal and bentho-pelagic fish.
	Reference Scenario	Food Production (fish landings)	EcoOcean	**Atlantic Ocean**: decrease 5.4%. **Pacific Ocean**: declines 5%. **Indian Ocean**: initial decline, eventual 1% increase. **Mediterranean:** 7% increase. All between 2003-2048.	Value of landings optimised with fishing effort as the driver, until 2010, after which only small pelagic fleet allowed to change.
	Increase in small pelagic fleet	Food Production (fish landings)	EcoOcean	**Atlantic Ocean:** increase 7%. **Pacific Ocean:** large increase. **Indian Ocean:** less than 5% increase. **Mediterranean:** 50% increase, then level. All between 2003-2048.	2% increase in pelagic fishing effort per year after 2010. Increases in small pelagic.
MA	*Global Orchestration*	Water induced Soil Erosion	IMAGE 2.2	Significant increasing pressure, global area of soil with high water erosion risk increases from circa 22 Mkm^2 in 2000 to circa 28 Mkm^2 in 2050.	Large pressure as a result of precipitation increase, and to a lesser extent from land use change.
	Order from Strength	Water induced Soil Erosion	IMAGE 2.2	Significant increasing pressure, most of all the scenarios. Approximately 50% increase in the global area of soil with high water erosion risk by 2100 (from circa 22 Mkm^2 in 2000 to 32 Mkm^2 in 2050 and 40 Mkm^2 in 2100).	Large pressure as a result of land use change to a lesser extent from increased precipitation and agricultural practices.
	Adapting Mosaic	Water induced Soil Erosion	IMAGE 2.2	Significant increasing pressure, global area of soil with high water erosion risk increases from circa 22 Mkm^2 in 2000 to circa 28 Mkm^2 in 2050.	Pressure due to increased precipitation and land use. Agricultural practices have a positive impact owing to localised objectives to prevent soil erosion which slows the degradation of active agricultural land and significantly restores previously degraded land.
	Techno-Garden	Water induced Soil Erosion	IMAGE 2.2	Significant increasing pressure but less than other scenarios. Global area of soil with high water erosion risk increases from circa 22 Mkm^2 in 2000 to circa 28 Mkm^2 in 2050 and increases to circa 31 Mkm^2 by 2100 (lowest of all scenarios).	Pressure due to increased precipitation and land use. Agricultural practices have a positive impact since they are more ecologically proactive.

NOTES

All projections from 2000 to 2050 unless stated

* "Original forests" here means forests that were present in 1970 and have not changed their attributes through agricultural expansion, timber production or climate change. Historic rate refers to rate between 1970 - 2000 rate.

2.3 The most important assumptions and examples of different categories of scenarios used in the assessments

		Population	**Overall GDP Increase**	**Energy Use**	**Agricultural production & consumption**	**Primary Goals**	**Environmental protection**	**Trade**	**Technology development**
Business as usual	OECD Baseline	9.1 bn in 2050 (40% increase); 8.2 bn in 2030 (27% increase)	Annual global GDP increase of 2.8%. Overall world GDP increases 87%; India and China increase over 300%. (2005 - 2030)	280 EJ to 470 between 2000 and 2030.	Consumption increases 50% globally by 2030; 70% in developing countries. stable in OECD countries.	Not defined	Both reactive and proactive	Weak globalisation	Average
	IAASTD Baseline	8.2 bn in 2050	Developed regions will see relatively low and stable to declining growth rates between 1 and 4% per year out to 2050. East and SE Asia growth rate of between 4-7% per year to 2050. LAC region 3.5-4.5% growth per year to 2050	280 EJ (year 2000) increases to 500 EJ by 2030 and to over 700 EJ in 2050. Biggest rises in developing countries; but higher energy consumption per capita in developed countries.	Number of malnourished children will decline from150 million (2000) to 130 million in 2025 and to 100 million in 2050. Total area of agricultural land worldwide increased by 10% in 2050.	Not defined	Both reactive and proactive	Current trade conditions continue to 2050 – no trade liberalisation or reduction in sectoral protection.	
Conventional	GEO 4 *Markets First*	9.2 bn by 2050	Approximately 500% increase in global GDP by 2050.	Increases from 400 EJ in 2000 to over 1000EJ		Maximum economic growth	Reactive	Significant increase in global trade (from	Rapid

		Population	**Overall GDP Increase**	**Energy Use**	**Agricultural production & consumption**	**Primary Goals**	**Environmental protection**	**Trade**	**Technology development**
				in 2050				approx 10 trillion US$ in 2000 to approx 75 trillion US$ in 2050)	
Reformed Markets	MA Global Orchestration	7.2 bn by 2020 increasing to 8.1 bn in 2050. Population projected to be 6.8 bn in 2100.	Annual growth rates of GDP per capita (% per year) is 3% between 2020 and 2050 and 2.3% between 2050 and 2100.	Increases from 400 EJ in 2000 to 1200 EJ by 2050		Globally connected society with a focus on global trade and economic liberalisation	Reactive	Trade liberalisation	Rapid
	GEO 4 *Policy First*	8.6 bn by 2050	Approximately 500% increase in global GDP by 2050	400 EJ in 2000 to 600-700 EJ in 2030 and around 800-900 EJ in 2050		Centralised approach in order to balance strong economic growth with reduced potential environmental and social impacts	Both reactive and proactive	Increase in global trade (from approx 10 trillion US$ in 2000 to approx 60 trillion US$ in 2050)	Rapid
Competition Between	GEO 4 *Security First*	9.7 bn by 2050	Nearly 300% increase in global GDP by 2050	400 EJ in 2000 to 600-700 EJ in 2030 and around 800-900 EJ in		Security	Reactive	Trade increases from approx 10 trillion US$ in 2000 to 20 trillion	Slow

Deleted: MEA

		Population	**Overall GDP Increase**	**Energy Use**	**Agricultural production & consumption**	**Primary Goals**	**Environmental protection**	**Trade**	**Technology development**
				2050				US$ in 2050, the smallest increase of all four GEO4 scenarios	
	MA Order from Strength	7.7 bn by 2020 increasing to 9.5 bn in 2050, reaching 10.5 bn in 2100.	Annual growth rates of GDP per capita (% per year) is 1.0% between 2020 and 2050 and 1.3% between 2050 and 2100.	400 EJ in 2000 to 800 EJ in 2050		Security and protection, emphasis on regional markets	Reactive	Trade barriers, regional markets	Overall technological development is low (medium in industrial countries)

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3 APPENDICES FOR CHAPTER 4: ASSESSMENT OF IMPACT OF KEY ASSUMPTIONS

3.1 Terrestrial Models

(Score # indicates number of criteria (columns) for which the model does not provide information)

Model name	**Ecosystem Service Provision**				**Biodiversity**	**Economic Value of Output**	**Scale of Output**	**Earlier applications in assessments**	**Score**
	Provisioning services	**Supporting services**	**Cultural services**	**Regulating services**					
Integrated assessment models									
GUMBO	Harvested organic matter, water supply, mined ores, and extracted fossil fuel	Soil formation (decomposition), nutrient (N) cycling	recreation, cultural (positively related to total biomass and density of social network, negatively related to human population size)	gas regualtion (C flux), climate regulation (temperature), waste assimilation, disturbance regulation (variation in total biomass)	x	valuation: marginal product of ecosystem services in both the model's production and welfare functions	global, 11 biomes globally aggregated, not spatially explicit	x	2
IMAGE	Agricultural production, including grass/fodder production and livestock/milk production, demand for wood products, timber, fuelwood	Soil fertility	x	Carbon flux, carbon plantations, ocean carbon model, water-erosion sensitivity, air pollution, soil moisture	MSA through link with GLOBIO	x	Global (with details for 24 world regions (energy, trade emissions) or or 0.5º x 0.5º grid (land cover, land use)	SRES, MA, GEO, OECD, IAASTD, EURURALIS	2

Model name	**Ecosystem Service Provision**				**Biodiversity**	**Economic Value of Output**	**Scale of Output**	**Earlier applications in assessments**	**Score**
	Provisioning services	**Supporting services**	**Cultural services**	**Regulating services**					
MIMES	Food production, production of raw materials	Soil formation, nutrient cycling	recreation, cultural	climate regulation, waste assimilation , disturbance regulation	x	valuation: marginal product of ecosystem services in both the model's production and welfare functions	global, 1º by 1° resolution	x	2
AIM	Water supply, food and timber production	x	x	greenhouse gas emissions, air pollution, carbon sequestration, human health (malaria distribution), flood damage	Vegetation distribution	x	Focused on Asian-Pacific region, but linked to a global model representing 9 regions; 5° x 5°	SRES	3
IGSM	Agricultural production (can be separated into crops, livestock and forestry)	SOC	x	human health impacts, sea level, air pollution, carbon emissions and stocks	x	GDP growth	global, 16 regions with special studies on European countries, 0.5º to 4ºby5º grid, depending on submodel for the biogeochemical part	x	3
IIASA	timber production, agricultural food production,	x	x	carbon sequestration	x	x	global, 0.5º grid	SRES	4

Model name	Ecosystem Service Provision				Biodiversity	Economic Value of Output	Scale of Output	Earlier applications in assessments	Score
	Provisioning services	Supporting services	Cultural services	Regulating services					
	renewable water resources								
Ifs	Agricultural production, including marine fishing and aquaculture	x	x	Human health, CO2 emissions	x	x	Global (with details for 182 regions/countries), not spatially explicit	x	5
Scenario building tools									
PoleStar	water resources, raw materials and agriculture	x	x	solid waste management, environmental loadings	x	income distribution and poverty	x	SRES	4
Threshold 21	agriculture, consumption of natural resources (renewable and nonrenewable), resource depletion (e.g. forests)	land degradation	x	soil erosion, greenhouse gas emissions, air and water quality (pollution)	x	x	focussed on the national level, globally applicable	x	4
Economic models									
ENV-Linkages	timber production, agricultural production (crops and	x	x	x	x	x	Global, aggregated in 34 countries/regions	x	6

Model name	Ecosystem Service Provision				Biodiversity	Economic Value of Output	Scale of Output	Earlier applications in assessments	Score
	Provisioning services	Supporting services	Cultural services	Regulating services					
	livestock, intensive and extensive production)								
GTAP	agricultural food production	x	x	x	x	x	Country level, not spatially explicit	Used in combination with IMAGE in a number of assessments	5
Land-use models									
CLUE	None (but land used for agriculture, grazing, forestry)	x	x	x	Land cover diversity explicit	x	Europe (EU-27), also case studies in a.o. Costa Rica, Ecuador, Honduras, the Netherlands, China, Java, Phillippines, Malaysia, Vietnam, Kenya, USA, 1x1km, case studies between 30m and 32km	EURURALIS	4
Biogeochemical models									
IBIS	water runoff	NPP, SOC, N balance	x	carbon balance, water regulation	Vegetation composition (functional types)	x	0.5 - 4º	x	3

Model name	**Ecosystem Service Provision**				**Biodiversity**	**Economic Value of Output**	**Scale of Output**	**Earlier applications in assessments**	**Score**
	Provisioning services	**Supporting services**	**Cultural services**	**Regulating services**					
LPJmL	runoff volumes, crop production	annual NPP	x	CO2 exchange, water balance	vegetation cover (fraction of different plant functional types per grid cell); Vegetation composition	x	global, 0.5º grid cells	x	3
SAVANA	livestock production, grass and timber production, water supply (runoff, deep drainage)	NPP, nutrient cycling	x	water balance	Species distribution and abundance (plants + animals); community composition	x	regional, resolution depending on input data and studied ecosystem	x	3
Agro-IBIS	water supply, crop production	NPP, SOC, N balance	x	carbon flux, N leaching, water regulation	Vegetation composition (functional types)	x	currently only run for North America, global application planned, 0.5º grid	x	3
PICUS	timber production	nitrogen cycling in forests	x	carbon sequestration, soil moisture (water cycling)	forest species composition (diversity, naturalness indicators)	x	temperate forests, Europe, 100m^2 patches	x	3
CENTURY	grass, tree and crop production, water supply (stream	N, P and S balance, SOC	x	Water balance, decomposition, CO2 flux, erosion	x	x	any resolution (depending on input?)	x	4

Model name	Ecosystem Service Provision				Biodiversity	Economic Value of Output	Scale of Output	Earlier applications in assessments	Score
	Provisioning services	Supporting services	Cultural services	Regulating services					
	discharge)								
IMPACT -WATER	Agricultural food production (crops and livestock)	x	x	x	x	x	global: 115 regions and countries, intersected with 126 river basins (281 spatial units), uncluding EU-15 and eastern Europe	x	6
Hydrological models									
(E)-SWAT	water supply	x	x	erosion control	x	x	calculations are done on the scale of sub-watersheds	x	5
WaterGAP	water supply	x	x	x	x	x	global, country, river basin, grid cells 0.5° by 0.5°	OECD, GEO, MA, in combination with IMAGE, IMPACT, EcoSim and AIM	5
WBM (+)	water supply, livestock production	x	x	soil water content	x	x	0.5° by 0.5° grid (30'grid)	x	5
Biodiversity models									

Model name	Ecosystem Service Provision				Biodiversity	Economic Value of Output	Scale of Output	Earlier applications in assessments	Sco re
	Provisioning services	Supporting services	Cultural services	Regulating services					
GLOBIO	FROM link with IMAGE: Agricultural production, including grass/fodder production and livestock/milk production, demand for wood products, timber, fuelwood	FROM link with IMAGE: Soil fertility	x	FROM link with IMAGE: Carbon flux, carbon plantations, ocean carbon model, water-erosion sensitivity, air pollution, soil moisture	mean species abundance (MSA)	x	global, (0.5º by 0.5º for climatic data, 1km by 1km for land use data)	OECD, GBO	2
BII	x	x	x	x	biodiversity intactness index	x	global, scale of aggregation: 104 to 106 km2	x	6
EUROMOVE	x	x	x	x	number of species	x	Europe, 2500km2 grid cells	x	6
MIRABEL	x	x	x	x	habitats at risk Not available	x	28 European countries, 13 ecological regions	x	6
SAR	x	x	x	x	number of species; Vegetation composition/ species distribution	x	global, calculated for different biogeographical units (biomes, ecoregions), not spatially explicit	x	6
GARP	x	x	x	x	Vegetation composition/ species distribution	x	x	x	7

Model name	Ecosystem Service Provision				Biodiversity	Economic Value of Output	Scale of Output	Earlier applications in assessments	Score
	Provisioning services	Supporting services	Cultural services	Regulating services					
Regional models / Assessments									
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	x	Europe 15 + Norway and Switzerland, 10' by 10' grid	x	2
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 sequestration, erosion control, water quality	species richness (feeding and breeding habitat regqurements of 37 terrestrial vertebrate species, dispersal ability)	x	regional, resolution flexible; case study: Willamette Basin, Oregon, USA (30 m x 30 m grid, for results: 500 ha units)	x	2
PLM, Costanza et al 2002	water supply, primary production of natural vegetation, plantations, grasslands, agriculture	soil nutrients	land prices based on surroundings	water quality	x	x	Patuxent River watershed, Maryland, USA; variable resolution, maximum resolution: 200 by 200m	x	3
Naidoo et al 2008	grassland production of livestock,	x	x	carbon sequestration and carbon	mammal, bird, reptile, and	x	global, maximum resolution 0.5°	x	4

Model name	**Ecosystem Service Provision**				**Biodiversity**	**Economic Value of Output**	**Scale of Output**	**Earlier applications in assessments**	**Score**
	Provisioning services	**Supporting services**	**Cultural services**	**Regulating services**					
	water supply			storage	amphibian species distribution				
Swallow et al, 2009	food production, (water supply)	x	x	erosion control, (flood mitigation, water quality)	x	x	Lake Victory basin; multiple spatial scales, smallest: 5km by 2.5km (arial photograph), sub-basin, country division, river basin	x	5

3.2 Marine Models

(Score # indicates number of criteria (columns) for which the model does not provide information)

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
ASSETS	Estuarine fisheries/aquaculture; water quality	Not applicable	Primary production, nutrient cycling	Recreation	Negatively impact fisheries/aquaculture; revenue from recreation; Toxic algal blooms can be harmful to human health.	Estuarine/Watershed level. Currently, there are 157 assessed estuarine systems in ASSETS primarily based in the U.S. But there are a number of international records. Resolution of output is based the the bathymetry grid used, however the details are not specified in the peer-reviewed methodology.	Not applicable	2
Aus-Connie	Larval recruitment to fisheries	Ecosystem connectivity (inc. genetic and nutrient flows), larval dispersal and recruitment	Nutrient cycling	Not applicable	Understanding sustainability of fisheries, dispersal of contaminants possibly harmful to marine resources and humans thus reducing ecosystem services, general understanding of the sustainability and connectivity of ecosystem services.	Australia; 0.5 degree geographical grid; All statistics were based on currents and trajectories computed at a fixed depth of Z = 20m, which was taken to be representative of surface waters where larval concentrations tend to be highest.	Not applicable	2

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
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.	Reduction in nutrient cycling ability (e.g. through dead zones/pollution); Impacts on habitats and their services.	Impacts on recreation, aesthetic values and experience, spiritual enrichment etc.	Model implies that areas that are more highly impacted will not be able to provide the quality and range of ecosystem services as less impacted areas.Reduced goods and services will have a general negative impact on human health.	Global but can be applied at the local- and regional-scale; 1km2 resolution grid.	Not applicable	1
EwE, EcoSpace & EcoVal	Fisheries (inc. their ecosystem effects).	Biomass and fluxes	Population dynamics (Top-down vs. Bottom-up controls)	Economic valuation of resources (Ecoval).	Bioaccumulation effects; food security; economic value of ecosystem goods and services under different management scenarios;	Multi-scale, ecosystem models. Ecospace is the only component that provides spatial representation and uses user-defined grid cells.	Millennium Ecosystem Assessment scenarios and the GEO-3 and -4 projections.	0

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
GEEM	Fisheries (inc. their ecosystem effects).	Biomass and fluxes	Population dynamics (trophic controls); biological maintenance of resilience; changes to ecosystem community structure may impact on other ecosystem services;	Not applicable	Negatively impact fisheries; possible threats to food security; negative impacts on livelihoods if ecosystem functionaility/services are lost potentially impacting vulnerable coastal communities.	Multi-scale, ecosystem model based around food webs. Resolution measures are not applicable as spatial representation of outputs is not available.	Not applicable	3
Impact of Climate Change on Global Biodiversity	Fisheries (commercial and artisanal).	Not applicable	Changes to ecosystem community structure may impact on other ecosystem services.	Artisanal fishing practices	Negatively impact fisheries economics, particularly the vulnerable coastal communities that rely on small, artisanal fisheries	Global; 30' X 30' grid cell size. Can be scaled to local and regional levels.	Not applicable	3

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
RamCo	Food security of coastal systems; Water provisioning/water quality; commercial products provided by coastal zones.	Ability of coastal zone to provide regulating services generally.	Supporting services related to coastal zones generally, e.g. Primary production, nutrient cycling, maintenance of habitats, population dynamics etc.	Ability of coastal zone to provide cultural and spiritual services generally.	Polluted water has negative impacts on human health, potential for risks to food security if coastal system functionality is lost, increased or modified flood patterns can cause direct risks to coastal communities.	RAMCO can handle cellular models with dimensions up to 500 by 500 cells. Useful on grids which resolution varies from 50 to 500 meters. RamCo can to deal with spatial dynamics at different levels & will generally have two coupled components: one for macro-level, long range and large scale processes and a second one for processes operating on the micro-level, short range and micro-scale. Sub-models will in general operate at one level, but may exchange information with sub-models at the other level.	Not applicable	3

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
Reefs at Risk	Coral reef fisheries; Raw materials fro medicines; Other raw materials (seaweed and algae for agar, manure etc.); Curio and jewellry; Live fish and coral collected for aquarium trade.	Nitrogen fixation; CO2/Ca budget control; Waste assimilation.	Mantainence of habitats; maintenance of biodiversity and genetic library; biological maintenance of resilience; mobile links between ecosystems; export of organic production between ecosystems; protection of adjacent shorelines - in doing so supporting wetlands, seagrass beds, mangrove fisheries, population centres etc.; generation of coral sand; build up of land.	Recreational Value; ecotourism; sustaining livelihoods of local communities; aesthetic value; support of cultural, religious and spiritual values.	Negatively impact economic benefits of coral reefs (fisheries, medicinal products, curio/jewellry, aquarium trade); Increase vulnerability of coastal communities and habitats to natural hazards; Reduce food availability impacted on human health; Negatively impact livelihood associated with coral reefs; negatively impact spiritural, cultural, and aesthetic values associated with coral reefs.	Global coral reefs; 4km resolution	Not applicable	1

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
ERSEM II	Fisheries (understanding environmental drivers and bottom-up processes impacting fish populations; impacts of fisheries).	Ecological fluxes; nutrient limitations.	Lower trophic level habitat modelling for pelagic and benthic systems;	Not applicable	Bottom-up control of fisheries; Marine bacteria and virus dynamics; Influence of weather and climate on marine ecosystem services (e.g. Food security).	Dependent on resolution of the model that it is coupled to. ERSEM's upper boxes extend from the surface to 30 m, the lower boxes from 30 m to the bottom. coupled to high resolution hydrodynamic models, large geographical scales. Basin scale and open ocean applications in 1, 2 and 3 dimensions	Not applicable	3

Model name	**Ecosystem Service Provision**				**Economic Value of Output**	**Scale of Output**	**Earlier application in assessments**	**Score**
	Provisioning services	**Regulating services**	**Supporting services**	**Cultural services**				
ICTHYOP	Larval recruitment to fisheries	Ecosystem connectivity (inc. genetic and nutrient flows), larval dispersal and recruitment	Bottom-up support of food webs.	Not applicable	Understanding sustainability of fisheries; general understanding of the sustaiability and connectivity of ecosystem services.	The environmental state variables are provided on a discrete three-dimensional grid by archived simulations of the ROMS or MARS oceanic models. The Icthyop model sees the Eulerian velocity field at the same spatial scale as the Eulerian primitive equation models. Subgridscale parameterisations can be added in the IBM to address scales unresolved by the primitive equation models. The fields of salinity, current velocities, and temperature are interpolated in space to provide values at any individual location in Icthyop.	Not applicable	2

4 APPENDICES TO CHAPTER 5: WORKSHOP

4.1 Workshop Programe

Wednesday, 13 May 2009 – Where we are and where we want to go	
10:00	**Opening and Introduction: What this study aims to do?** *Robin Miège*, DG Environment
10:15	**The role of the scenarios and models project in the TEEB context** *Patrick ten Brink, IEEP*
Session 1: Review of available models and scenarios: “State of the Art” Chair: *Leon Braat, Alterra*	
10:30	**Key findings of the project** *Tom Kram, PBL*
10:45	**Discussion**
11:45	**Coffee Break**
Session 2: Assessment of key assumptions in the available quantitative tools *Chair: Matt Walpole, UNEP-WCMC*	
12: 00	**Key findings of the project**, *Leon Braat, Alterra*
12: 15	**Discussion**
13:15	**Lunch Break**
Session 3: Policy recommendations: How to use the quantitative tools for policy development within TEEB *Chair: Patrick ten Brink, IEEP*	
14:00	**Short presentations (10 minutes) on recommendations for TEEB by five key-experts**
14:50	**Discussion**
15:50	Closing of the conference *Alexandra Vakrou, DG Environment*
16:00	**End of the Workshop**

4.2 Attendance List

Name	First Name	Organisation
Alkemade	Rob	Wageningen University and Research Centre
Andre	Viviane	European Commission
Bidoglio	Giovanni	European Commission, Joint Research Centre
Braat	Leon	Alterra
Braeuer	Ingo	Ecologic Institute, Berlin
Christensen	Villy	University of British Columbia
Eppink	Florian	Helmholtz Zentrum für Umweltforschung (UFZ)
Gerdes	Holger	Ecologic Institute, Berlin
Heuermann	Nicol	Netherlands Environmental Assessment Agency (PBL)
Kram	Tom	Netherlands Environmental Assessment Agency (PBL)
McConville	Andrew	Institute for European Environmental Policy (IEEP)
Miège	Robin	European Commission
Neuville	Aude	European Commission
Pereira	Henrique Miguel	Universidade de Lisboa
Pirc-Velkavrh	Anita	European Environment Agency (EEA)
Poggi	Patrizia	European Commission
Richard	Dominique	European Topic Centre on Nature Protection and Biodiversity
Romanowicz	Agnieszka	European Commission
Rosenstock	Manfred	European Commission
Saether	Bent Arne	Ministry of the Environment, Norway
Scharlemann	Jorn	United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC)
Spangenberg	Joachim	Sustainable Europe Research Institute (SERI)
Tallis	Heather	Stanford University
ten Brink	Patrick	Institute for European Environmental Policy (IEEP)
Torta	Giuliana	European Commission
Tucker	Graham	Institute for European Environmental Policy (IEEP)
Vakrou	Alexandra	European Commission
van Vuuren	Detlef	Netherlands Environmental Assessment Agency (PBL)
Walpole	Matt	United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC)