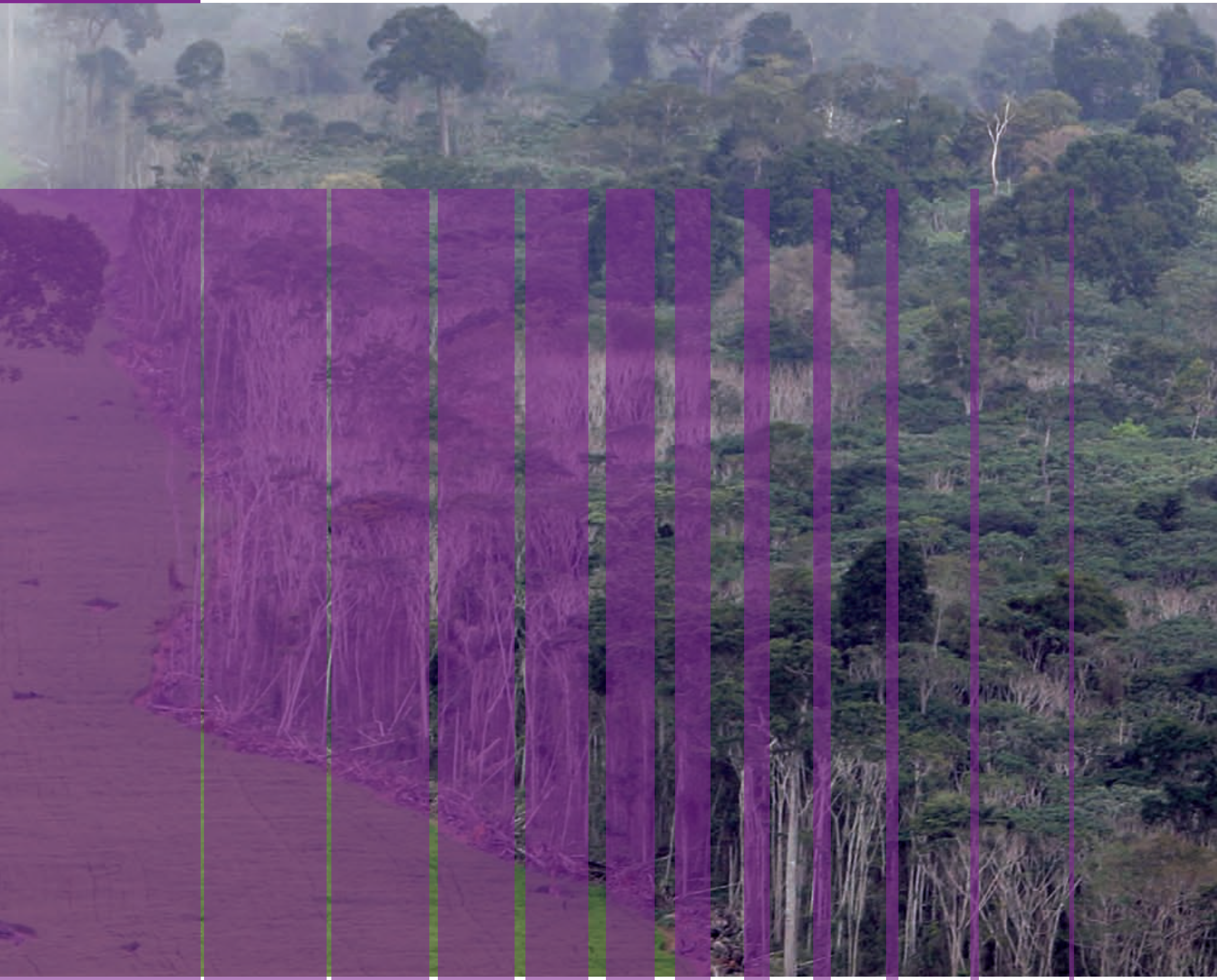
Rethinking Global Biodiversity Strategies



Netherlands Environmental Assessment Agency

Rethinking Global Biodiversity Strategies

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Exploring structural changes in production and consumption to reduce biodiversity loss

A contribution to the project on
The Economics of Ecosystems and Biodiversity (TEEB)

In cooperation with

Agricultural Economics Research Institute of
Wageningen University and Research Centre

Sea Around Us Project of the Fisheries Centre of
the University of British Columbia, Canada

Netherlands Environmental Assessment Agency

Rethinking Global Biodiversity Strategies: Exploring structural changes in production and consumption to reduce biodiversity loss.

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Corresponding author:
Ben ten Brink (ben.tenbrink@pbl.nl)

The Netherlands Environmental Assessment Agency (PBL) is the national institute for strategic policy analysis in the field of environment, nature and spatial planning. We contribute to improving the quality of political and administrative decision-making by conducting outlook studies, analyses and evaluations in which an integrated approach is considered paramount. Policy relevance is the prime concern in all our studies. We conduct solicited and unsolicited research that is both independent and always scientifically sound.

Office Bilthoven
PO Box 303
3720 AH Bilthoven
The Netherlands
Telephone: +31 (0) 30 274 274 5
Fax: +31 (0) 30 274 44 79

Office The Hague
PO Box 30314
2500 GH The Hague
The Netherlands
Telephone: +31 (0) 70 328 8700
Fax: +31 (0) 70 328 8799

E-mail: info@pbl.nl
Website: www.pbl.nl/en

Foreword

The world has not succeeded in reducing the rate of biodiversity loss by 2010 – neither globally, nor regionally, nor nationally. Why is this so? Because it has not been regarded as genuinely important, or because economic interests are too great and economic powers too strong? Or is it because we do not know how to reduce biodiversity loss – maybe because it is too complicated? We are changing the global landscape at an unprecedented rate and scale, changing vital cycles of water, nutrients, soil and energy to our own short-term benefit.

How can we balance short-term personal profits against long-term public and seemingly intangible gains? The ‘tyranny of small decisions’ and the ‘social dilemma’ are key issues to overcome. Moreover, it is becoming increasingly clear that solutions for one problem come at the expense of others. Business and political decisions are made in a myriad of parliaments, councils and boardrooms, in a highly competitive world. Discussions on climate change, biodiversity, development and food availability are held in different global arenas. We have improved our management in specialised fields, but have lost the overview of consequences that transcend them. Moreover, it is complicated enough to make progress within one single field.

The PBL has conducted this study on behalf of Minister Gerda Verburg from the Dutch Minstry of Agriculture, Nature and Food Quality, following the request by Mr Achim Steiner, UNEP's Executive Director.

With this study, the PBL hopes to contribute to the quality of strategic policy debate by providing an integral assessment of the consequences of various policy actions.

Director of the PBL - Netherlands Environmental Assessment Agency

Professor Maarten Hajer

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This study was conducted at the request of the Executive Director of the United Nations Environment Programme (UNEP) by the Netherlands Environmental Assessment Agency (PBL), in close cooperation with the Dutch Agricultural Economics Research Institute (LEI-WUR), and the 'Sea Around Us Project' of the Fisheries Centre of the University of British Columbia, Canada.

We thank the Advisory Group of the UNEP project on The Economics of Ecosystems and Biodiversity (TEEB) for the Terms of Reference for this analysis and their permanent feedback; the Secretariat of the Convention on Biological Diversity (CBD) for conducting a survey (Notification No. 2010-055) of the focal points of the Parties on the feasibility and desirability of policy options for reducing biodiversity loss. We thank the Parties who participated in the survey. We thank Aude Neuville and Francois Wakenhut of the European Commission for their encouragement to undertake this study at short notice. We thank Thomas Brooks, Tim Christophersen, Henk de Jong, Peter de Koning, Fred Langeweg, Rik Leemans, Markus Lehmann, Anil Markandya, Gert-Jan Nabuurs, Aude Neuville, Robert Nasi, Alfred Oteng, Henrique Pereira, Walter Reid, Carmen Revenga, Bob Watson and many others for their valuable comments and suggestions on the drafts of this report. This study received additional financing from the Netherlands Government as a further contribution to The Economics of Ecosystems and Biodiversity project.

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- Improving prospects for future global biodiversity requires rethinking the strategic orientation from common policies and measures towards structural changes in production and consumption of goods and services. Significant and lasting improvements in the downward biodiversity trend will have to come from changes in human activities including agriculture, forestry, fishing, and energy use. Enhanced 'eco-efficiency' (that is: producing with lower ecological impact per unit output) could slow down biodiversity loss by reducing the expansion of agricultural land; stemming overexploitation of terrestrial and ocean ecosystems; and limiting climate change.

- An ambitious, comprehensive and cross-sector strategy would cut the rate of biodiversity decline up to 2050 by half, compared to what was projected without any new policies. Measures in the combination explored include an expanded protected area network, more efficient agriculture and forestry, improved forest management, less meat intensive diets and limiting climate change. By design the combination of options contributes to other goals such as mitigating climate change and improving food security.

- Human development increases demand for food, timber and other goods and services with direct consequences for the extent of natural areas. In addition, economic activities put a range of pressures on both natural and cultivated land, including climate change, air pollution, encroachment and disturbance. Most of these pressures are not directly relieved by conservation and protection, but by structural changes in production and consumption.

- More traditional biodiversity policies focus on conservation and protection measures. Expanded and intensified measures continue to be important, for example in protecting ecosystems and selected species, and also in continuing provision and support of valuable ecosystem services. However, these commonly pursued policies have limited effect on ongoing pressures. And, if implemented alone would have negative impacts on other global issues, notably reducing malnutrition and hunger.

- Biodiversity policies and measures should be selected and implemented in accord with human development interests, and prevent negative impacts. Coordination of targets, strategies and instruments across different policy fields is essential to reap co-benefits and to prevent unintended negative side-effects. Bilateral and multi-stakeholder policy processes will be an important prerequisite for successful development and deployment of cross-sector and cross-issue policies and measures.

What is the problem?

The key challenge in preventing biodiversity loss is to strike a balance with human activity, not least in currently underdeveloped and emerging economies

Human development and, indeed, mere existence rely critically on provision of goods and services, often at the expense of ecosystem extent and quality. However, production and use of agricultural and wood products, fish and water tend to induce degradation of the natural environment. Despite efficiency gains, the increasing global population and increasing income per head will drive up demand for such commodities. Large land areas are needed to provide essential resources, such as food and wood, at the expense of natural areas.

Overexploitation and pollution of soils, water and atmosphere affect not only areas converted for human use but also the remaining natural areas. Historically, the compound effect has been to diminish the extent of near natural land cover and to reduce the quality of the remaining natural area leading to biodiversity loss. Degradation of ecosystems with implications for biodiversity affects the provision and support of valuable ecosystem services – another reason for concern.

Current studies indicate that global biodiversity loss is not slowing down

Several studies including the Global Biodiversity Outlook-3 conclude that at best progress is mixed towards the 2010 targets of the Convention on Biological Diversity (CBD). Biodiversity state indicators show that the ambition to reduce the rate of loss in quantitative terms is not met on different scales, although some progress has been made mostly on local and regional scales.

Current studies indicate that global biodiversity loss will continue without additional policies

The crucial issue is what additional policies are needed to reduce biodiversity loss and what could these achieve. Several studies indicate that in the coming half century, the trend is likely to change little unless structural changes are made to human activities and practices. This conclusion raises crucial questions:

- Can future biodiversity loss be significantly reduced or even halted with specific policies and measures?
- To what extent can the rate of loss be slowed down by specific measures?
- What are the trade-offs and synergies between these measures?

These questions are central to this report which examines the effectiveness of options for reducing biodiversity loss as either individual options or as part of an ambitious combination of options. The report aims to provide insights for a strategic debate on orientation of international biodiversity policy making. Key elements of institutional opportunities and, probably numerous, hurdles for effective implementation are not investigated here. Such issues concerning feasibility of policy proposals, more concrete measures and their institutional implications, warrant further attention.

Biodiversity is not easily preserved

The historic trend suggests that is difficult to achieve a balance between nature and biodiversity, and material human needs and activities that demand instant supply of marketable goods and services. Nature and biodiversity, however, constitute less tangible, public services that are often only missed after they are gone. This is an over-simplification because there are plentiful examples of ‘naturalness’ and biodiversity representing a well recognised and exploited economic asset. In other cases, ethical, cultural and religious arguments in favour of nature and biodiversity conservation tip the balance towards protecting ecosystems and biodiversity. But on the whole, developments to date suggest that human development tends to override biodiversity concerns. Attempts are being made to value currently un-priced benefits of nature and biodiversity in order to assess the cost of policy inaction, and possibly to weigh the net benefits of policy interventions against the cost incurred. The UNEP Economics of Ecosystems and Biodiversity (TEEB) study is a recent example. However, methodologies and data are hampered by large uncertainties, methodological problems, and dispute. This is further complicated by opposing views on the inherent value of nature and on the justification of mankind to exploit it from an essentially anthropocentric perspective.

In the absence of a widely adopted metric for balancing natural and human aspects, alternative practices are sought to fulfil future human demands that have less impact on nature and biodiversity.

Estimating biodiversity

Biodiversity is difficult to define and even more difficult to measure

Biodiversity comprises the diversity of life on Earth across genes, species and ecosystems, and is difficult to define. According to the Convention on Biological Diversity, biodiversity is:
‘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’.

Based on this broad definition, biodiversity cannot be monitored and projected by a single metric or indicator. Various indicators are deemed to be more practical and meaningful than simply striving for the highest number of species in as many ecosystems as possible. The CBD agreed on a set of five indicator categories to represent the state and change in state of biodiversity:

- extent of ecosystems;
- abundance and distribution of species;
- status of threatened species;
- genetic diversity;
- coverage of protected areas.

The CBD definition and indicator groups imply that meaningful assessment of future biodiversity requires a variety of indicators across the different CBD categories. It is worth noting that biodiversity state and trends are interpreted and judged according to the choice of indicators and their weighting.

This study uses a small set of indicators and an integrated model suite

This study aims to be comprehensive on the global scale, and addresses several indicators suitable for model-based analysis of future pathways. Much of the findings and discussion focuses on outcomes for the indicator of terrestrial

Mean Species Abundance (MSA). This is in essence an indicator of 'naturalness' of ecosystems as the compound result of human-induced pressure factors. It considers the composition of species in numbers and abundance compared with the original state and provides a common framework to assess the major causes of biodiversity loss. These range from land cover change, management changes, fragmentation, and climate change to nutrient deposition. To illustrate, conversion of forest to agricultural land induces massive change in species and frequency of occurrence, and thus MSA is much lower than in the original state.

The MSA indicator maps the compound effect of drivers of biodiversity loss, and uses a suite of direct and indirect drivers provided by the PBL integrated assessment modelling framework (IMAGE) in conjunction with an economic model at LEI (GTAP). The compound effect on biodiversity is computed with the PBL GLOBIO3 model for terrestrial ecosystems (and recently also for freshwater systems). Marine impacts are estimated with the UBC EcoOcean model system. In addition, the future pathway of direct and indirect drivers depend on a variety of socio-economic assumptions, technological developments and policy assumptions, which are represented in the IMAGE and GTAP model. As the IMAGE model and the GLOBIO3 are spatially explicit, the impacts on MSA can be analysed per region, per main biome and per pressure factor.

As stated above, biodiversity cannot be captured by one single indicator. To get a more complete view, additional measures associated with the CBD category of ecosystem extent were applied. Natural area is derived directly from the land cover projections of the models. In addition, the extent of largely undisturbed ecosystems is assessed as the extent of natural area in which the MSA is greater than 80%, referred to here as 'wilderness area'.

While MSA loss closely relates to direct biodiversity parameters, it cannot be considered one-on-one as 'the biodiversity'.

Results on all indicators presented in this report must be interpreted with caution. In particular, the global coverage implies that fine-scale local conditions, even though extremely relevant, cannot be captured. Likewise, the level of the seven regions for which results are reported represents the aggregated outcome over vast areas. Global results for the extent of aggregated biomes provide at best an indirect indication of issues of regional and local concern.

Analysis of options for reducing future biodiversity loss

The baseline shows future population, economy, environment and biodiversity in the absence of new policies

The baseline serves as backdrop against which to evaluate the options. It is not the best-guess or most 'realistic' future as the assumed absence of new policies is hardly likely up to 2050. Incorporating expected future policies tends to hide potential future challenges and risks, and makes evaluation of alternatives less transparent. The baselines used for the various options fall within a narrow range for the key drivers and settings used in the latest OECD Environmental Outlook 2008.

Table S.1 Eight options for reducing global biodiversity loss

Priority setting in conservation		
1	Expanding protected areas	Conserving rare and valuable habitats, endemic species, hotspots, and a representative selection of ecoregions.
2	Reducing deforestation	Maintaining carbon uptake and storage in forests; synergy with climate change mitigation.
Reduced agricultural expansion & eutrophication		
3	Closing the yield gap	Increasing agricultural yields to reduce agricultural expansion.
4	Reducing post-harvest losses	… in the food chain, thus lowering agricultural production and reducing expansion of agricultural land.
5	Changing diets	… to less meat consumption patterns, reducing the agricultural area for cattle feed and grazing.
Reduce overexploitation of habitats		
6	Improving forest management	More forestry plantations with high productivity, and more reduced-impact logging outside plantations.
7	Reducing marine fishing efforts	Bringing potential future marine catches to a higher, but sustainable level.
Limit climate change		
8	Mitigating climate change	Reducing the impact of climate change with and without bio-energy to investigate trade-off from growing energy crops.

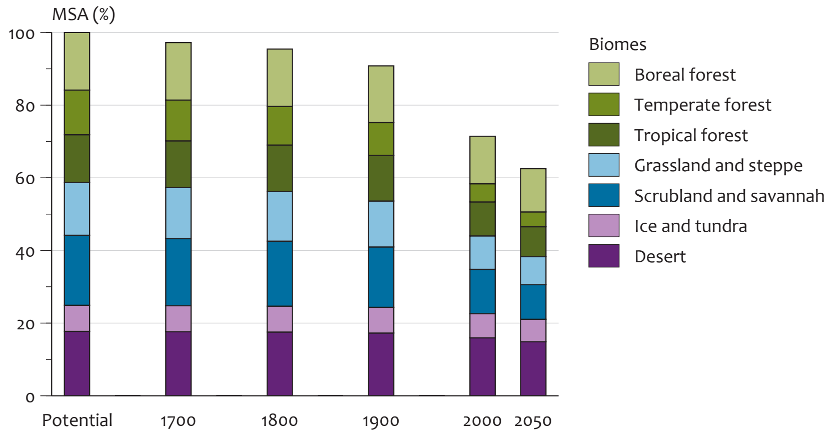
Options for reducing biodiversity loss are evaluated for effects in the target year compared to the baseline

The individual options listed in Table S.1 explore the potential and prospects of potentially promising interventions. They draw on a range of studies, most of which have not been done exclusively with biodiversity concerns in mind. The cases explored are, therefore, not strictly consistent, and assumptions in some cases are for extreme conditions without consideration of feasibility. For instance, the 50% Protected Area case has consequences for the size and location of agriculture areas which seem highly impractical but was added as sensitivity variant to provide perspective for the 20% Protected Area case. Similarly, the No Meat variant under the option of Changing Diets pictures a future consumption preference very differently from current trends, preferences and established interests, but is helpful in identifying the contribution of meat production in a range of global issues. The options are explored on their prospects in 'technical' terms.

Most options do not have biodiversity as primary focus

The options illustrate how other issues and concerns interact with biodiversity, and what interventions by which groups of stakeholders could deliver the results shown. Issues of viability and feasibility of implementation are not addressed in depth, nor is the cost of implementation investigated explicitly. Some notions on these aspects are added ex-post for each option.

Global MSA in baseline scenario **Figure S.1**



The projected development of global MSA per biome in the baseline scenario shows a loss between 2000 and 2050 at a similar rate as over the 20st century. MSA loss in earlier centuries occurred mostly in temperate biomes, while impact on subtropical and tropical biomes takes off from 1900.

Options are combined to exploit complementary reductions in pressures while minimising side effects

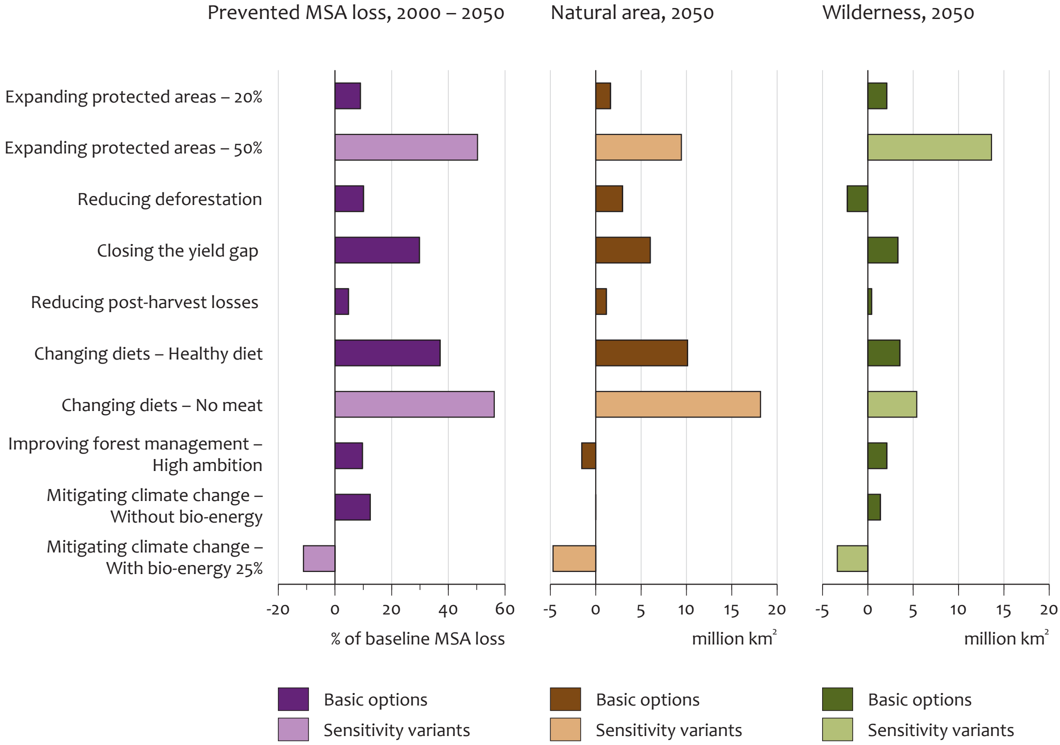
Individual options have a positive effect on one or few pressures on biodiversity, but sometimes negative side-effects on others. A well-considered combination may achieve more for biodiversity by addressing several pressures and contributing to several other goals and partly overcome negative side-effects. One comprehensive example was tested with due consideration to the results of the individual options. Extremes were avoided in favour of ambitious but conceivable targets for each option, assumed to be implemented between 2010 and 2030 (see Table S.2). The assumptions were either based on ambitious policy targets (e.g., for climate change) or on indications in the literature about achievable levels under ambitious policy effort (e.g., yield improvement).

Main findings of the model analysis

In the baseline scenario, MSA drops from 70 to 60% between 2000 and 2050

A drop from 70 to 60% between 2000 and 2050 is roughly the same rate of loss as observed over the 20th century (see Figure S.1). Although the change may appear small at first sight, it is a global average over the whole terrestrial area. About one fifth of all land is estimated to remain close to its natural state because it is too poorly suited for widespread human activity (hot deserts, polar and high-latitude boreal regions). Global MSA is thus not expected to drop below 30 to 35% which puts the reduction loss from 70 to 60% by 2050 in a different perspective. To illustrate, if the 10 percent point MSA loss were to occur in one contiguous area, that would be equivalent to 1.5 times the area of the USA that changes from a

Figure S.2 **Change in global biodiversity per option compared to baseline scenario**



Effect of basic options on global biodiversity indicators illustrate the potential for improvement through a combination of protection and measures for food, wood and fibre production and consumption. Change in global bioversity of options expanding protected areas and reducing deforestation by 2030.

pristine, natural state to zero original species within 50 years. Many species-rich ecosystems in the tropical, sub-tropical and temperate zones are, and would continue to be, more seriously affected than the global average (see Figure S.1). Over the same period, the natural area not occupied by intensive human activity decreases from 93 to 86 million km², a drop of 7.5% and an area three quarters of the size of the USA.

Over the next 50 years, current wilderness areas as large as 18 million km², roughly the size of Russia and about one quarter of the 71 million km² in 2000, are set to deteriorate in quality below the 80% mark and no longer count as wilderness in our terminology. The main direct drivers of biodiversity loss include expansion of the agricultural crop area to feed a global population of around 9 billion people by 2050; expanding infrastructure resulting in habitat loss, urban sprawl and disturbance of bordering natural areas; overexploitation of wild fish resources and forests; and nitrogen deposition and climate change.

The results under baseline conditions in this study compare well with a range of similar scenario studies. The statement that without intensified and new policies, worldwide biodiversity loss will continue is robust and is not significantly influenced by the current economic problems, or by future business cycles. A different choice of indicator, for example emphasising species-rich biomes located in the tropics, would show greater impacts in the associated biomes and a more rapid decline in overall global biodiversity..

Grassland and forest biomes suffer the largest biodiversity losses in the baseline scenario

Future biodiversity loss is not evenly distributed worldwide but rather concentrated in regions such as Central and South America, Sub-Saharan Africa and Asia. Biomes most affected are temperate and tropical grassland and forests that are most suitable for human settlement (see Figure S.1). These regions contain many ecoregions considered to be the richest in number of species. The remaining natural areas will be increasingly situated in mountainous, boreal/sub-polar, arid and semi-arid zones. Options for improving the situation would have their largest effect on the most affected biomes and regions.

Besides expanding protected areas, reducing global biodiversity loss through alternative development pathways offers good prospects

Improvements in the way ecosystem goods such as food and wood are produced can reduce biodiversity loss, and contribute to addressing concerns about poverty, water, energy and climate. Beneficial effects of traditional nature conservation measures have been demonstrated, such as protecting valuable and unique ecosystems. Meeting the demand for food products from a smaller agricultural land area reduces biodiversity loss and, if achieved at lower costs, helps to improve food security. In addition, greenhouse gas emissions would decrease and freshwater quality and availability would improve.

Options for reducing global biodiversity loss are widely accepted and conventional, and include less expansion of agricultural land, improved forestry, limiting climate change, and reshaping capture fisheries. The spatial distribution on the global map where these options would have their effects (world regions, biomes) is plausible following the trends by region and biome of the drivers behind the losses.

Each option can reduce biodiversity loss but none has sufficient potential to reverse the trend

The comprehensive assessment of earlier studies on the impact of individual measures to reduce future biodiversity loss confirms their potential. A total of eight single options (and some variants) were evaluated. However, none would be sufficient to fully reverse the trend of future biodiversity loss. Excluding sensitivity variants that explore technical limits, the maximum effect is a 40% reduction of the MSA lost in the baseline (see Figure S.2). Biodiversity loss is caused by multiple pressures and distinct drivers so that there are limits to what each option can achieve on its own. This implies that no simple solution for halting biodiversity loss in the near future was found. Natural and wilderness areas often show a similar pattern as MSA, but occasionally react differently to options, at times in opposite direction. Comparison of the magnitude of effects must be made with due consideration to the levels of implementation assumed.

Table S.2 **Combination of Options***

	Assumption
Expanding protected areas for biodiversity (1) and carbon stocks (2)	(1) 20% of protected area (representing ecosystems and areas with threatened endemic species. (2) 9% area covering carbon-rich vegetation. In total 29% in protected area.
Improving agricultural productivity	Rate of increase in yields 50% higher than in baseline (in OECD countries to a maximum increase of 1.5% per year).
Reducing agricultural losses	Worldwide agricultural losses reduced from 20 to 13%.
Changing diets to less meat	Worldwide consumption patterns converge to 50% above the consumption level suggested by the health oriented Willett diet.
Improving forest management	Expansion of forest plantations meets 40-50% of timber demand by 2050. Remaining selective logging close to full use of reduced impact logging practices.
Mitigating climate change	Long-term temperature change of 2 °C or 450 ppm CO_2 eq concentration (bio-energy grown only on abandoned land).

* Note that the implementation level of options can differ from what they were as individual options. This is reflected here by names not always identical to Table S.1

Options that increase efficiency in the supply chain of ecological goods have prospects for reducing biodiversity loss, especially in the agricultural sector

Increasing production efficiency of ecological goods appears to contribute significantly to reducing future biodiversity loss as measured with three indicators. The options *closing the yield gap*, *reducing post-harvest losses and improving forest management* all focus on producing at least the same amount of goods with lower biodiversity impact. Moreover, the option *changing diets* reduces biodiversity loss by shifting consumption to less land-intensive commodities. Measures in the agricultural sector show the largest impact because in the baseline, expanding agricultural land is one of the largest drivers of biodiversity loss. The impact of forestry on the baseline loss is significantly smaller, and as a result there is less improvement from improved forest management.

Biodiversity loss can be reduced by expanding protected areas, mitigating climate change and reducing deforestation

The effectiveness of increasing protected areas depends on the level of ambition but also on the biodiversity indicators. On the global scale, the net MSA gain is limited unless the option is pushed to its extreme. In terms of the impact on naturalness (MSA), increasing protected areas in a region could lead to expansion of agricultural land in other areas in the same region, or even to a shift to other regions. However, if properly implemented, the measure may well be effective in preserving unique ecosystems. Climate change mitigation might prevent slightly more than 10% of the baseline biodiversity loss. This percentage may seem relatively low, but due to inertia in the climate system the difference in impact from the baseline is still limited in 2050. If climate policy is implemented by using bio-energy up to economic level and without additional policies to control negative side-effects, the net impacts are uncertain. The impact of bio-energy strongly depends on implementation, which could include using residues, more advanced bio-energy chains, and using degraded land areas. Nonetheless, risks for biodiversity are associated with high levels of bio-energy use. Finally, deforestation can be reduced for different reasons, such as emission reduction from deforestation as climate change mitigation measure. This would effectively help to maintain biological quality of forests. However without accompanying policies, these measures run the risk of shifting biodiversity impacts from forests to grassland ecosystems. In MSA terms, this ‘leakage’ reduces the overall effectiveness significantly.

Many studies point to strong interactions between reduction options

For instance, an increase in agricultural productivity implies that less land is required to grow crops, and thus less global biodiversity loss. But less demand for agricultural land would reduce land prices and hence food prices. This, in turn, would make it easier to achieve development goals on hunger eradication. The net outcome is positive for both issues and for other issues such as climate change and eutrophication. The latter depends on the assumed improvement in nutrient-use efficiency as an integral part of enhanced agricultural technology and management. This would mean less pollution leading to eutrophication. As a rule, options that lead to less agricultural land use than in the baseline scenario have a downward effect on land and food prices. While they are bound to have a positive effect on biodiversity, availability of cheaper land makes alternative uses, such as energy crops, also more economical. Thus, the success of single options depends on additional measures to avoid counter-productive side effects.

The options promise co-benefits for climate change mitigation and food supply

Several options were shown to have significant co-benefits. In addition to preventing biodiversity loss, these options would benefit climate change mitigation and food supply. Reduced conversion of natural habitats keeps carbon stocks and uptake capacity intact, and a more efficient and less wasteful agriculture and food sector would contribute to more stable and affordable food supply, especially in developing countries.

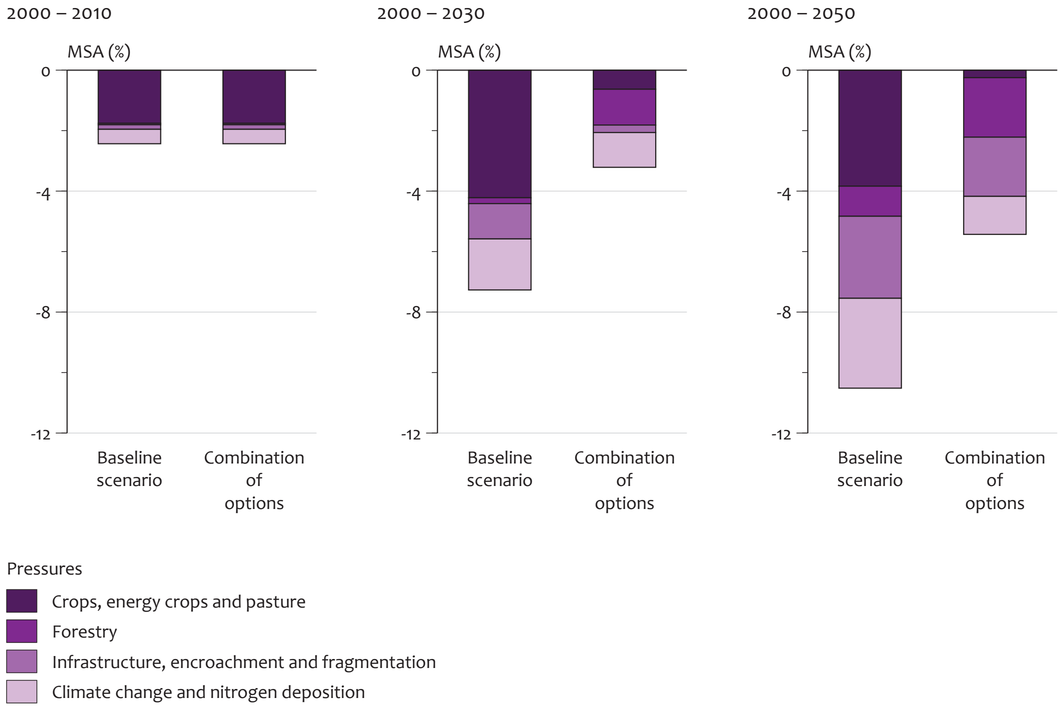
The comprehensive, ‘ambitious yet feasible’ combination of options cuts biodiversity loss significantly and contributes to various other goals

Compared with the baseline scenario, the ‘ambitious yet feasible’ combination of seven options would halve the rate of loss in the MSA indicator between 2010 and 2050 (see Figure S.3).

In the combination of options, the natural area would increase by around 9.5 million km^2 in 2050, concentrated in OECD countries, Central and South America and Sub-Saharan Africa (see Figure S.4). The wilderness area would expand even slightly more, at 10.5 million km^2 above the baseline, particularly in tropical, sub-tropical and temperate biomes.

This ambitious combination of options cannot halt biodiversity loss altogether. One reason is that the negative direct and indirect effects of expanding infrastructure are virtually unchanged from the baseline, as they are assumed to be inextricably linked with a growing and increasingly wealthy population (see Figure S.3). Another reason is that ongoing climate change cannot be undone despite ambitious long-term goals. Even under the ambitious goal assumed, global temperature will continue to rise gradually and eventually reach a 2 °C increase on pre-industrial level.

Figure S.3 **Pressures driving global biodiversity loss**



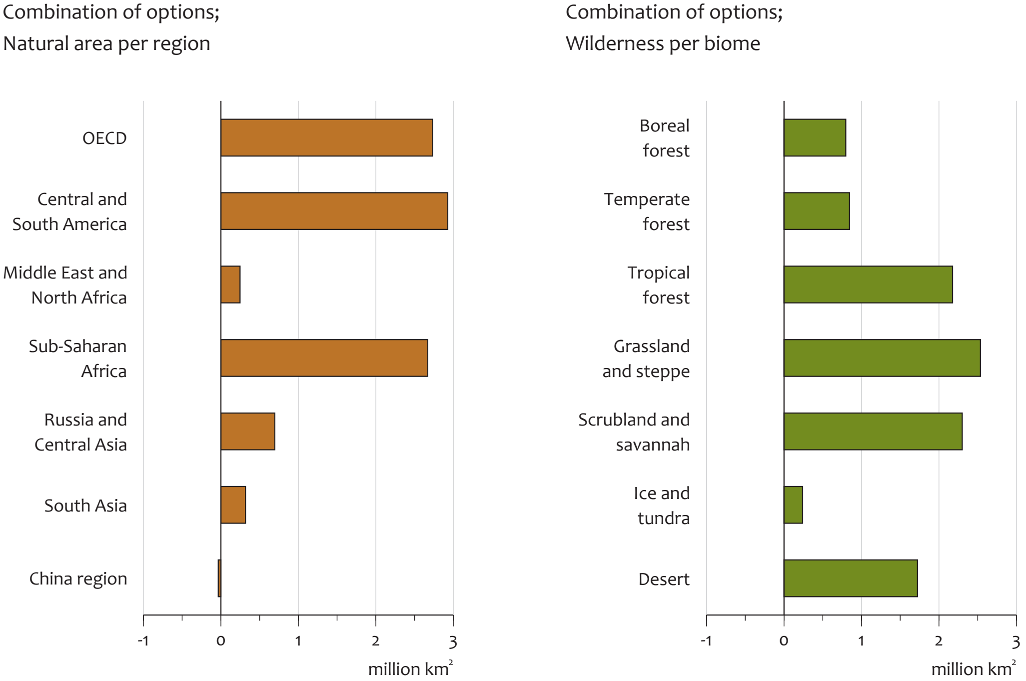
The combination of options would prevent half of the biodiversity loss (in MSA) estimated to occur by 2050 under Baseline conditions. Mitigated agriculture expansion and climate change are the important factors behind the reduced loss.

As a whole, the combination of options would make meaningful contributions to achieving policy goals on biodiversity, alleviating under-nourishment (higher food consumption in developing regions), and mitigating climate change (global temperature by 2050 up by 1.5 °C versus 2.3 °C in the baseline).

The combination of reduction options requires careful consideration

The combination of options includes some measures that increase the pressure of expanding human land use and some that relax the pressure through more efficient land use and consumption changes. The cumulative effect on land prices and on global food consumption from stepwise introduction of the first four options is presented in Figure S.5. Protecting more land for biodiversity and carbon sequestration limits the available land, increasing land prices and decreasing food consumption. The subsequent steps imply that less and less land is required to meet human needs, and hence land and food prices drop. Consumption would increase, and does so if agriculture becomes more efficient. In the last step of changing diets, consumption increases further in lower income regions. In higher income regions with high calorie intake and meat intensive diets, such as OECD

Change in natural area and wilderness compared to baseline scenario, 2050 **Figure S.4**



The distribution over regions and biomes shows that improvements over regional improvements and biomes are not uniform.

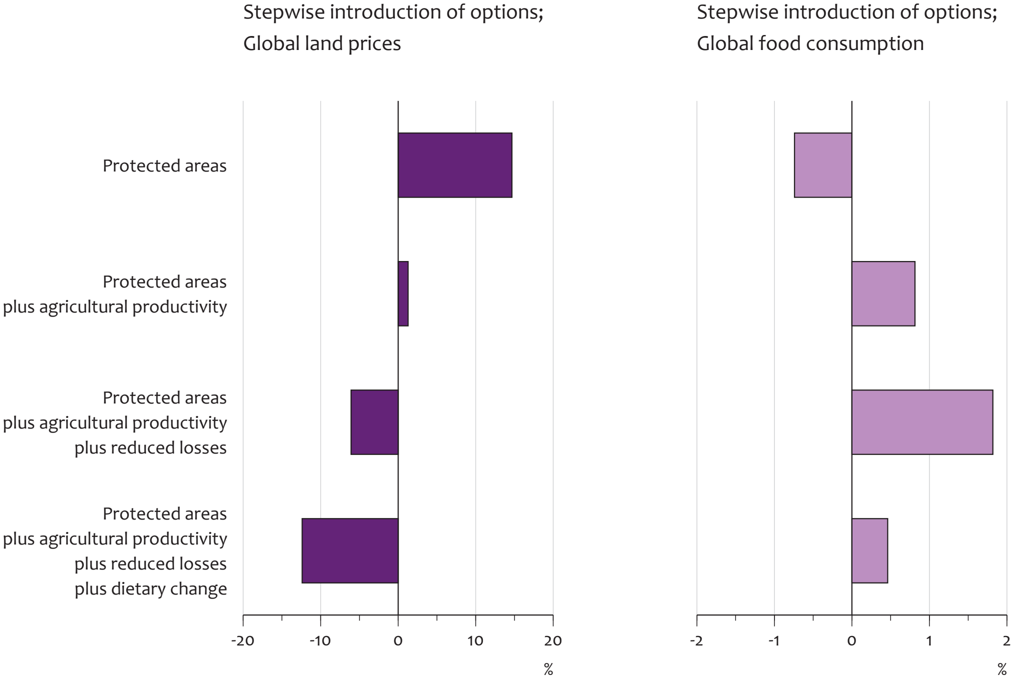
countries and China, net consumption in terms of calories decreases slightly with a less meat diet, which shows in the global total.

Note that direction and relative size of effects for the assumptions made here (see Table S.2) are more robust than absolute percentages and numbers.

The two remaining options, *improving forestry management* and *mitigating climate change* are also bound to have implications for land prices and food consumption but this was not studied.

The overall positive picture does not say there are no trade-offs in the options combination, for example with bio-energy. As a rule, more efficient agricultural production reduces food prices making more food affordable for low income groups. The associated smaller area needed to grow food would reduce biodiversity loss because less natural land is used for production and abandoned agricultural land may gradually be restored to a more natural state. However, these conditions also favour production of bio-energy with otherwise negative implications for biodiversity. Reducing climate change always has a positive effect on natural ecosystems.

Figure S.5 Change in land prices and food consumption compared to baseline scenario, 2030



Food consumption increases with lower land prices as these lead to lower food prices. The opposite effect of the dietary change is caused by a reduction in calorie intake in regions with a high and meat intensive consumption (OECD, China).

The finding that options need to be combined is robust, but ranking the options in terms of effectiveness in preventing biodiversity loss should not be based on this study alone because this depends on the specific assumptions made.

Many fish populations are overexploited or depleted and future catches will be below maximum sustainable levels and of less commercial value.

Production from marine capture fisheries has been stagnant since the late 1980s, with an estimated 27% of fish populations overexploited. As a consequence, the effort needed to catch a given amount of fish is steadily increasing. The baseline assumes that the effort stays constant at the 2004 level for all fleets. The net result is a decline in yearly total catches from around 80 to 60 million tonnes by 2050. In high commercial value, large-fish population catches reduce by more than two thirds in most ocean areas. Capture fisheries will fall further below the increasing demand. Demand is estimated to rise from around 140 million tonnes in 2004 to almost 190 million tonnes by 2030, and to 227 million tonnes by 2050. The supply gap is assumed to be filled by a variety of aquaculture operations.

A drastic reduction in current wild catches would allow fish stocks to restore in order to support maximum sustainable yield levels. Stocks could recover over the next 20 to 30 years and from then on support more than 30% increase in future catch volume. No further depletion of fish biodiversity is expected with a drastic reduction of fisheries effort, according to the marine depletion index of the EcoOcean model. In contrast, the depletion index declines by 40% from 2004 up to 2050 in the baseline. The temporarily wider gap between catches is assumed to be filled by stepping up aquaculture production. Whether or not such a production volume trend can be put into practice has not been investigated.

The feasibility of the reduction options warrants attention but is not covered in-depth in this study

When considering measures that would mitigate direct drivers of global biodiversity loss, attention to issues of governance and diverging interests could identify bottlenecks and areas where efforts could best be concentrated. Aspects to be considered include the technical feasibility, subject to regional differences. Next, attention needs to focus on whether there are built-in incentives in the form of direct benefits for the sector or stakeholders. Furthermore, consideration needs to be given to the extent to which interests coincide between the actors implementing the reduction option and other stakeholders, or whether these conflict.

Implications for a global biodiversity policy discussion

Biodiversity targets and policies need to be framed by and mainstreamed into other policy domains

The well-established role of nature conservation and biodiversity protection policies and measures continues to be important, but should be complemented by other initiatives. Coordination with other policy fields can identify and pursue policies and measures with co-benefits. The risk of unintended side effects needs to be reduced as well as leakage and rebound effects that may undermine the effectiveness of the reduction options.

The future of biodiversity depends on structural and lasting improvements in production and consumption of goods and services

Biodiversity loss is the compound result of a range of external pressures from production and consumption of goods which need to become more ‘eco-efficient’ in terms of their pressures on the natural environment per unit of output. Besides efficiency gains, changes in consumption patterns of food and wood products also have major potential. Biodiversity concerns should be taken into account in policies and practices in the relevant sectors of agriculture, forestry, fishery, food processing and retailing, and energy. The notion that a variety of global concerns can be addressed while slowing down biodiversity loss is illustrated clearly in the combination of options.

Closer co-ordination between biodiversity policymakers and international bodies in other policy areas is essential for meaningful progress

International bodies in other priority areas include IPCC and UNFCCC (climate), FAO and UNFF (food, forestry) and WHO (health). For instance, biodiversity considerations could be included in selecting sites for reduced deforestation under a climate mitigation regime. Similar co-ordination initiatives on smaller scales such as sub continent or country level would set helpful examples and facilitate international discussion.

A multi-option strategy with cross-sector measures is a promising way forward

A well-designed combination of reduction options could not only slow down biodiversity loss but also contribute to a variety of human development issues. Moreover, a combined strategy implies initiatives in many sectors and human activities, which makes the final result less dependent on less-than-expected contribution from one or more of the reduction options.

Implementing options to protect biodiversity in 2050 needs to start now

The analysis focuses in most cases on 2050. For the options to take full effect by that time, implementation should start much earlier. For instance, forest plantations take considerable time to grow. Similarly, climate mitigation measures take decades to make a significant impact on atmospheric concentration of greenhouse gases. The actual climate effects such as global mean temperature increase take even longer to unfold. Achieving widespread and large-scale increase in agricultural productivity takes time, but the anticipated positive and quick effect on biodiversity warrants early implementation. Early implementation is also vital because most of the projected agricultural expansion is expected to takes place in the next 30 years and opens a window of opportunity.

Short-term losses may be unavoidable in creating future gains

Short-term biodiversity losses are sometimes unavoidable in order to create future gains, for example establishing wood plantations on natural land with the prospect of reducing the impact of logging in larger near-natural forest areas. As for keeping agriculture expansion in check, action delayed until after 2030 will substantially increase the restoration challenge. Preventing losses is more efficient, and early action would also fit well with the agendas of other relevant policy fields. For instance, addressing food security, human health and development which are part of the Millennium Development Goals set for 2015. Keeping global temperature increase below 2 0C calls for concerted worldwide action to start early in the next decade.

The policy window for these options before rather than after 2030 is highly plausible.

1

Introduction

Background to the report

This report has been prepared at the request of the United Nations Environment Programme (UNEP) as a contribution to the project on ‘The Economics of Ecosystems and Biodiversity’ (TEEB). Its main objective is to identify options for reducing global biodiversity loss in the face of increasing food, wood and energy demands from a world population of 9 billion people, in 2050, and increasing pressures of infrastructure and climate change on the natural environment. The challenge is to reconcile human development issues with protection of the natural environment including biodiversity. The difficulty of the challenge is underlined by the third Global Biodiversity Outlook, which concluded that, by 2010, the rate of loss had not been significantly reduced at any level – globally, regionally or nationally. The insights of this study may contribute to the pursuance of the post-2010 targets as agreed upon in the tenth meeting of the Conference of the Parties of the Convention on Biological Diversity, in Nagoya, in 2010.

Four types of contributions

This report makes four types of contributions to the development of biodiversity policies. The first contribution consist of determining major and minor options for reducing global biodiversity loss. The loss resulting from various highly autonomous scenarios of socioeconomic development has been signalled in the Millennium Ecosystem Assessment (MA, 2005), the Global Environmental Outlooks (UNEP, 1997, 2002, 2007), the OECD Environmental Outlook to 2030 (OECD, 2008), and in the second and third Global Biodiversity Outlooks (sCBD, 2006; sCBD and PBL, 2007; sCBD, 2010). This report supplements these reports by specifically identifying alternative development pathways for economic sectors and consumption (options), which, potentially, could reduce biodiversity loss. The potential of eight options (Chapter 4) have been identified by testing each option against the strictly no-new-policies baseline scenario described in Chapter 3. The options have been derived from the recommendations made in the third Global Biodiversity Outlook (GBO3) and are linked closely with, and even primarily inspired by, policy fields other than biodiversity. These options include, among other things, increasing agricultural productivity, improving forest management, mitigating climate change, and reducing capture fisheries. Some variants have been elaborated to give an indication of the range of effects, for example, climate change mitigation with and without bio-energy intensive measures.

The second contribution is an analysis of the synergies, trade-offs and total effect of a combination of certain options implemented simultaneously (Chapter 5). To that end, a set of individual options was constructed and analysed, and each option was set at an implementation level considered to be feasible but ambitious by the research team. The extent to which this combination of options could succeed in reducing biodiversity loss is an interesting and relevant result, but the combination should not be viewed as a final, optimal mix of policies. Further dialogue with policymakers is needed, in which region-specific scenarios and combinations of options are analysed.

The third contribution consists of biophysical input for economic analysis and valuation of ecosystem services. In 2008, the Netherlands Environmental Assessment Agency (PBL) made a contribution to the project on 'The Economics of Ecosystems and Biodiversity' (TEEB) by modelling the change in global biodiversity up to 2050, in case no new policies would be set. The biophysical result served as input for the TEEB project. Using this input, a preliminary assessment was made of the economic consequences, as reported in 'The Cost of Policy *Inaction*' (Braat and ten Brink, 2008) and 'The Economics of Ecosystems and Biodiversity, An interim report' (European Communities, 2008). Contrary to that previous study, the change in global biodiversity under a situation of 'Policy *in Action*' has been modeled for this report. The results from this model-based analysis also served as input for UNEP project on The Economics of Ecosystems and Biodiversity. These economic findings have been reported separately and are not included in this report (Hussain et al., 2010; see also www.teebweb.org).

The fourth contribution is the indication of how pro-biodiversity policies relate to policies on climate change mitigation and energy production, agriculture, food production, Millennium Development Goals, food availability, and water quality (see Chapter 6). Competing claims on dwindling resources such as productive land, water and energy, confirm the fact that solutions can no longer be found in isolation. Because solutions in one field may impede the achievement of goals in other fields, coordination is required to reap mutual benefits in cases of conflicting interests.

An integrated modelling approach as requested by UNEP

This report was prepared at the request of the Executive Director of UNEP. The study was carried out by the Netherlands Environmental Assessment Agency (PBL), the Dutch Agricultural Economics Research Institute (WUR-LEI) and the *Sea Around Us* Project of the Fisheries Centre, University of British Columbia, Canada, in the period from February to September 2010. Use of a series of interlinked models (LEITAP, IMAGE, TIMER, GLOBIO, EcoOcean and GISMO) has enabled a quantitative and integrated approach (Annex B). Estimates on biodiversity are presented in terms of indicators of *ecosystem extent* (natural area) and *mean species abundance* (MSA, see Chapter 2). These two indicators were derived from the CBD 2010 target indicators (CBD, decision VII/30). A third indicator of biodiversity is the remaining areas of wilderness and is defined as highly intact natural area. The impact on living marine resources is presented in terms of the Depletion Index (Chapter 2).

The results are presented for the period up to 2050, on a global scale as well as for seven terrestrial biomes and seven geo-political regions (Annex B). All options were compared with the no-new-policies baseline scenario of the OECD Environmental Outlook to 2030 (OECD, 2008), or with similar baseline scenarios (Chapter 3).

Giving the short time frame, this report was based mainly on existing analyses carried out for the fourth Global Environmental Outlook (UNEP, 2007), the OECD Environmental Outlook to 2030 (OECD, 2008), the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2009), the second and third Global Biodiversity Outlooks (sCBD, 2006; sCBD and PBL, 2007; sCBD, 2010), together with ongoing modelling work at the PBL. The analysis required additional model runs, in order to assess the impacts per option, to capture additional functionality offered by more recent model versions, and to assess options not considered in earlier work. The particular combination of options was composed specifically for this study, and an updated baseline scenario was applied that includes the current economic crisis.

Framework and limitations of this study

For this study, we examined world biodiversity policies essentially as an issue of growing and competing resource use. Within this framework, the study homes in on 'direct drivers of change'. This choice determined the scope of the study to search for pro-biodiversity options. The starting point of the analysis was the urgent need to significantly reduce the rate of biodiversity loss, and the consequences for specific regions if we fail to do so. This study does *not* predict the future, and has several limitations (Chapter 7). It does explore the technical potential for change, in certain sectors, aimed at reducing projected biodiversity loss. But it does not discuss the policy instruments, such as taxation, subsidies, regulation, and innovation, which could bring about these changes. The list of options is not exhaustive and use of existing studies and models largely determined the scenarios, options and indicators applied. The focus is on terrestrial ecosystems and, to a lesser extent, on marine and inland waters.

Much could and should still be explored. A follow up of the dialogue with policymakers could identify alternative development pathways, and other measures to bring these about. For more information on future analyses, used scenarios and regional results, please contact either the PBL at info@pbl.nl, or the corresponding author.

2

Assessing trends in future biodiversity

2.1 Introduction

Biodiversity is a broad concept with many definitions and indicators to monitor biodiversity trends

The concept of biodiversity has many dimensions and different interpretations, which influence the way in which changes in biodiversity are measured. The definition most used is that of the Convention on Biological Diversity: ‘*Biodiversity is equal to 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).* Other aspects of biodiversity than variability are often also emphasized, such as the importance of naturalness. To some degree, the differences in interpretation relate to underlying reason to conserve biodiversity. This can arise from the intrinsic value of biodiversity based on an ethical conviction that biodiversity should be sustained in its own right. It may also come from the notion that biodiversity underpins many ecosystem services provided by nature such as climate regulation and water purification. Other reasons start from a precautionary principle, such as loss of biodiversity may reduce the resilience of ecosystems to convert suddenly to another configuration, passing a tipping point.

The broadness of the biodiversity concept and the different interpretations imply that many different indicators have been used to measure biodiversity. While some indicators focus on species and emphasize the importance of retaining species richness at different geographical levels, other indicators focus on the extent and intactness of the original ecosystems. Yet other indicators focus on the drivers of biodiversity loss largely because these are easier to monitor. However, most indicators have been developed for small, well-known ecosystems and can generally not be applied at global level. At this level, indicators need aggregation over large areas, grouping together entirely different systems, but are hampered by insurmountable data gaps.

Biodiversity indicators can be structured

Biodiversity indicators can be structured using the list of indicator categories agreed upon by the CBD (Decisions VII/30 and VIII/15 made in Kuala Lumpur, 2004). Five of the categories listed are dedicated to the status and trends of the components of biological diversity. These indicators looking into the state of biodiversity are:

1. Trends in the extent of selected biomes, ecosystems and habitats;
2. Trends in abundance and distribution of selected species;
3. Change in status of threatened species;
4. Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance;
5. Coverage of protected areas.

A subset of these indicators can be produced for future scenarios on a global scale (for an overview, see Leadley et al., 2010). Some indicators, such as the main indicator used in the report (Mean Species Abundance), relate to several elements on the list, while there are also linkages between the different types of indicators. Some of the indicators used in global assessments are described below, including their strengths and weaknesses, and the relation to the purpose of this report to assess ex ante global biodiversity impacts of sector-based options in the future.

Indicators for the extent of selected biomes, ecosystems and habitats

The most direct loss of biodiversity results from conversion of natural habitats to agricultural, plantation forestry or urban areas. This loss in habitat can be described by indicators showing the *extent of selected biomes, ecosystems and habitats*. The extent of the remaining relatively undisturbed or non-converted area is a straightforward indicator (Sanderson et al., 2002). The extent of specific ecosystems, such as forests, mangrove and coral reefs are reported in several assessments (sCBD, 2010; MEA, 2005). These indicators are rather straightforward and easy to measure. However, they have the disadvantage that the extent of a system does not imply its quality. This is partly overcome by estimating wilderness areas (e.g., Mittermeier et al., 2002), which are defined as relatively untouched areas providing a high level of biodiversity. But the very distinction between wilderness and non-wilderness is difficult to determine.

Trends in abundance and distribution of selected species

Indicators to describe changes of species abundance focus mostly on a single or limited number of species groups (Butchart et al., 2010). Human activity generally decreases the abundance of many original species, and increases the abundance of a few opportunistic species. This decrease in species abundance may lead to local extinction and eventually after a long trajectory of deterioration, to extinction. Therefore, changes in species abundance and especially species in the original composition of ecosystems indicate changes in major aspects of biodiversity, such as the integrity or intactness of ecosystems. These changes are linked to local and global extinction of species (Majer and Beeston, 1996; Loh et al., 2005; Scholes and Biggs, 2005). Trends in species abundance are sensitive indicators and may also indicate processes, such as homogenisation (ten Brink et al., 1991, 2000; Lockwood and McKinney, 2001).

At global level, a more aggregated indicator using multiple species groups is used such as the Living Planet Index (Loh et al., 2005). These indicators have a high data requirement, and are not used in a modelled scenario context. Indicators designed for use in a scenario context are the Biodiversity Intactness Index (Scholes and

Biggs, 2005) and the Mean Species Abundance Index (Alkemade et al., 2009). These indices are based on estimates of the relative change in population size of species compared to undisturbed or intact ecosystems. This follows the notion that conserving intact ecosystems can also conserve the highest number of species in most cases. However, these indices have the disadvantage that they are based on generic estimates and thus can no longer be related to individual species.

Change in status of threatened species and species richness

Indicators of species richness have often been applied as diversity indicators at the local level. However, while they relate directly to the concept of diversity, they tend to be relatively data insensitive and only signal once a species has disappeared. Even more important, species richness often increases as original species are gradually replaced by new, human-favoured species. This is called the intermediate disturbance diversity peak (Lockwood and McKinney, 2001), and may provide a misleading picture.

Related indicators have been developed that can also be applied on a more aggregated scale such as Species-Area relationships. For example, in the Millennium Ecosystem Assessment, extinction rates for vascular plants were estimated by using Species-Area relationships (MEA, 2005; van Vuuren et al., 2006). Alternatively extinction risks can be derived from estimates of the remaining suitable area for individual species (Thomas et al., 2004; Jetz et al., 2007).

An established index, the Red List Index summarises threats to species, and combines this with species sensitivities to these threats including risk of extinction. Red List indicators for several species groups are used in the Global Biodiversity Outlook 3 (sCBD, 2010). These lists are based on the knowledge of many experts and on monitoring of species trends. However, application of this index is not straightforward in a scenario context.

Trends in genetic diversity of domesticated animals, cultivated plants, and fish species of major socio-economic importance

One of the few set of indicators to measure this aspect of biodiversity, the GBO3 (sCBD, 2010) reports on risks to extinction of breeds of domestic animals. This index is similar to the Red List Index and has the same advantages and disadvantages. Unfortunately, as no indicator can be produced in the context of scenario analyses, we are not able to report on genetic diversity.

Coverage of protected areas / wilderness areas

Coverage of protected areas is a response indicator rather than a state indicator because one way to preserve biodiversity is protection. Several indicators have been proposed that measure level of protection, either by simply looking at the total (extent of protected areas) or the degree of coverage of key ecosystems (e.g., protection of biodiversity hotspots, minimum protection of unique biomes or protection of key bird areas). Key targets for protection are intact ecosystems and wilderness areas. Several indicators have been proposed that simply estimate the degree of wilderness areas globally (Mittermeier et al., 2002; Sanderson et al., 2002).

Other indicators

Other indicators are proposed for ecosystem integrity and services (for example, the Marine Trophic Index) and the threats to or pressures on biodiversity. Sala et al. (2000) presented an interesting approach by estimating trends in biodiversity based on expert judgement of different pressures on various ecosystems and their trends. Other categories are indicators for sustainable use (e.g., ecological footprint); and status of traditional knowledge, access and benefit sharing, and of resource transfers (sCBD, 2010).

2.2 Key indicators used in this report

Given the purpose of the report, the biodiversity indicators used are:
1. applicable on a global scale and also provide information on underlying ecosystem types;
2. applicable in a scenario context;
3. based on sound scientific principles;
4. meaningful;
5. policy relevance for the CBD.

Based on these criteria, five indicators have been selected that provide an overview of key biodiversity trends. These indicators directly relate to the list of CBD state indicators discussed in Section 2.1. The first is *biome extent* (natural area) expressed in million km² and subdivided into a selection of seven globally aggregated biomes. The second is the relative *mean species abundance* of originally occurring species (MSA) as an indicator for trends of species abundance. This indicator is also a measure for the intactness of ecosystems (Alkemade et al., 2009). Third is a combination of ecosystem extent and MSA and yields the *wilderness* indicator, presenting the extent of highly intact natural areas. These indicators are presented schematically in Figure 2.1, and elaborated below. The other two indicators are *Marine Depletion Index* (DI) to indicate the state of living marine resources and the *degree of vascular species extinction* based on species-area relationships (SAR). An overview is presented in Table 2.1. Overview of biodiversity indicators used in this study.

Biome extent (natural area)

Biome extent was measured by subtracting agricultural areas, forestry plantations, and urban areas from a biome according to the climatic and geographical potential. Agricultural areas include converted land used for crops and fodder, and permanent pastures with relatively high-stocking rates. Forestry areas, except for forestry plantations, are included as natural area because these land uses are exploitation forms of natural or semi-natural forests. The areas were estimated using outcomes of IMAGE (see Section 2.3), combined with Global Land Cover data from 2000 (Bartholomé and Belward, 2005).

Mean Species Abundance (MSA)

Trends in species abundance were measured in terms of the relative *mean species abundance* (MSA) of the original species. MSA has been used in numerous earlier assessments, for instance the Global Biodiversity Outlooks, Global Environmental

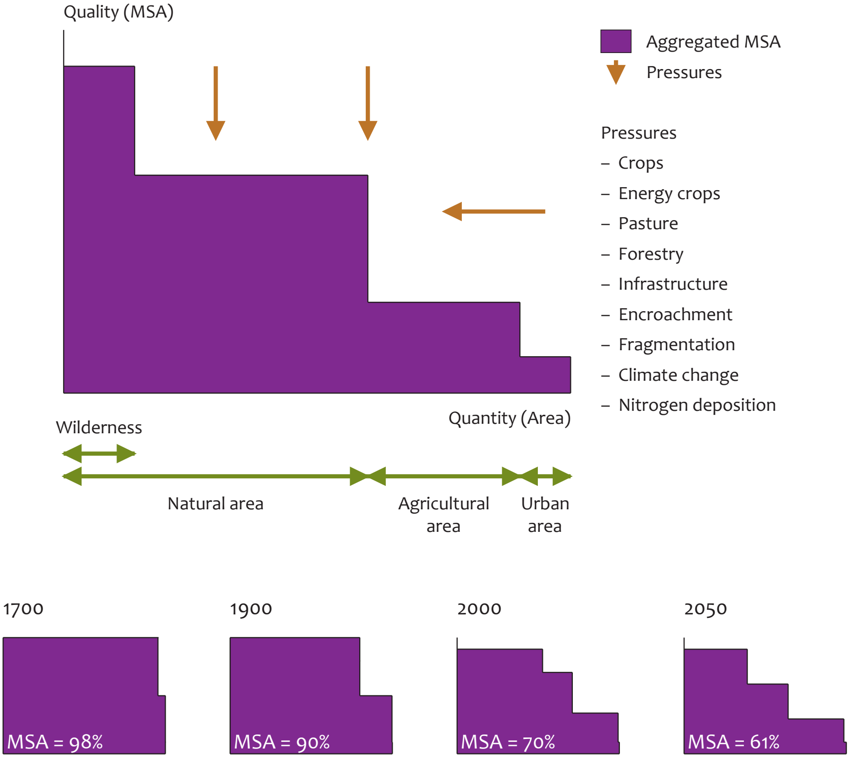
Table 2.1 Overview of biodiversity indicators used in this study

Indicator	Link to CBD state indicator	Description	Application
Extent of biomes (natural area)	1	The size of a biome having its original cover (the original area of a biome minus the converted area used for agriculture, forestry plantation and urbanisation). It does not provide information on the quality of the natural area.	Applied to all options mostly to show the effectiveness of measures to reduce habitat loss by conversion.
MSA	2	Measures the change in populations of species relative to intact ecosystems. It provides supplementary information on the *mean* quality of natural areas and of agricultural areas.	Used in this study as the main indicator of biodiversity loss. Applied universally in all options and scenarios and for all areas, natural and man-made areas. Applied at different levels of scale, in maps of 0.5 by 0.5 degree grid cells, and as quality measure to determine wilderness areas.
Wilderness area	1	Measures the size of relatively undisturbed (intact) ecosystems, with a MSA value above 0.8 (directly derived from the MSA). Provides supplementary information on which part of the natural area is of high quality.	Applied to all options and scenarios as an additional indicator to determine high-quality natural areas.
Marine Depletion Index	2	Measures the change of estimated biomass of living marine resources (29 functional groups) relative to a situation of low fishery pressure (1950). It concerns mainly fish but also crustaceans, bivalves and other exploited groups. The indicator is an abundance indicator and closely related to MSA.	Applied in the changing marine fisheries option.
Number of vascular plant species	3	The number of the original species remaining in a biome calculated by a SAR relationship at the level of 65 unique biomes.	Applied as an additional indicator of global biodiversity trends for the *combination of options* only, also to explore the robustness of the MSA calculations.

Outlooks and OECD Environmental Outlook to 2030. This indicator uses the species composition and abundance of the original ecosystem as a reference situation. The level of intactness of ecosystems is measured by the change in species composition and abundance as a consequence of changes in driving forces or pressures, such as land use, exploitation. If the indicator is 100%, biodiversity is assumed to be similar to the undisturbed or low-impacted state, implying that the abundance of all species equals the natural state. If the indicator is 50%, the average abundance of the original species deviates by 50% from the undisturbed state. The range in MSA values and the corresponding land use and impact levels are visualised for grassland and forest systems in Figure 2.2.

In the intact situation, MSA is 100%. Converting natural systems to agriculture, plantation and urban area is assumed to have an immediate impact on the MSA which can be further reduced by environmental pressures. MSA is determined by multiplying the impact of different pressures and summing the MSA values of different use types and ecosystems. The calculation method is explained in Figure 2.1. For more information on MSA and the relationship with environmental pressures, see Alkemade et al. (2009) and www.globio.info.

Representation of indicators in this study **Figure 2.1**



The MSA methodology. Ecosystems have two components: quantity measured as area and quality measured by MSA. For both components, the original state is used as reference and equals 100%. Pressures including agriculture, forestry, and climate change lead to MSA loss and are most severe in human-dominated areas. Areas of high MSA are denoted as wilderness area (quality value > 80%). The trend from 1700 to 2050 is illustrated in the lower part of the figure. Real calculations at detailed grid level show greater variation in results than suggested here.

MSA is used in this report as the central biodiversity indicator, with the implication that the focus is more on preserving naturalness, ecosystem intactness and species abundance than, for instance, on species richness (see Section 2.1). The choice for MSA is based on broad coverage of the biodiversity concept. MSA together with biome extent and wilderness cover most of the categories in the CBD indicator list (see Table 2.1).

The driving forces of biodiversity loss, or pressures, considered in this report are:

- Agricultural production on *croplands*, including the production of bio-energy crops;
- The use of *pastures* by livestock grazing, ranging from extensively used natural grassland to intensive livestock production systems;

- *Forestry*, including clear-cut, wood plantation and selective logging of natural forests;
- *Infrastructure*. The disturbance of animal populations caused by transport infrastructure and traffic;
- *Encroachment*. The small scale development of human settlements and the exploitation of natural areas by hunting, extraction of fuel-wood and recreation;
- *Fragmentation*. The reduction of patch sizes of natural areas due to development of agricultural land, forestry, roads and other infrastructure;
- *Climate change*. Change of local climate conditions;
- *Nitrogen deposition*. The exceedance of critical loads for nitrogen of natural areas by nitrogen deposition.

Wilderness area

The area of relatively undisturbed ecosystems can be estimated by distinguishing areas of relatively high intactness, for instance a MSA of 80% or more is defined as wilderness in this report. The choice of 80% is somewhat arbitrarily and estimates of wilderness areas are therefore not equivalent to definitions used in other reports (e.g., Mittermeier et al., 2002).

Depletion Index

The trend in species abundance in marine systems is measured using the depletion index (DI). Biomass changes due to fisheries of various functional groups of fish, crustaceans and molluscs are calculated using the EcoOcean model (Annex B). For each functional group and region, the estimated biomass is divided by the biomass calculated for the year 2004. DI is the weighted mean of these ratios per species and has been adapted from the original depletion index described in (Alder et al., 2007).

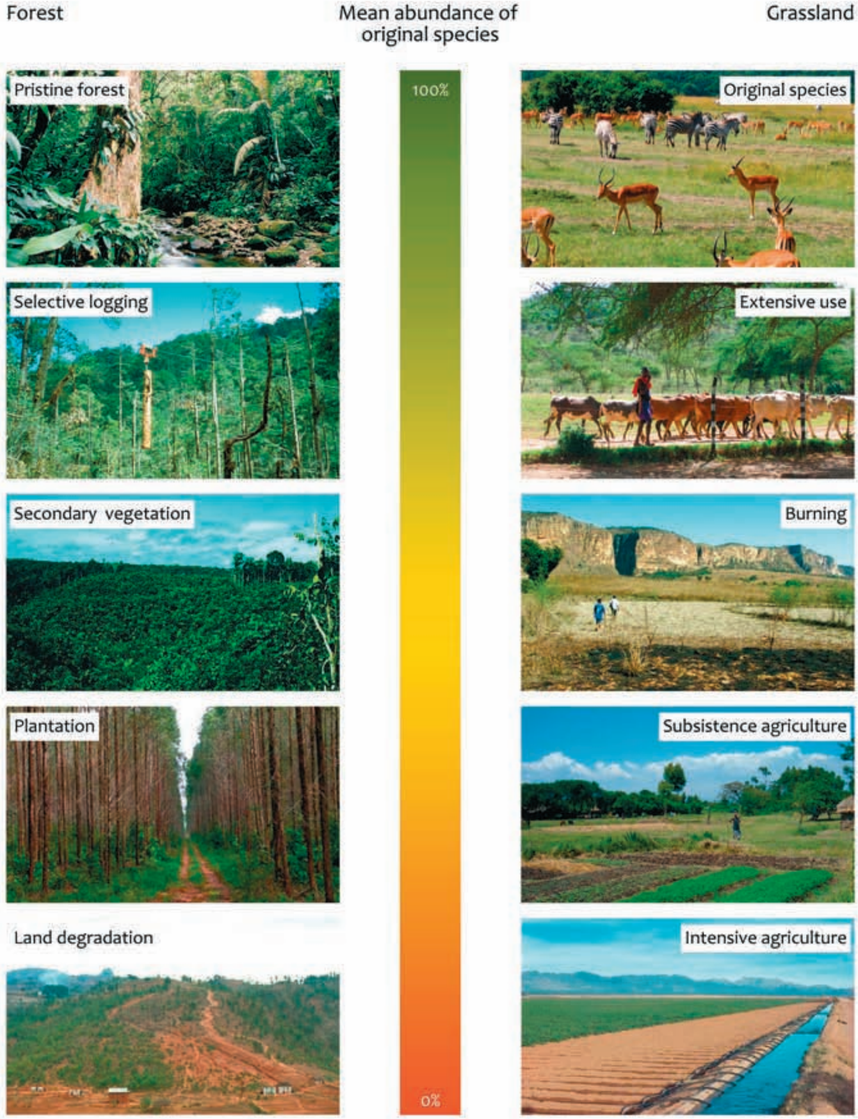
Number of vascular plant species

The Species-Area-Relationship (SAR) based indicator (van Vuuren et al., 2006) is used to describe changes in vascular plant species richness on a global scale for the

Box 2.1: How to interpret MSA changes

Global MSA is used throughout this report as an overall indicator of the impact of a certain option. As with any aggregated index, changes in values may be difficult to interpret. As indicated in Figure 2.1, changes in MSA values occur because of changes in environmental pressure and the extent of ecosystems. Changes in the values can thus also be expressed in both indicators. The reference MSA value for 2000 of 71% implies that globally 29% of the original naturalness of ecosystems has disappeared. However, a considerable part of the remaining MSA is tundra and desert systems, biomes types that are difficult to convert. The total historical loss of 29% is equivalent to a loss of the size of Asia in terms of its biodiversity value. Similarly, future trends can be evaluated. The baseline shows an additional MSA loss of 9 percent points, equivalent to a loss of the size of North America in terms of biodiversity value. The loss is almost exclusively forest and grassland ecosystems, with little change in desert and tundra systems.

Photographic impression of mean species abundance indicator **Figure 2.2**



The value of the MSA indicator gradually changes due to human impacts from highly natural ecosystems (MSA of 90 to 100%) to highly cultivated or deteriorated ecosystems (MSA about 10% or less).

Millennium Ecosystem Assessment. The method applies SAR to describe changes in the equilibrium of species richness (once the total level of species richness is in equilibrium with the area size) at the level of 65 unique ecosystems (biome–realm combinations) as a function of habitat loss, climate change and nitrogen deposition. In contrast to the MSA, changes at ecosystem level are weighted by the amount of endemic species harboured (for a comparison between MSA and SAR, see Box 5.2).

2.3 Application of biodiversity indicators to assess the effectiveness of different options

The future is unknown. Scenario analysis has been developed as a tool to explore uncertain futures by focusing on 'what-if' questions under a set of key assumptions. Over the past two decades, integrated assessment models of global environmental change have been successfully used to support scenario analysis on issues, such as climate change, land use change, and biodiversity assessment. Such models provide consistent trends for a set of global driving forces of biodiversity loss. In this study, scenarios developed using the Integrated Assessment Model IMAGE 2.4 (Bouwman et al., 2006) have been used to provide information on changes in key driving forces (population and income changes, land use and land cover change, climate change and nitrogen deposition) as input for the biodiversity assessment. A detailed description of the IMAGE 2.4 model is provided in Annex B. Based on the IMAGE output, the GLOBIO model, including GLOBIO-aquatic was used to calculate changes in the indicators of the MSA framework (extent, MSA, wilderness area). The same output also forms the basis for the indicator for the number of vascular plant species that have been applied. The EcoOcean model is used to evaluate the consequences of change in global fisheries and to calculate the depletion index. (A detailed description of the models is given in Annex B).

In assessing the impact of policy measures, three types of scenarios have been used:

- Baseline scenarios to describe possible trends under the assumption that current trends will basically continue and with no major policy shifts. These scenarios mainly form a trajectory of reference. The baseline scenario for this study is discussed in Chapter 3;
- A single option superimposed on a baseline scenario to investigate the impact of this option on biodiversity loss. The results compared to the baseline are presented in Chapter 4;
- Combination of options superimposed on a baseline scenario to investigate the interaction of various policy measures and their combined result (see Chapter 5).

3

Business-as-usual scenario: projections up to 2050

3.1 Key drivers of biodiversity loss

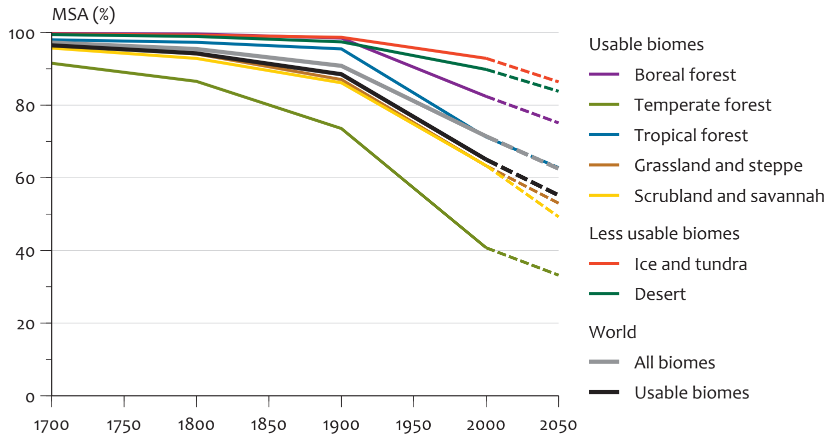
Future prospects for biodiversity are driven by growth in population and income, changes in the structure of GDP, and technological improvements in production. This study uses a baseline scenario that projects these key drivers into the future. The projections originate from the OECD Environmental Outlook to 2030 and cover the period 2000 to 2050 (Bakkes et al., 2008; OECD, 2008). The baseline assumes that, without any new policy action, world economic growth and globalisation will follow trends similar to the past few decades. Key aspects of this baseline scenario relevant to biodiversity loss are:

- Population growth follows the UN medium scenario and increases from 6 billion in 2000 to more than 9 billion people in 2050;
- Technological progress is driven by labour productivity. All countries eventually move toward 1.75% per year productivity growth. This is a rough historical average for OECD countries. Yields of major staple crops, aggregated at global level, increase on average by a factor of 1.6 up to 2050 roughly following FAO projections (Bruinsma, 2003; FAO, 2006);
- Per-capita income grows in all regions and most strongly in emerging economies. Hence, Brazil, Russia, India and China gain increasing ground as key global players. As a result, the total global economic output grows fourfold up to 2050.

No new policies related to the environment and global trade are considered; only current (and firmly planned) legislation is assumed. No measures are taken to promote bio-energy beyond current incentive schemes, or to reduce CO_2 emissions from deforestation or forest degradation. No incentives are assumed to promote further measures on sustainable forestry. The size of protected areas, currently around 14% of the global terrestrial area, is assumed to remain constant in the coming decades.

Demand for energy and food will rise steadily but not as rapidly as GDP. Global energy use increases from 400 EJ in 2000 to around 900 EJ in 2050. In line with the IEA World Energy Outlooks of 2004 and 2006, fossil fuels continue to dominate in the absence of additional climate mitigation policies (OECD and IEA, 2006). Hence,

MSA per biome in baseline scenario **Figure 3.1**



Historic and projected MSA develop differently for the biomes under the baseline scenario

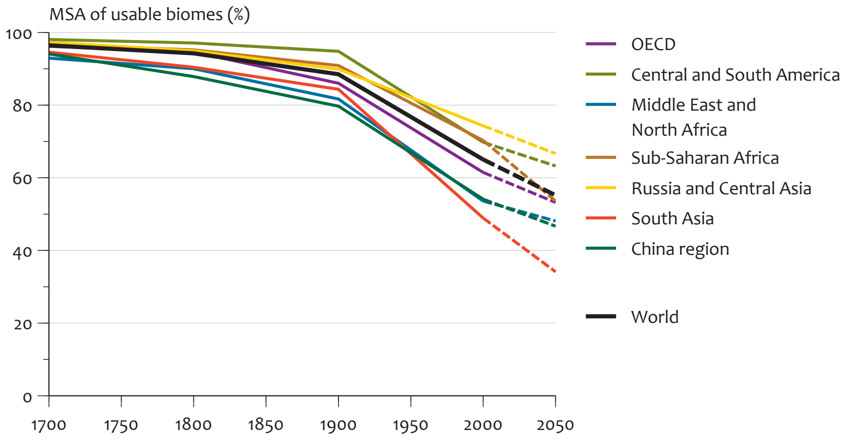
greenhouse gas emissions increase and lead to an ongoing build-up of greenhouse gases in the atmosphere. As a result, the average global temperature continues to rise and, by 2050 is 1.6 °C above pre-industrial level.

Global production of both food crops and animal products in 2050 is twice the volume in 2000. Production of animal products in 2050 is twice the volume in 2000. Global demand for fish is expected to increase, largely driven by developing countries, and enabled by the purchasing power of a growing middle class. According to projections the annual fish demand (and hence supply) will increase from the 2004 level of almost 140 million tonnes to almost 190 million tonnes by 2030, and to 227 million tonnes by 2050 (Cork et al., 2005). Capture fisheries will not be able to contribute sufficient to cover the increased demand.

Baseline scenario: assumptions on the future

The baseline provides a reference level on which the effects of the various options can be compared. Using one baseline instead of, for instance, four entirely different scenarios that depict alternative futures enables a clear analysis of the effectiveness of different options. A clear view of major and minor options is key information for policymakers. However, uncertainties about autonomous future developments and how they influence biodiversity loss are not shown in this analysis. This uncertainty has been illustrated recently in economic growth. According to the OECD Outlook for 2030, the uncertainty of the baseline is asymmetrically on the side of higher pressures on the environment, reflecting possible accelerated growth and consumption in dynamic emerging economies (Bakkes et al., 2008). However, if the current global economic crisis affects structural growth, the reverse could be the case. Uncertainty also surrounds the energy system because of assumptions on lifestyle and technology. These uncertainties influence projections on biodiversity loss in the baseline as well as the effects of the various options (Table 3.1).

Figure 3.2 **MSA of usable biomes per region in baseline scenario**



Historic and projected MSA develop differently for world regions under the baseline scenario.

3.2 Projections on biodiversity loss and natural areas to 2050

The baseline developments indicate an increase in the drivers of biodiversity loss. More food is needed to sustain larger populations with continuous demand for new agricultural lands. This will be at the cost of natural habitats, and will increase environmental problems, such as fertiliser run-off and water use for irrigation. A corresponding increase in agricultural productivity will not be sufficient to compensate for the higher demand for agricultural land. Demand for industrial round wood, pulp and firewood will increase with the growth in population and affluence. And, in addition, substantial amounts of firewood will continue to be used for energy. In addition, rising levels of affluence generate demand for more luxury products including higher meat intakes in most diets, although culture, preferences and habits could influence this development worldwide.

Biodiversity loss will continue without new policies

Global biodiversity in terms of mean species abundance (MSA) is expected to decrease by 10 percent points (pp) from about 70% in 2000, to about 60% in 2050. A loss of a mere 10 percent points seems small compared to the quadrupling of the world economy in this time span. However, one should realize that the indicator is a global average across biomes. Some 20% of land area is inaccessible for human production, for example polar and tundra regions, hot deserts. The MSA in these regions will stay close to its pristine state. Land converted to agriculture will face a loss in biodiversity, but not a total loss. The *lower limit* of MSA in these biomes is around 15%. Also the constructed global indicator can drop very little below 30 to 35%.

Uncertainties in underlying indirect drivers of biodiversity loss **Table 3.1**

Population growth	Fairly certain. Based on UN medium projection. The low and high projections show 8 and 10.5 billion people in 2050, respectively.
Economic growth	The direction (increase) is certain but the size is considerably more uncertain. Uncertainty skewed towards more environmental pressure from higher growth in industrialising countries. Current economic down-turn is expected to have no significant effect on long-term economic trends.
Consumption growth	The direction (increase) is certain, but the size is considerably more uncertain, being generally a combination of demographic and economic development.
Agricultural productivity	Considerable discussion about the capacity to continue long-term growth rates as assumed in the baseline scenario which include, for instance, the Green Revolution jump. Assumptions based on FAO projections.
Energy use	Direction certain (growth), but developments in the energy system uncertain, and depend on lifestyles, economic growth, and technology.
Technology and labour productivity	Labour productivity assumed to converge towards (not necessarily reaching) long-term average for industrialised countries. Assumed trend includes large technological transitions (e.g., ICT) but future timing is difficult to predict.

Uneven distribution of impacts on biodiversity over regions and biomes

Changes in MSA are not evenly distributed worldwide and over the earth's biomes. Dryland ecosystems – grassland and savannah – will experience the highest loss in the coming decades (see Figure 3.1). Ever more of the world's remaining natural ecosystems will be mountainous, boreal, tundra, ice, semi-dry or dry habitats unsuitable for human settlement and exploitation.

Regional differences are caused by differences in demographic growth and economic development. MSA values for the remaining biodiversity differ greatly between regions, with MSA in South Asia, China and the OECD countries projected to drop to 60% or less by 2050 (see Figure 3.2). This reflects the higher proportion of usable land in use in these areas under pressure of population and economic growth. The highest projected *rates of loss* are in South Asia and Sub-Saharan Africa and provide an indication of where most gains could be made in reducing biodiversity loss. However, the reasons for the high rates (population growth, higher than average economic growth) may also indicate that increasing pressures are hardest to mitigate in these regions.

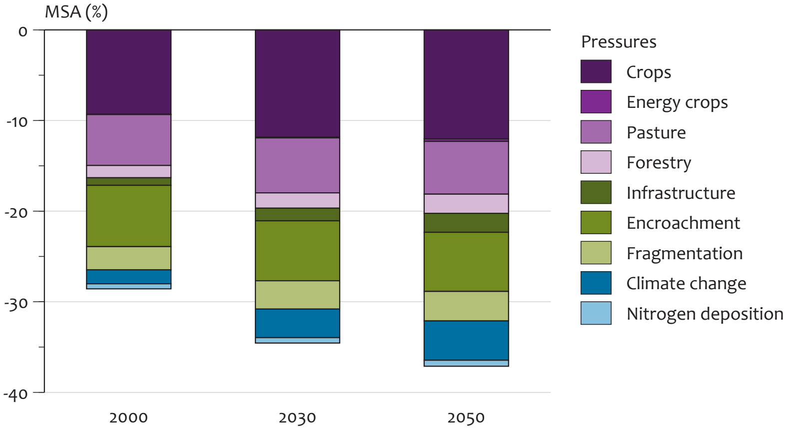
Pressures change with time

To date land-use changes in agriculture (crops, bio-energy, grazing and forestry) are the major pressures on loss in MSA (see Figure 3.3). The relative contribution of this pressure diminishes over time while climate change exerts increasing pressure on MSA. Global agricultural land use expands because improved yields do not meet increasing demand to feed larger and richer populations. Agricultural land expands primarily in the period up to 2030. Beyond that, expansion is expected to level off driven mainly by the assumed stabilisation in the population allowing productivity increases to compensate for increased demand (see Figure 3.4).

The extent of natural area and wilderness continues to decline

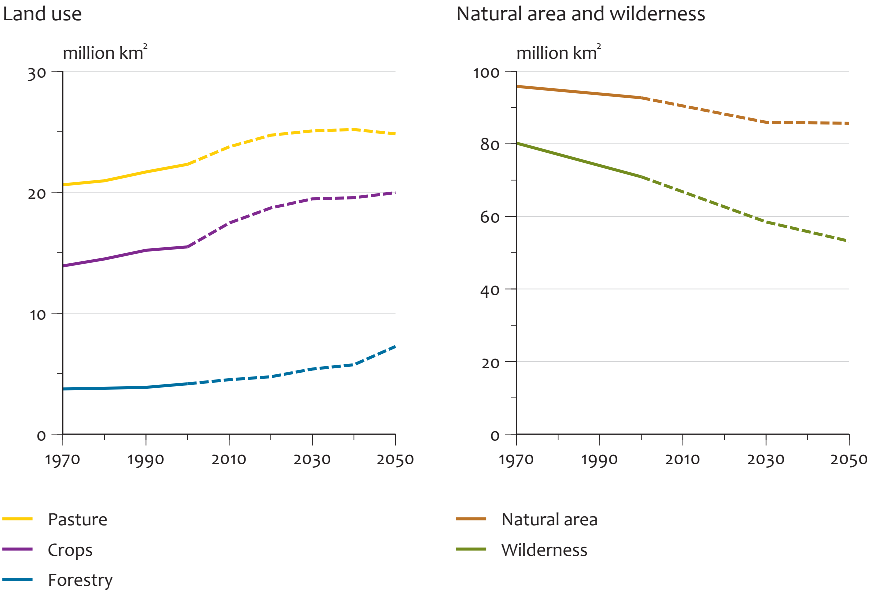
Projected developments in natural and wilderness areas complement the MSA figures. Globally, the extent of natural areas will decline by some 10 million km^2 or about 8% of total global terrestrial area (~130 million km^2, excluding Greenland and Antarctica). Wilderness areas will decline by some 15 million km^2 through habitat

Figure 3.3 **Pressures driving global biodiversity loss in baseline scenario**



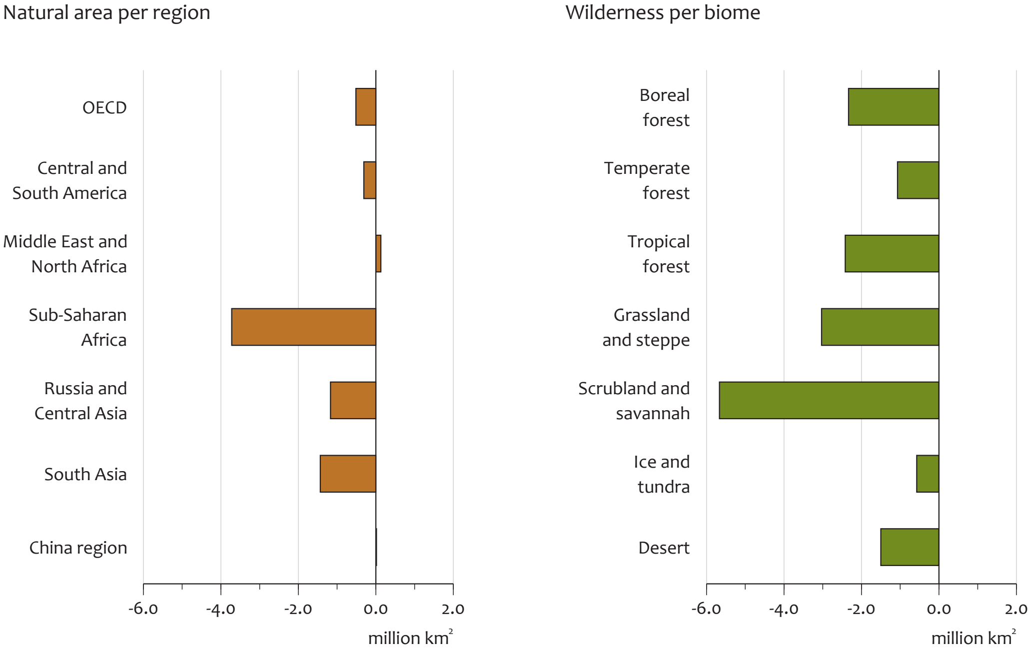
Projected MSA loss under the baseline scenario is the result of different human induced pressures, with a large role for agricultural land use, encroachment and climate change.

Figure 3.4 **Global land use and natural area in baseline scenario**



Under the baseline scenario, global land-use for forestry, crops and pasture will increase to 2030, and there after level off, except for forestry. As a consequence, the area of natural lands and wilderness decreases.

Change in natural area and wilderness in baseline scenario, 2000 – 2050 **Figure 3.5**



Losses in natural area and wilderness between 2000 and 2050 are especially prominent for grassland and savannahs in Sub-Saharan Africa.

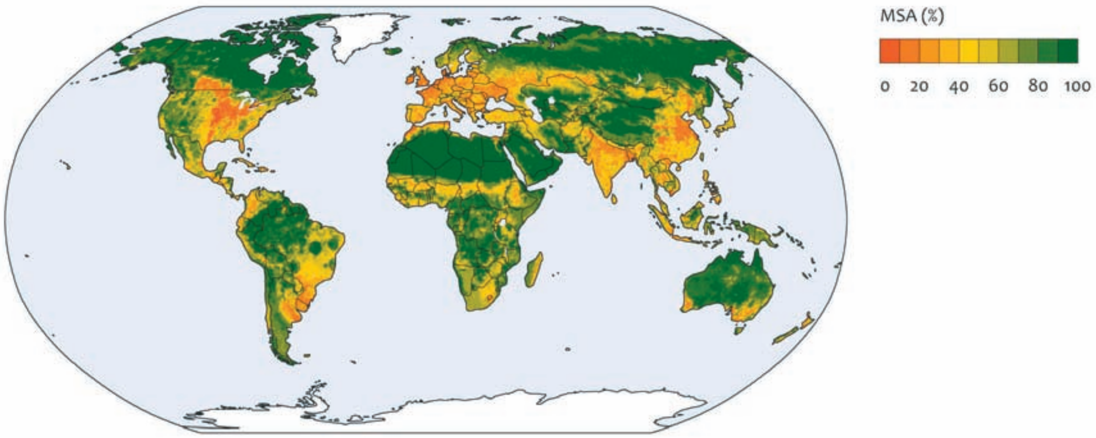
loss and degradation, and the loss is equivalent to over 11% of the world's terrestrial area.

Land use for human activity increases up to 2050, with the fastest increase in South Asia and Sub-Saharan Africa, resulting in those regions having by far the highest proportion of terrestrial area in use. Highly intact natural areas will suffer and be reduced by 2050 in Sub-Saharan Africa from 55 to 33% and in South Asia from 30 to l2% of the total land area. As a proportion of the usable land, these figures are much lower, 18 and 9%, respectively (see Figure 3.5).

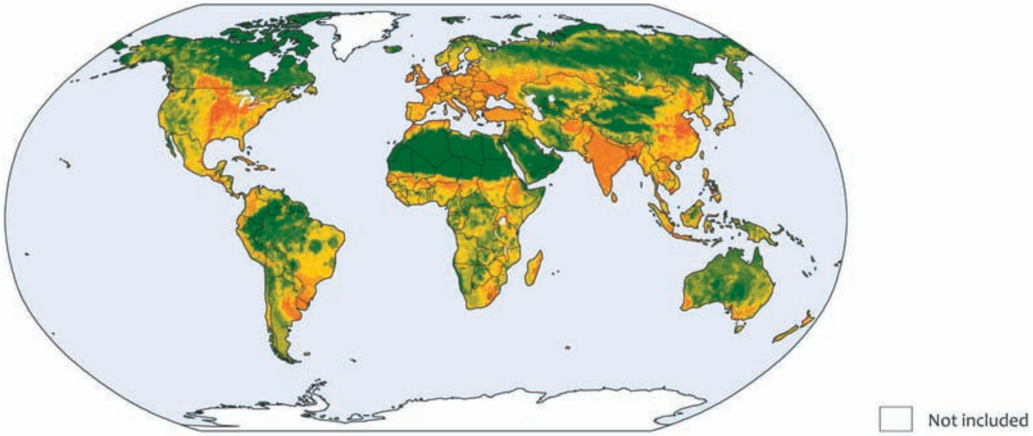
Next to differences on an aggregated level, biodiversity loss will differ between areas within regions and biomes (Figure 3.6). The used models allocate land-use and other pressures on a fine scale (see Annex B), but these results are more uncertain due to imperfect allocation rules.

Figure 3.6 **Mean Species Abundance, 2000 – 2050**

2000



Baseline scenario, 2050



Maps of terrestrial Mean Species Abundance in 2000 and for the baseline in 2050.

3.3 Variations to the baseline

The baseline projection is an assumption and should not be seen as a forecast of the future. It represents what might happen without major new events or policies. This section explores some of the uncertainties associated with the baseline.

Land-use changes in agriculture are crucial to future biodiversity loss. Future projections of demand for agricultural land have fairly wide uncertainty margins:

- More-rapid-than-expected warming of the planet could reduce agricultural productivity sharply (FAO and World Bank, 2009). If assumptions on productivity increases are overly optimistic, more land under agricultural production would be needed;

- The land area devoted to agriculture would also increase with increased demand for crops for biofuels as a result of higher than expected oil prices or due to specific policies;
- Expansion of areas for cattle ranging is uncertain. Although rising demands for meat would increase the number of animals ranged, demand may also be met by more intensive methods, depending on the costs and availability of land and technology;
- Where agricultural expansion occurs is important and whether this coincides with contraction and abandonment of agricultural lands elsewhere. While the net global agricultural area may increase slightly, shifts in production between regions could result in extensive conversion of natural areas. These regional shifts depend to a large extent on whether or not further trade liberalisation will take place.

This section explores two variants on the baseline. One variant assumes stagnation in agricultural productivity, and the second assumes strong trade liberalisation of agricultural products.

3.3.1 Stagnation in agricultural productivity

In the long term, climate change, water scarcity and other factors could have significant impacts on agricultural yields. The stagnation variant is a crude exercise to explore what could happen if crop productivity worldwide stagnates at 2010 levels, while food consumption continues to increase according to the baseline scenario. Livestock productivity is assumed to grow along baseline projections.

These assumptions yield the following trends:

- The total additional loss in MSA in 2050 is more than 5 percent points compared to the baseline scenario. This amounts to an additional 60% of the baseline loss

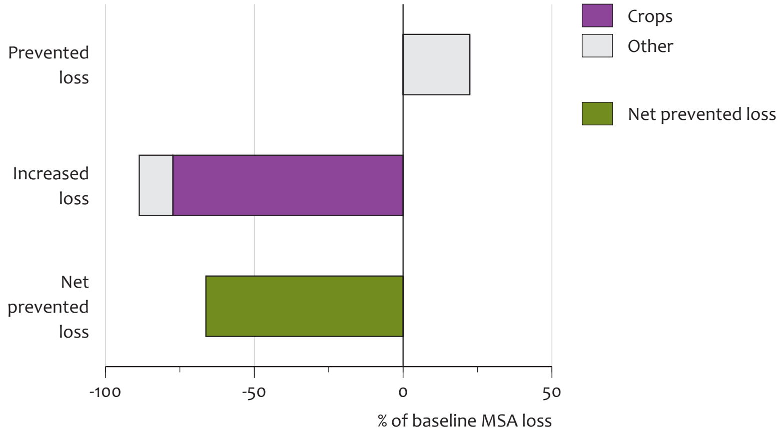
Box 3.1 A medley of baselines

This chapter describes the baseline used in the OECD Environmental Outlook. To analyse the impact of different options, a number of studies have been compiled, many of which used a different reference scenario than the OECD baseline. Variations in reference scenarios may be caused by different assumptions, model parameters or differences in drivers. For example, the policy package in Chapter 6 draws on a reference scenario implemented with an improved version of the IMAGE-GLOBIO model suite (a new forestry module), and assumes slightly different economic drivers (economic crisis).

The different reference scenarios span a considerable range of outcomes for biodiversity. Mean Species Abundance (MSA) in 2050 ranges from 60% to 65%. Biodiversity loss between 2000 and 2050 in terms of MSA ranges from 6.7 to 9.9 percent points in the different scenarios. Provided the impacts of biodiversity options are reported as a relative change to the baseline, the underlying baseline is assumed to be of lesser importance.

Figure 3.7 **Prevented global MSA loss compared to baseline scenario, 2000 – 2050**

Stagnation in agricultural productivity growth



With stagnation of agricultural productivity (compared to the baseline), additional MSA loss may occur by 2050 caused primarily by expanding agriculture.

between 2000 and 2050 (Figure 3.7). This large impact illustrates the sensitivity of baseline projections to assumptions on agricultural productivity;

- Natural areas shrink by an additional 9 million km² by 2050. This is mostly due to expansion of arable land into grazing areas, and conversion of grazing land to nature areas. Arable land would expand by more than 12 million km² compared to the baseline scenario for 2050 to about double the area in 2000 (Figure 3.8);
- The additional loss in wilderness area would be 6 million km² or some 40% higher than in the baseline scenario (see Figure 3.8).

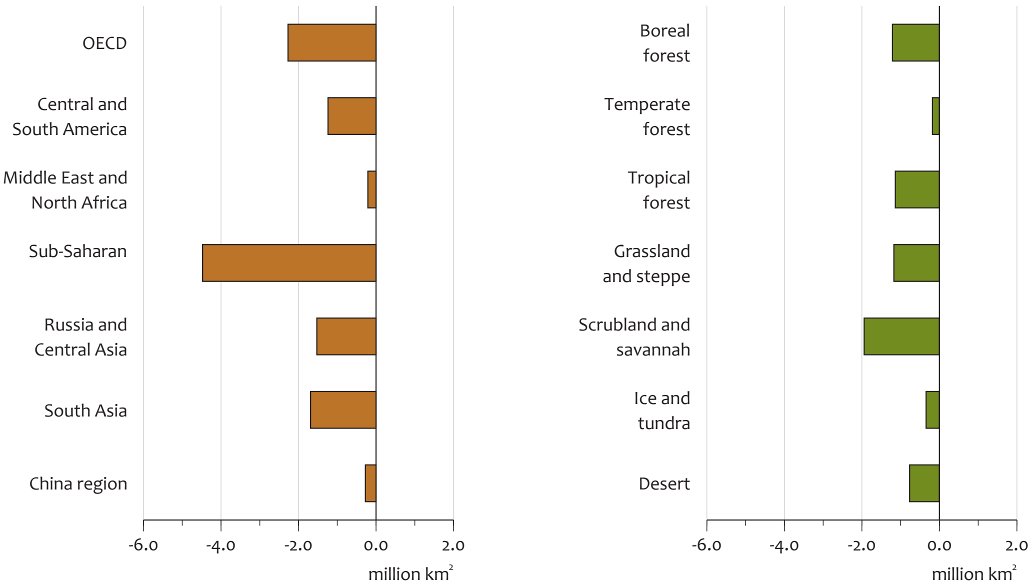
3.3.2 Liberalisation of agricultural trade

This variation assumes liberalisation of agricultural markets worldwide by the gradual removal of import tariffs and other market distortions up to 2015. Economic growth, food consumption and demographic developments follow baseline projections (based on Verburg et al., 2009).

Trade liberalisation works in multiple directions

The effects of agricultural trade liberalisation on biodiversity loss differ markedly between regions (Huang and Labys, 2001; Eickhout et al., 2006). Anticipated effects include better dissemination of environment-friendly agricultural technologies and improved efficiency by shifting production to the most productive regions (Antweiler et al., 2001). Natural areas with low costs of labour and land may see increase in agricultural production. This will incur biodiversity losses (Barbier, 2000; sCBD and PBL, 2007). Abandoned agricultural areas offer opportunities for nature restoration, but at the risk of losing specific elements of agro-biodiversity.

Change in natural area and wilderness compared to baseline scenario, 2050 **Figure 3.8**



Stagnation in agricultural productivity growth;
Natural area per region

Stagnation in agricultural productivity growth;
Wilderness per biome

With stagnation of agricultural productivity (compared to the baseline), further loss in natural area by 2050 is most prominent in OECD countries and Sub-Saharan Africa. For wilderness areas, several biomes are affected, mostly in tropical forests, savannah and grasslands.

Global results

The assumption of trade liberalisation of agricultural produce yields different trends:

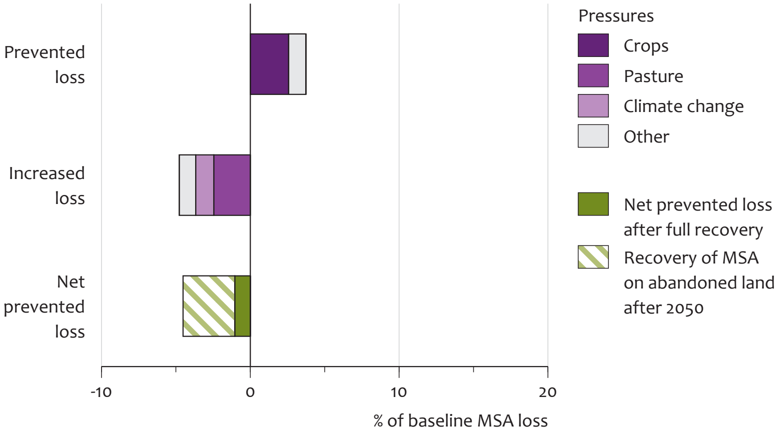
- The total additional loss in MSA is 0.3 percent points relative to the baseline scenario. This amounts to an additional 4.5% of the baseline loss between 2000 and 2050 (Figure 3.9). If abandoned land is left to fully recover to its natural state, biodiversity loss is only marginally larger than in the baseline (total potential after 2050);
- Natural areas will shrink by an additional 0.4 million km^2 by 2050;
- The additional loss in wilderness area would be around 1 million km^2, mostly tropical forest and grassland in Central and South America (Figure 3.10.). Land converted in the tropical forest biome consists of cerrado type vegetation, woodlands formerly cleared for timber and tropical rainforest (Verburg et al., 2009).

Small net global biodiversity effects mask large regional changes

The relatively small net global effect masks considerable regional impacts on biodiversity. Trade liberalisation results in expansion of grazing areas in Central

Figure 3.9 **Prevented global MSA loss compared to baseline scenario, 2000 – 2050**

Liberalisation of agricultural trade



With trade liberalisation of agricultural produce (compared with the baseline scenario), additional MSA loss may occur by 2050 caused primarily by shifting agriculture between world regions.

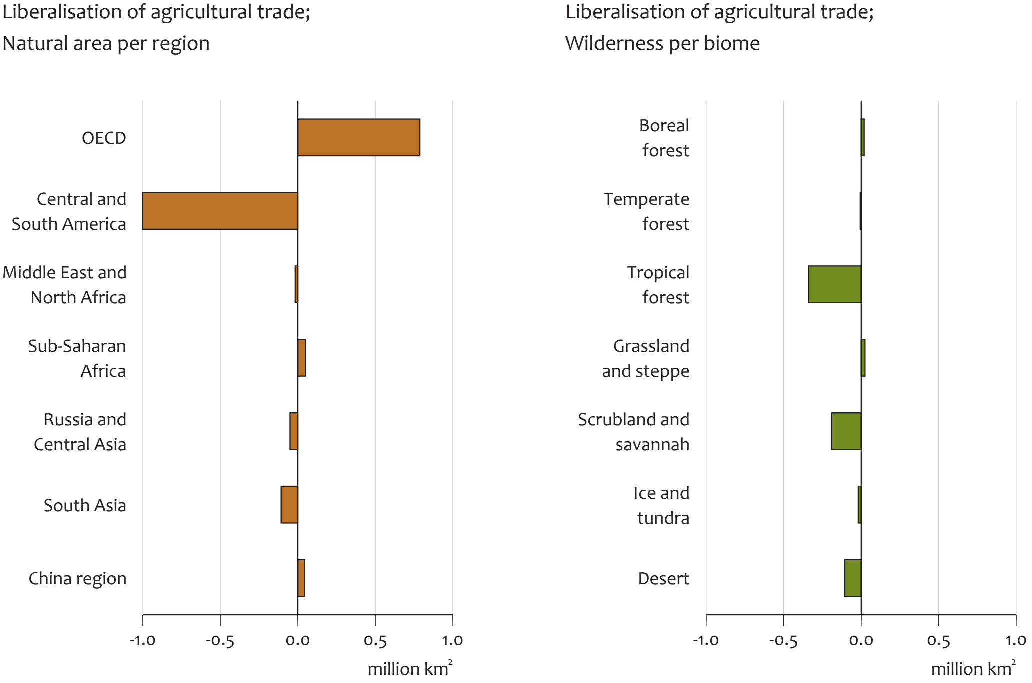
and South America at the cost of wilderness areas. Cropland will decrease in OECD countries, mainly in the European Union and North America. The principal reason is a shift in livestock production particularly beef cattle from the OECD region with heavy reliance on feed supplies to pasture-based production in Central and South America particularly Brazil with abundant land and lower labour costs. The imbalance between the net increase in pasture area (0.6 million km^2) and the decrease in cropland (0.3 million km^2) reflects differences in productivity between land-use in the two regions.

The effects of trade liberalisation are estimated to be less significant in other world regions. In China, for example, most of the suitable areas are already used for agriculture and in Sub-Saharan Africa, substantial agricultural expansion is also foreseen without trade liberalisation. Further acceleration is held back by constraints other than international trade opportunities (see Sections 3.2 and 6.1)1). In this option, trade liberalisation has no effect on economic growth and consumption levels, which could aggravate the environmental effects (as seen in the same option in: sCBD and PBL, 2007).

---

1) Most African nations have preferential access to the EU or other OECD markets, which would erode with global trade liberalisation. Opportunities for regional trade are considered to be economically more rewarding for Sub-Saharan Africa (FAO and World Bank, 2009).

Change in natural area and wilderness compared to baseline scenario, 2050 **Figure 3.10**



With trade liberalisation of agricultural produce, natural area will be lost by 2050 mainly in Central and South America, while natural areas will increase in OECD countries. This affects mostly tropical forests and grasslands.

4

Eight options for reducing global biodiversity loss

4.1 Introduction

Eight options for addressing the main drivers of global biodiversity loss

This chapter explores eight options for reducing biodiversity loss globally in the coming decades. The first two options highlight the need to prioritise and make choices in conservation efforts (expanding protected areas) and in maintaining ecosystem services of global importance (reducing deforestation for climate change mitigation). Six further options aim at the main drivers of biodiversity loss and are associated with a range of actors and economic sectors including agriculture, fisheries, forestry, energy and climate policy, and food consumption and production.

According to the Millennium Ecosystem Assessment and the Global Biodiversity Outlook-3 (sCBD, 2010) biodiversity loss is caused by several key factors or drivers. The most important are: 1) expansion of agricultural area and associated habitat loss; 2) overexploitation of natural habitats by, for example, grazing, fishing and logging; 3) pollution, for example eutrophication; 4) invasive species; and 5) climate change. Options for reducing these drivers can help in reducing future biodiversity loss.

Option selection

Options covering the main drivers except for invasive species were selected from existing and current scenario studies performed with the IMAGE and GLOBIO models. The selected options are presented in Table 4.1. For references to existing scenario studies, see the option descriptions.

There are more options for targeting the drivers of agricultural expansion, eutrophication, and overexploitation. Also, an important pressure not mitigated by these options is infrastructure development and fragmentation. The selected options, however, address the main drivers of biodiversity loss and are therefore promising in limiting future loss. These options have been mentioned in assessments as the priority avenues to reduce the rate and extent of global biodiversity loss, and most recently in the third Global Biodiversity Outlook (sCBD, 2010).

Eight options for reducing global biodiversity loss **Table 4.1**

Priority setting in conservation		
1	Expanding protected areas	Primarily aimed at conserving rare and valuable habitats, endemic species, hotspots, and a representative selection of ecoregions.
2	Reducing deforestation	Maintaining the role of forests in carbon uptake and storage, with an emphasis on synergy with climate change mitigation.
Reduced agricultural expansion & eutrophication		
3	Closing the yield gap	Increasing agricultural yields, thereby reducing projected agricultural expansion.
4	Reducing post-harvest losses	… in the food production and consumption chain, thus lowering agricultural production and reducing expansion of agricultural land.
5	Changing diets	… towards less meat-intensive consumption patterns, reducing expansion of agricultural area for feed and cattle grazing.
Reduce overexploitation of habitats		
6	Improving forest management	Emphasizing forestry plantations and reduced impact logging, increasing forestry productivity and reducing areas impacted by logging.
7	Reducing marine fishing	To bring future potential marine catches to a higher and sustainable level.
Limit climate change		
8	Mitigating climate change	With and without bio-energy (reducing the impact of climate change and investigating possible trade-offs with growing energy crops).

The potential of the options depends on the ambition level

The extent to which biodiversity loss can be reduced is estimated for a certain level of implementation. In that sense, the options do not represent a maximum technical or bio-physical potential, but rather include assumptions for achievable implementation levels. This is because for most options, a technical potential is impossible to define, or would result in misleading numbers. For instance, the maximum technical potential for expanding protected areas would be to protect all remaining natural areas. Such changes are inconceivable, at least within one generation. Furthermore, options have implications for consumers, economic sectors and trade balances that influence their feasibility in practice. This makes the maximum technical potential of options even less relevant for medium-term policy advice, where trade-offs with other sectors and regions are important considerations. Nevertheless, a few additional variants are presented for some options for exploring the hypothetical extent of trade-offs, and can be regarded as sensitivity runs.

Demographic change and economic activity (translating into higher consumption levels per capita) are indirect drivers which influence most of the drivers mentioned. Measures to limit population growth or economic activity are not explored here. Growth in population and income are considered to be exogenous. These processes are highly autonomous (population growth is highly determined by current demography, for instance) and difficult to change over a period of a few decades.

Option origin and interaction between options

The options reported in this chapter are based on existing and on-going studies. They were modelled by applying a single change (representing the option) to a baseline scenario and projecting the corresponding effects and implications up to 2050 (or for some studies up to 2030) for comparison with the baseline outcome. However, and as highlighted above, most options have implications that reverberate through sectors, trade and consumption. Thus when options are combined and implemented in the same time-period, there may be interactions, rebound effects, trade-offs and synergies. An initial exploration of interactions between options is presented in Chapter 5.

Feasibility of options

The options simulate changes in drivers of biodiversity loss but do not represent policy instruments. For an option to become effective, it needs to be implemented in policy by means of regulatory, financial or other policy instruments. This requires setting public priorities, acceptance by electorates, and aligning potentially very diverse interests. The feasibility and potential barriers to implementation can differ greatly between options. Relevant aspects are briefly discussed for each option.

4.2 Expanding protected areas

- Expanding the network of protected areas worldwide increases conservation of a more representative selection of the earth's ecoregions, biodiversity hotspots, valuable habitats, wilderness area and endemic species.
- Expanding protected areas to 20% of all ecoregions has modest side-effects on competing land use for agricultural production. To accommodate limited agricultural expansion, complementary sectoral options have to be implemented to increase productivity.
- Expansion of protected areas to 50% has a higher global impact on biodiversity indicators but also limits agricultural expansion substantially and could even result in food and fibre deficits.
- A trade-off for expanding protected areas is a shift in land use to other non-protected areas to meet growing demand for food and fibre.

Introduction

Establishing protected areas is the most direct way to conserve habitats that are important for highly valued ecosystems and their biodiversity. To facilitate reducing biodiversity loss, a sub-target of 10% effective protection for each ecoregion was formulated (CBD 2004; Decision VII/30). To date, about 19 million km^2 of terrestrial area has protected status (this is 14% of global terrestrial area excluding iced and rocky areas; Coad et al., 2009).

The 10% conservation target has been reached on a global scale for most of the major 14 biomes. But looking in more detail, almost half (45%) of all 800 terrestrial ecoregions defined by (Olson et al., 2001) still fall short of the 10% target (Coad et al., 2009). New targets are to be discussed under the Convention on Biological Diversity.

Expanding protected areas is important for threatened species.

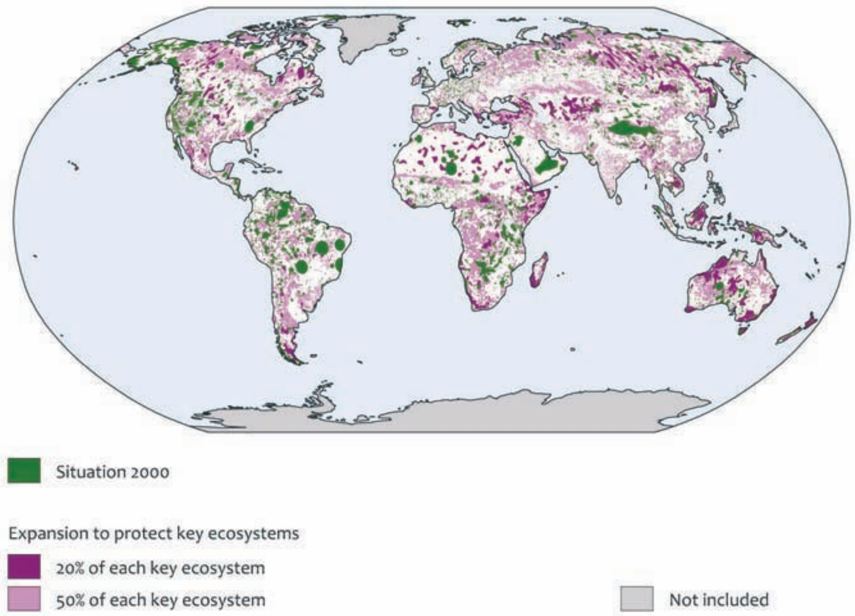
Expanding the global protected area network is an important measure to enhance species conservation, and priorities on what to protect need to be set strategically (Olson et al., 2001; Brooks et al., 2006). Species that require larger areas of intact ecosystems will benefit from increasing the size and connectivity of protected areas. It can also facilitate adaptation of flora and fauna to climate change and safeguard the provision of specific ecosystem services.

Option description

A basic option and a variant were analysed for expanding the network of terrestrial protected areas by constructing maps of protected areas (Figure 4.1):

1. Basic: 20% Protected areas
   Increasing the protected area to 20% of each of 65 terrestrial ecoregions (according to biomes and ecological realms; (Olson et al., 2001). This option was originally developed for the second Global Biodiversity Outlook (sCBD and PBL, 2007). A map of protected areas in 2000 served as a starting point (IUCN and UNEP, 2006). Additional protected areas were selected to cover a representative selection of the earth's ecosystems and areas with concentrations of threatened and endemic species. For this, a combination of hotspot maps proposed for priority setting was used (cf. Brooks et al., 2006). Areas present in several of these priority maps were used to expand the protected area cover. The following hotspot maps were used: WWF Global 200 terrestrial and freshwater priority ecoregions (Olson and Dinerstein, 2002); amphibian diversity areas (Duellman, 1999); endemic bird areas (Stattersfield et al., 1998); and Conservation International hotspots (Myers et al., 2000).
2. Variant: 50% Protected areas
   Increasing the protected area to 50% originates from a pilot study on a Green Development mechanism including biodiversity compensation (Bakkenes and

Figure 4.1 **Protected areas for preserving biodiversity**



Current protected areas (baseline), and protected areas (options) for expansion of the current protected areas to at least 20% and 50% of each key ecosystem.

ten Brink, 2009). This variant has been included as a stylised illustration to better understand the effects on food and wood production.

These options have been implemented in the IMAGE-GLOBIO model framework to analyse their effects in a context of expanding land use in the period between 2000 and 2030. No protected areas have been included for freshwater and marine areas.

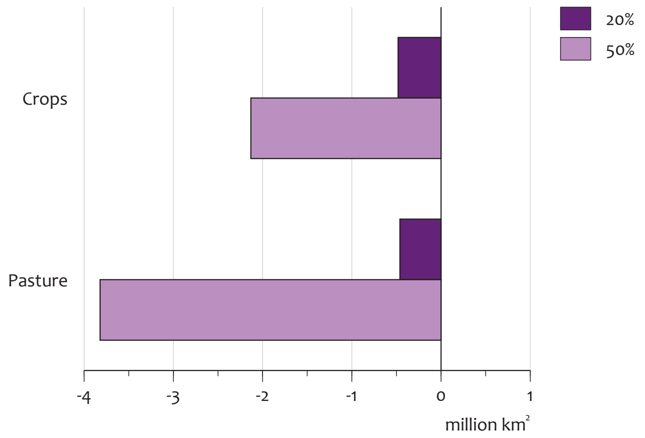
Results

Implementing the 20% protected area option leads to reduction in agricultural land use for crops and pasture (almost 1 million km^2 or 2% reduction in total agricultural area; see Figure 4.2). Thus, agricultural expansion in the baseline scenario up to 2030 would be restricted (10% less expansion).

The 20% option further shows a small increase in mean species abundance (about 0.5 percent point of MSA, which is about 9% prevented MSA loss) compared to the baseline scenario for 2030 (Figure 4.3). At first glance, this gain seems too small, but closer inspection reveals that the area needed for food production would shift to widely available non-protected areas elsewhere. Thus in terms of MSA, direct local gains for biodiversity from effective protection are counterbalanced by losses in neighbouring non-protected areas. However, the increase in wilderness area is significant (increase of 2.4 million km^2; Figure 4.4). Further, the 20% protected area network shows a better coverage of the 65 ecoregions (Figure 4.5), compared

Change in global land use compared to baseline scenario, 2030 **Figure 4.2**

Expanding protected areas



Land use for crops and pasture by 2030 is about 1 million km² smaller in area under the option with expanding protected areas to 20% and about 6 million km² less in the option with expanding protected areas to 50%.

to the baseline network. Thus, the representativeness of the earth's ecosystem diversity is better served with this expanded network.

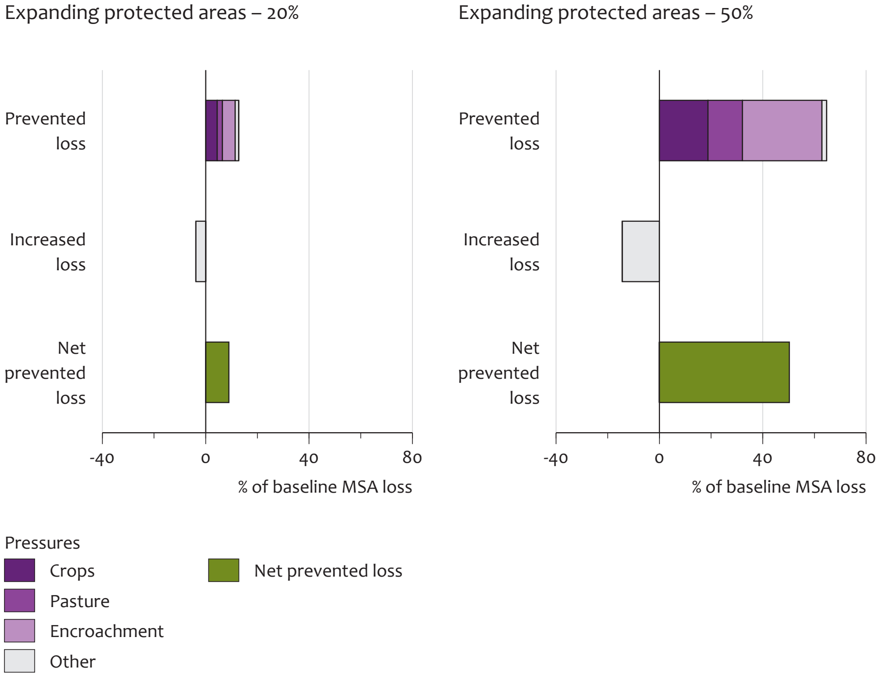
Implementing the 50% protected area option would yield significant biodiversity benefits of a 2.8 percent points increase in MSA (about 50% prevented MSA loss; Figure 4.3) and an additional 13.8 million km² of wilderness area (Figure 4.4). But agricultural land use would be almost 6 million km² less (12% reduction compared to the baseline scenario in 2030), which may lead to unwanted food and fibre deficits . In the 50% option, decreases in total wilderness area in tropical forests are due to shifts in agriculture from other tropical biomes to forested areas.

Effects of increasing protected areas on carbon emissions and climate change are discussed in Chapter 6.

Discussion

Setting up a well-chosen network of protected areas with relatively large and intact ecosystems may well protect the most threatened species from extinction. In both options analysed, protected areas are assumed to be effective. These areas are free from agricultural land use, infrastructure development and 'hunting and gathering'. Thus, the protected areas are assumed to stop land conversion, limit human settlement in areas still intact, and enable recovery of partly degraded protected areas. Nevertheless, it was assumed that protected forests can be used for wood production when there is a shortage in regional wood supply from forest areas.

Figure 4.3 **Prevented global MSA loss compared to baseline scenario, 2000 – 2030**



The prevented global MSA loss by 2030 is modest when protected areas are expanded to 20%, and about 50% when protected areas are expanded to 50%. Baseline MSA loss between 2000 and 2030 is represented by 100% on the horizontal axis.

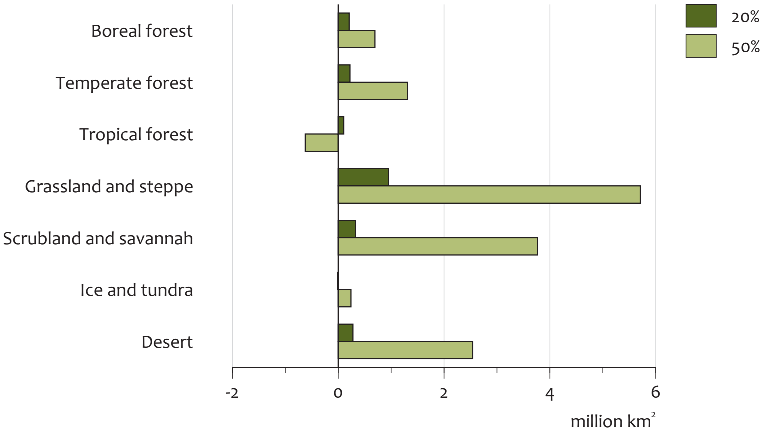
The effect of this option is not easily captured in a suitable indicator from the model framework applied here. In terms of MSA, the net gain of the expansion of protected areas to 20% is relatively small. This is partly due to the fact that MSA does not measure species uniqueness but rather the naturalness of an area. Gains from an increased protected area network are partly countered because agricultural activities move to adjacent areas. Furthermore, because pressures such as nitrogen deposition, fragmentation, existing roads and climate change continue to affect protected areas.

A Red List index or indicator sensitive to species uniqueness and extinction would probably show stronger positive effects (Ferrier et al., 2004). Such an indicator is under development for use in the model. For now, indicators are used such as the degree to which the ecoregions distinguished are protected by the proposed expansion of protected areas, and the wilderness area.

In this study, ‘effective’ protected areas are assumed. In reality, many protected areas suffer from shortcomings with no guarantee that their biological, cultural and aesthetic values will be protected in the future. Some of the key issues are ‘paper parks’ (existing only on paper), bad design or location, impacts of poaching and

Change in wilderness compared to baseline scenario, 2030 **Figure 4.4**

Expansion of protected areas



The area of wilderness is increased especially in grassland and steppe biomes as a result of expanding protected area networks.

more subtle effects of air pollution or climate change, isolation and fragmentation if surrounding land use changes or intensifies. Improvements in these issues will require firm political commitment and adequate financial support, together with effective participation of all categories of stakeholders (Mulongoy and Chape, 2004).

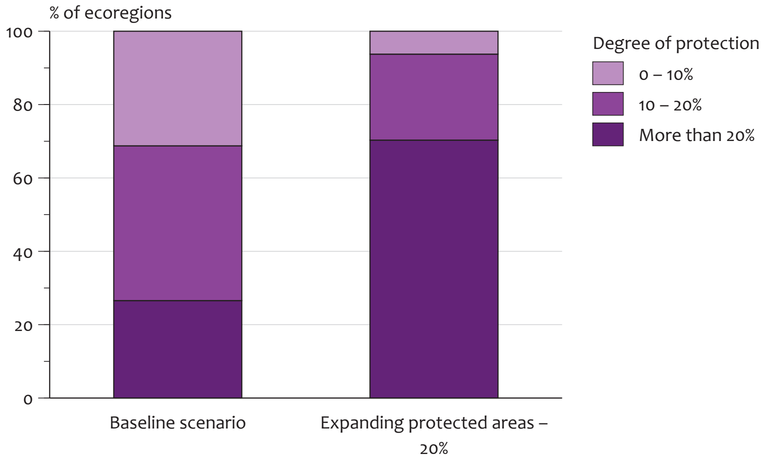
Feasibility

Setting priorities for conservation

Using MSA as indicator, several global assessments show that all current available biodiversity cannot be preserved while simultaneously meeting the needs of a growing global human population (Kok et al., 2008; UNEP, 2008). Therefore, protecting biodiversity-rich areas deserves high priority, because this prevents additional irreparable loss and provides a bottom line to the loss of the world's species and ecosystem diversity.

However, priority setting is a subjective and thus a controversial topic. The challenge in expanding protected areas is to make an informed choice on what to preserve, where, and to what extent. This should, for instance, be done by gap analysis (Margules and Pressey, 2000; Brooks et al., 2006). For the options mentioned above, a map has been drawn based on different proposed priority indicators (hotspot maps) but there is no formal agreement about combination of priorities. Such an agreement would greatly help in the allocation of new protected areas in the short term.

Figure 4.5 **Degree of protection of ecoregions, 2030**



The representativeness of the protected area network is improved when the network is expanded to 20% of each of the distinguished ecoregions (65 in total).

Relationship to agricultural expansion

This analysis has shown that expanding the protected area network will interfere with expanding land use for crop and livestock production. Competition for land may hamper the establishment of new protected areas and threaten the protection status of existing areas. Therefore, options that reduce pressure from agricultural expansion (reduced meat consumption or increased agricultural yields) would facilitate expansion of protected areas, especially in areas where this competition is most prevalent.

Box 4.1: Funding for protected areas globally

Globally, about 14% of terrestrial areas are within the boundaries of a protected area (Coad et al., 2009; excluding Antarctica and Greenland). However, these areas are not equally distributed over biomes and ecoregions. There are also large differences in the adequacy of funding required for effective protection. Without effective management, protected areas are vulnerable to influences that are not in line with an area's purpose. Costs associated with management of protected areas can depend on management objectives, accessibility and size of the area (Bruner et al., 2004). The annual global investment in conservation was estimated to be USD 6 billion (using 1996 USD; James et al., 2001). Funding gaps for management of the existing protected areas in developing countries are estimated to range from USD 1 to 1.7 billion annually (Bruner et al., 2004). Funding gaps in developed countries are assumed to be smaller (James et al., 2001).

Conservation priorities differ among regions and scales

While the CBD target of protecting 10% of each ecoregion provides some guidance in allocation, actual implementation is more difficult. Ecoregions can be spread over multiple countries, or one country can have multiple ecoregions within its borders. Furthermore, preservation priorities may differ on local, national and global scale, depending on benefits derived and values attached to different areas or species.

Uneven distribution of costs and benefits of conservation

There are several arguments for cost sharing of protected area management and expansion between countries:

- Biodiversity is unevenly distributed worldwide. Some regions have a higher species-richness, or have more natural areas remaining, and of a larger variety.
- The benefits from ecosystem services and biodiversity conservation are enjoyed on widely differing spatial scales - local, national and global.
- Developing countries provide the highest potential for expansion of biodiversity conservation. They also have the least means to do so. In addition, economic growth and development require expansion (e.g., agriculture), which could conflict with protected area expansion.
- Through consumption and trade, much pressure on biodiversity in developing countries is driven by demand from richer societies. However, internalisation of environmental costs by developing countries would harm competitiveness in the short term and therewith development prospects.

To provide long-lasting incentives for protection, especially in developing countries, mechanisms to facilitate and upscale international financing of protected areas are needed, most likely involving significant financial transfers from developed countries (James et al., 2001; Balmford and Whitten, 2003; Bakkenes and ten Brink, 2009). International burden sharing plays a similar role for financing climate change mitigation (Hof et al., 2009). For biodiversity, the existing mechanism of the GEF might be used, but as it functions through voluntary government replenishments it is not a systematic and reliable long-term financing mechanism.

4.3 Reducing deforestation

- Preventing conversion of all forested areas would contribute significantly (15-20%) to reducing greenhouse gas (GHG) emission levels so that the scenario of a maximum 2 °C temperature increase becomes more likely. This results from reduced conversion of carbon intensive ecosystems and a larger extent of natural area remaining that increases uptake capacity of carbon from the atmosphere.
- Part of the projected agricultural expansion would shift from forests to grassland biomes with biodiversity benefits in forest areas but higher biodiversity losses in grasslands and steppes. Thus this option involves trade-offs between different ecosystems, and between carbon and biodiversity protection.

Introduction

Forests store about half of the terrestrial carbon. If only above-ground pools are considered, forests store 80 to 90% of all terrestrial carbon (van Minnen, 2008).

Protecting forest areas contributes to climate and biodiversity goals.

Thus, deforestation for agricultural expansion, mining, or other reasons as well as forest degradation are important sources of CO_2. Historically, these sources have been responsible for about 600 Gt CO_2 emissions in the period 1850 to 2005, which is comparable to half of the historical fossil-fuel related CO_2 emissions (Houghton, 2008). Currently, forest changes contribute about 20% of annual anthropogenic CO_2 emissions (Achard, 2002). Thus, reducing emissions from deforestation and degradation (REDD) and planting new forests (afforestation) can substantially contribute to limiting the build-up of atmospheric CO_2.

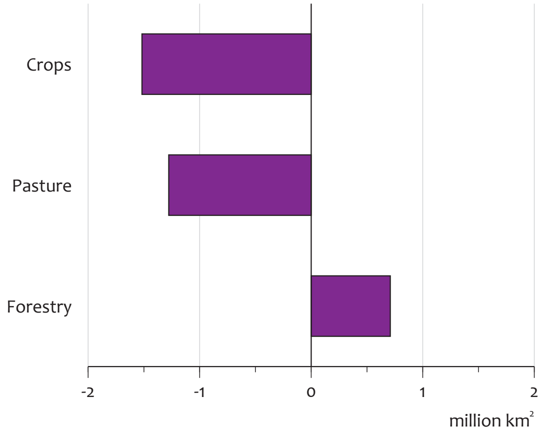
To support this global ecosystem service, UNFCCC has endeavoured to design a scheme that rewards countries for reducing their rates of deforestation and forest degradation. By conserving forests and preventing forest degradation, REDD initiatives may also contribute to conservation of biodiversity. Explicitly looking for these synergies in designing REDD policies is addressed as REDD plus (Laurance, 2008; sCBD, 2009).

Option: Prevent forest conversion worldwide

The option illustrates the effects and implications of prioritising conservation of intact forest carbon areas. Implementation of a REDD scheme is not explicitly assumed because of the uncertainty surrounding the negotiations for such a scheme and possible ways in which it could take shape. The option assumes protection of all forested areas globally from conversion from 2010 onwards (Stehfest et al., forthcoming). Here, forests are defined as areas with closed tree cover and thus do not include savannah, scrubland, and wooded tundra.

Change in global land use compared to baseline scenario, 2030 **Figure 4.6**

Reducing deforestation



Reducing deforestation will result in less agricultural expansion by 2030.

No distinction was made between the carbon content of different patches of forest. The effect on global land use, cumulative carbon emissions and biodiversity have been analysed for the period from 2000 to 2030.

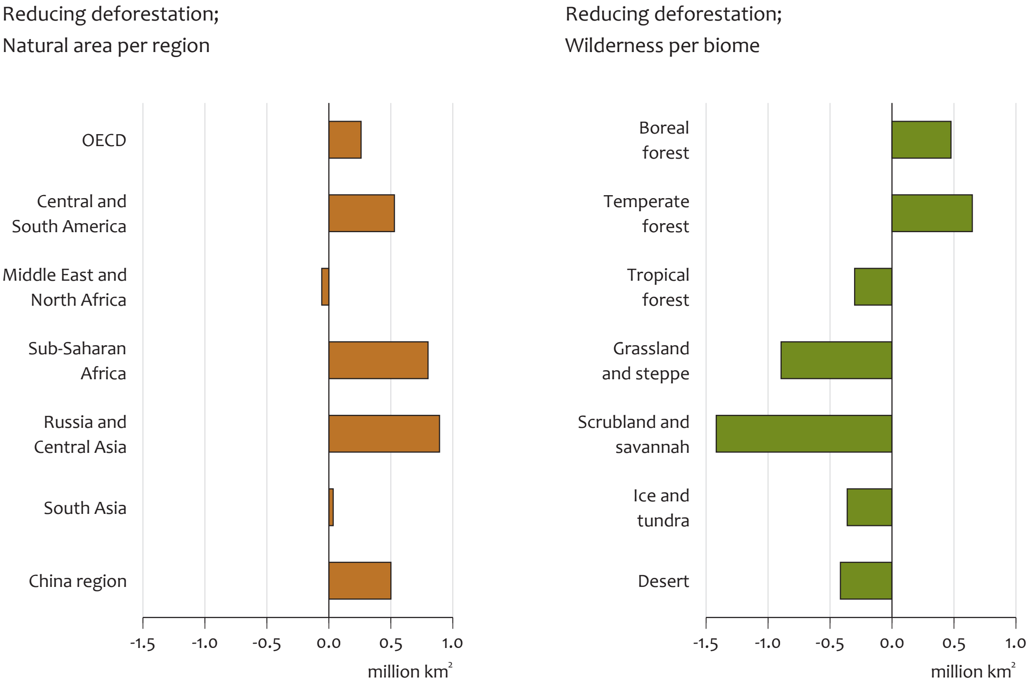
Results

Preventing forest conversion leads to less removal of carbon dense vegetation and more natural areas remaining than projected in the baseline for 2030. This results in less GHG emissions from land conversion, and a larger remaining natural area implies a higher capacity for total uptake of CO_2 from the atmosphere. This option would reduce GHG emissions by 130 Gt CO_2, in the period from 2000 to 2030 or by some 15-20% of the emission reduction required by 2030 for a 2 °C climate policy scenario. The climate benefits of the biodiversity options are addressed in Chapter 6.

As the option prevents conversion of densely forested areas, it results in a smaller increase in land use for crops and pasture than projected in the baseline (around 1.5 million km² or one third less than the projected baseline increase in 2030; Figure 4.6). This is caused by increased land scarcity due to forest protection, which results in higher land prices, translating into higher commodity prices, higher yield increase and reduced consumption. As less timber is coming from logging for agriculture, more dedicated forestry is needed, resulting in a larger forestry area (Figure 4.6; see also Box 5.1 in Chapter 5). The reduced agricultural expansion translates into larger extents of natural area in every region but one (Middle East and North Africa), in 2030 (Figure 4.7). Two thirds of the agricultural expansion projected in the baseline remains but changes location from forest to grassland biomes.

As a result, wilderness area remains higher in forest ecosystems than projected in the baseline (Figure 4.7). The apparent additional loss of wilderness in the tropical

Figure 4.7 **Change in natural area and wilderness compared to baseline scenario, 2030**



Reducing deforestation will lead to more natural area in most regions, but at a cost of grasslands and savannah because agricultural expansion will shift to these biomes).

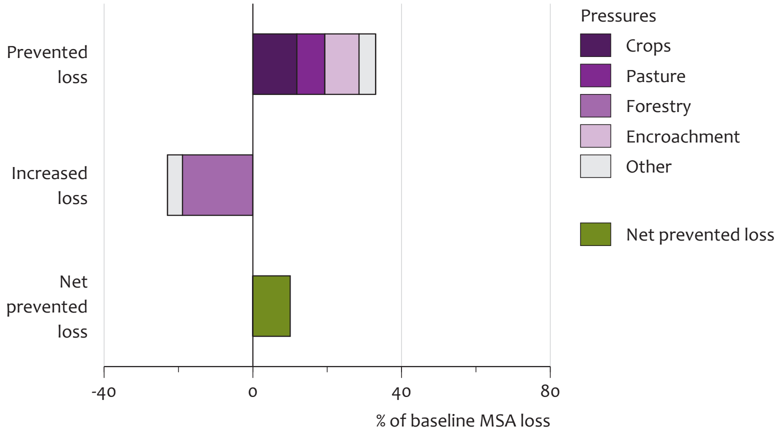
forests is caused by the use of a broader definition of the forest category to include tropical woodland. These woodland areas are not protected in the option because of the lower tree density. While more forest systems remain, the wilderness area in savannah and grassland is reduced as agricultural expansion shifts towards these systems. In addition, the area for forestry increases and puts additional pressure on forest systems.

Overall, forest protection in this option would result in preventing 10% of the global MSA loss projected in 2030. Most of this result comes from reduced pressure from agricultural expansion and corresponding encroachment (Figure 4.8). As discussed above, the MSA loss due to forestry also increases. Even though the option contributes significantly to reducing GHG emissions, this does little to reduce climate effects on biodiversity before 2030. Effects will become clearer in the longer term.

These results show that there is synergy between maintaining forest carbon and biodiversity. However, there may well be a trade-off as agricultural expansion shifts towards grasslands biomes.

Prevented global MSA loss compared to baseline scenario, 2000 – 2030 **Figure 4.8**

Reducing deforestation



The net prevented MSA loss from reducing deforestation is about 10%. The area for forestry increases because there is no more wood production from forest conversion.

Discussion

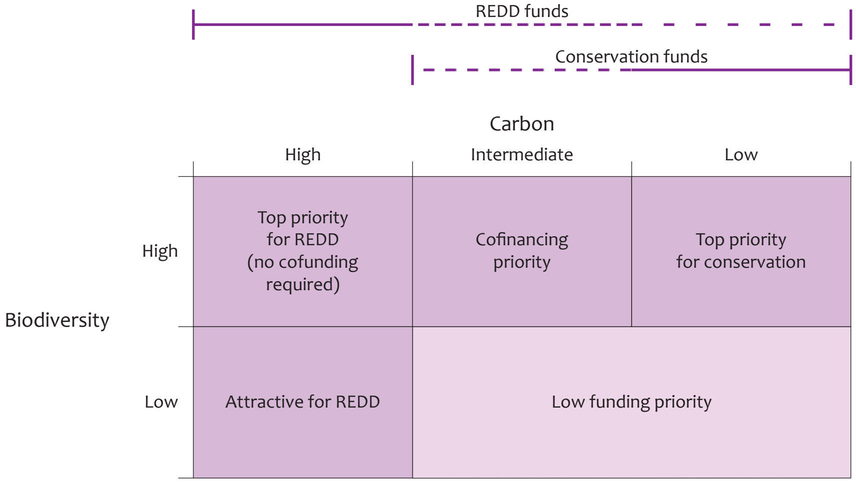
The option does not distinguish between the carbon content of different forest patches. A more refined approach would include maps of the global distribution of carbon storage in ecosystems, including underground stores. Further analysis of the effects of ambitious forest protection on land use and agricultural expansion into less productive lands is also warranted. The reduced expansion of agricultural land translates into either higher productivity or higher prices and lower total food production than in the baseline. A shift of impact from forest biomes (reduced) to grasslands (increased) is expected and could be analysed for different ambition levels.

Box 4.2 Cost estimates vary for a REDD scheme

A comparison using three models of global land use produces estimates that vary between USD 0.4 and 1.7 billion annually to reduce deforestation by 10%, and between USD 17 and 28 billion annually for a 50% reduction in deforestation - a highly non-linear relationship(Kindermann et al., 2008). An optimal allocation of funds based on agricultural opportunity costs of land could result in a highly skewed distribution with as much as 70 to 90% going to Latin American countries with 40 and 20% respectively reduction in deforestation (Venter et al., 2009). Another study though suggests Africa as the most attractive for REDD in terms of agricultural opportunity costs (Kindermann et al., 2008).

Figure 4.9 **Prioritising REDD and conservation funds**

Allocating conservation funds in combination with a working REDD scheme



		Carbon		
		High	Intermediate	Low
Biodiversity	High	Top priority for REDD (no cofunding required)	Cofinancing priority	Top priority for conservation
	Low	Attractive for REDD	Low funding priority	

REDD = Reduced Emissions from Deforestation and Forest Degradation

Combining funds for conservation and reducing deforestation requires making choices and strategies to obtain an optimum effect (adapted from Miles and Kapos, 2008).

Feasibility

The UNFCCC attempt to design a REDD scheme is a clear example of a choice on what to protect; in this case a specific biome (forests) for a specific ecosystem service. Because of the global public good characteristics of the ecosystem service, the REDD scheme is being organised in an international setting. The differences in geography and remaining forest areas create the need for a mechanism that shares the burden of costs (Box 4.2). Reduction in deforestation rates also yields local benefits, such as reduction in forest fire, air pollution and soil erosion (Nepstad et al., 2009).

Trade-offs with other ecosystems and ecosystem services

A REDD scheme aimed at forest carbon in the absence of rewards for other ecosystem services would create two trade-offs: i) forest areas harbouring less carbon receive less protection; and ii) less funds available for non-forest natural areas. As carbon content and biodiversity are not linearly correlated, optimisation of funds is possible. Based on species-area relationships, benefits of REDD to biodiversity may be doubled by accepting a 4 to 8% reduction in carbon benefits (Venter et al., 2009). To calibrate REDD in this way requires mapping areas for their ecosystem services and biodiversity, and prioritising from an international and national perspective (Karousakis, 2009). The trade-offs between forests and other biomes may also be mitigated provided REDD funds are additional to conservation spending. In that case, REDD finance could replace conservation funds in high-carbon forest areas. These funds could either be bundled with REDD finance in lower carbon (but high biodiversity) areas or in non-forest ecosystems that could come under additional pressure (Figure 4.9).

4.4 Closing the yield gap

- An increase in agricultural productivity is required if biodiversity preservation, food security and rural livelihoods are to be improved simultaneously.
- Improving yields 40% faster than the trend would reduce agricultural land use by more than 6 million km^2 by 2050, allowing cattle grazing areas to revert to natural habitats. In terms of MSA, this option would prevent over 20% of baseline loss by 2050.
- The largest reductions in projected biodiversity losses can be achieved in temperate and tropical grassland biomes in Sub-Saharan Africa, Central and South America and the OECD region.

Agricultural productivity need to be improved to limit expansion into natural areas

In the coming decades, substantial increases in agricultural productivity are needed to meet rising demands for food at affordable prices, while limiting expansion of agriculture into natural areas (Clay, 2004; Koning et al., 2008; van Vuuren and Faber, 2009; Godfray et al., 2010). Increased agricultural production is required to satisfy demand of larger populations, higher consumption levels, and diets that contain more meat. For instance, production of 1 kg meat requires roughly 2 and 10 kg feed for poultry and beef, respectively (Steinfeld et al., 2006).

Large gaps between actual and potential agricultural yields

In many regions of the world, there is a wide gap between crop yields and potential yields (IAASTD, 2009; Neumann et al., 2010). Yield gaps are particularly wide in Sub-Saharan Africa (IAC, 2004; FAO and World Bank, 2009; IAASTD, 2009). But there is also much scope for improvement in North America and Eastern Europe (Figure 4.10).

Between 1970 and 2005, agricultural yields increased on average by about 1% per year, but have since levelled off gradually, especially for cereals (Bruinsma, 2003; Dixon et al., 2009). Differences between estimated potential and actual yields suggest considerable room for improvement. Reasons for large yield gaps include low agricultural inputs, lack of location-specific technologies, and inappropriate agronomic practices. These issues are often caused by social, economic, infrastructural and institutional constraints (see Box 4.3). These extremely challenging constraints should be alleviated along with investments in the development and implementation of agricultural knowledge, science and technology (AKST) adapted to region-specific bio-physical and socio-economic conditions.

Option: Effects of improved agricultural productivity on global biodiversity

An option was explored to estimate the effects of changes in agricultural productivity. In this *improved productivity* variant taken from (Rosegrant et al., 2009), improved agricultural practices are assumed to result in 40% additional growth in crop productivity by 2050 (Figure 4.10) and 20% additional growth in livestock productivity compared to the baseline scenario. These practices could include improved planning and timing of operations, site-specific soil management,

more efficient water use, improved pest and disease control, and better suited crop varieties and livestock breeds. Such practices are not specifically identified, included or analysed in the model. Water use and the area of irrigated agriculture are assumed to be equal to the baseline.
Implementing these improvements will bring the agricultural productivity of different world regions closer together. Still, by 2050 wide yield gaps, such as in Sub-Saharan Africa, will not be completely closed.

Results

The option with improved productivity shows:

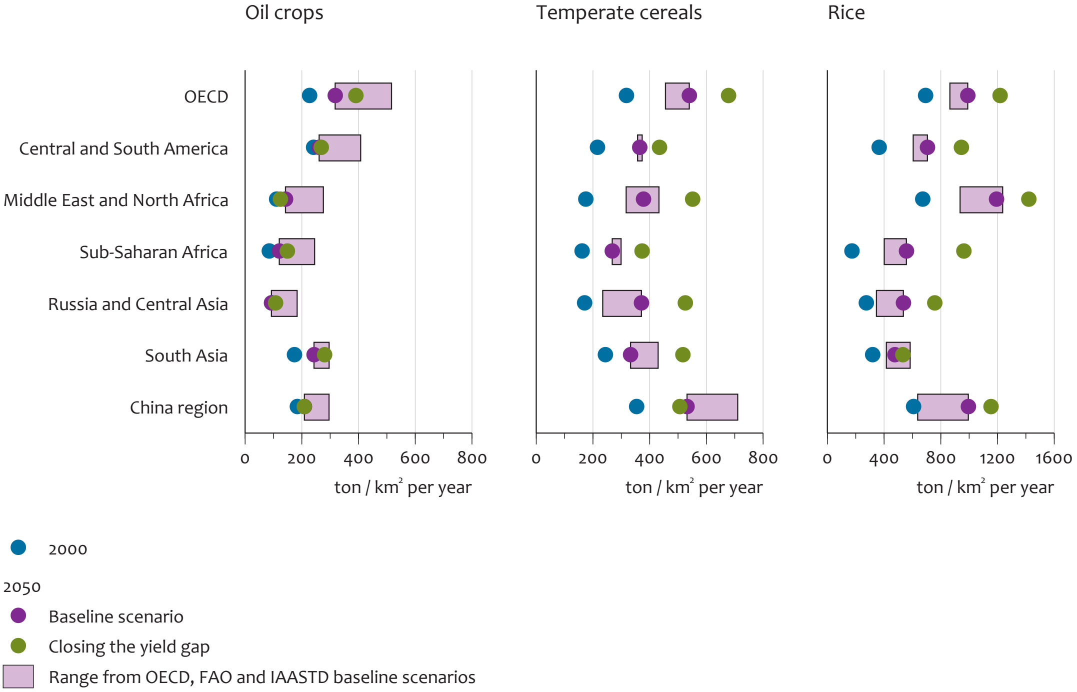
- Global biodiversity in MSA is 2 percent points higher in 2050 with a gain of almost 6 million km² in natural area compared to the baseline scenario. This means that about 20% of the baseline MSA loss is prevented by 2050 (Figure 4.12), mostly due to reduced agricultural expansion and contraction in some regions. Recovery of abandoned agricultural areas to their natural state could add an additional 0.5 percent point MSA after 2050. The gain in wilderness area in 2050 is over 2 million km² compared to the baseline (Figure 4.13).

Box 4.3 Key issues that complicate sustainable agricultural intensification

- *Access to land/land ownership. Particularly damaging are short-term land tenure contracts and occupation-based rights to land. The latter form an incentive to clear more land (e.g., by burning) than can be managed;*
- *Artificially low prices of food (e.g., due to dumping on the world market in times of plenty; and export bans or freezing prices in times of scarcity);*
- *High costs of production, low returns and poor access to markets due to poor logistics and unreliable rural infrastructure (such as roads, water, electricity, public transport, information, financial services);*
- *Unfavourable rural credit conditions (poor access, lack of collaterals, prohibitive interest rates debt traps);*
- *Capacity and adequateness of storage and marketing facilities;*
- *Bias of mainstream marketing chains against small-scale farm products;*
- *Absence of information networks for agronomic and marketing info (e.g., early warning systems using internet and cell phones);*
- *Absence of well-functioning structures (e.g., farmers unions or co-operatives) that would enhance economic and political clout of small-scale farmers;*
- *Security (theft of seeds, fertilisers, livestock, irrigation equipment, electricity wires, solar panels etcetera are often mentioned as major problems);*
- *Access to and relevance of training programmes and agricultural advisory services;*
- *Lack of R&D effectively oriented to needs and engaged with farmers and other rural stakeholders in order to promote the development and dissemination of locally adapted technologies.*

(Based on: FAO and World Bank, 2009; Gurib-Fakim and Smith, 2009; IAC, 2004; Izac et al., 2009; Pretty et al., 2003; Koning et al., 2008; van der Ploeg, 2010; Bruinsma, 2003; IAASTD, 2009; Lobell et al., 2009).

Regional yields **Figure 4.10**

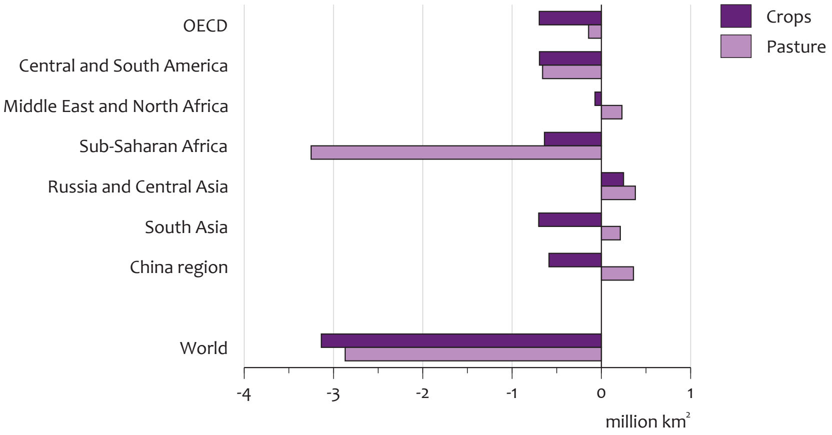


Potential for yield improvement differs between regions and crop types. Estimates of what is technically possible and socio-economically plausible vary between modelling groups. Data: OECD and MNP (2008); Rosegrant et al., 2009; Bruinsma (2003); Stehfest et al. (2009).

Improved agricultural techniques result in higher productivity.

Figure 4.11 **Change in land use compared to baseline scenario, 2000 – 2050**

Closing the yield gap



Increase in agricultural productivity would reduce the area needed for crops and pasture by almost 6 million km² in 2050. Reduction in land use for pasture would be substantial in Sub-Saharan Africa.

- The largest reductions in agricultural land use can be achieved in Sub-Saharan Africa where yield gaps are currently the widest and large areas of land suited for cropping are still available , followed by Central and South America and the OECD region. Sub-Saharan Africa would even show a decrease in pastureland, while the expansion of arable land would be affected very little (Figure 4.11).
- About half of the productivity gains would be translated into reduced agricultural expansion, as a consequence of rebound effects from changes in prices. The remainder would translate into higher consumption. Consumption of livestock products increases as a consequence of lower prices, particularly in low-income regions.
- The projected additional agricultural expansion in the former Soviet Union results from better production conditions and more than proportional increases in local production.

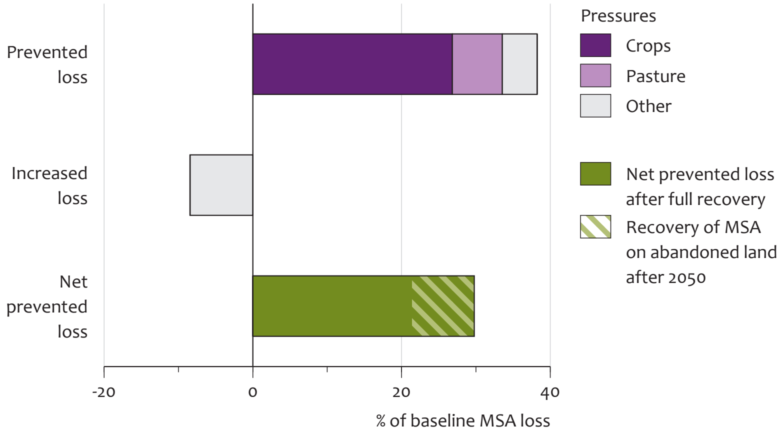
Effects of this option are small for North Africa and West Asia because their main biome is desert with little prospects for agriculture. Non-desert areas in these regions are intensively used for agriculture and this situation will continue irrespective of technological improvements. The story is similar for the China region with a large population and limited land resources.

Improved productivity also improves aquatic biodiversity

Compared to the baseline, increase in agricultural productivity would result in reduced net eutrophication and lower effects from nutrient loading in freshwater systems that receive water from agricultural areas. This on average positive effect is the result of two opposite processes. One is higher use of fertiliser or manure

Prevented global MSA loss compared to baseline scenario, 2000 – 2050 **Figure 4.12**

Closing the yield gap



Improved agricultural yields can prevent about 30% of MSA loss by 2050, but part of this is only achieved after recovery of abandoned agricultural lands. .

that leads to higher local nutrient loads, but in a relatively smaller agricultural area. Further, crop nutrient-use efficiency would be higher, due to investments and improved knowledge. This will lead to relatively lower losses of applied nutrients to the environment. The balance of all effects of intensification is favourable when averaged on higher spatial scales, according to global model outcomes.

The reverse is the case with stagnating agricultural productivity. More extensive agriculture leads to lower local nutrient loads from fertiliser, but to higher total loads from nutrient leaching from a larger area brought into cultivation. Hence agricultural expansion would increase eutrophication effects in freshwater systems compared to the baseline. Thus, aquatic biodiversity will benefit most in those regions where agricultural expansion is the less compared to the baseline scenario, such as Sub-Saharan Africa and South and Central America. The result could be different if agricultural intensification requires more irrigation, which is not included in the present analysis. Lower nutrient loading to rivers is also relevant for coastal marine areas and their biodiversity, but has not been explored further in this study.

Feasibility

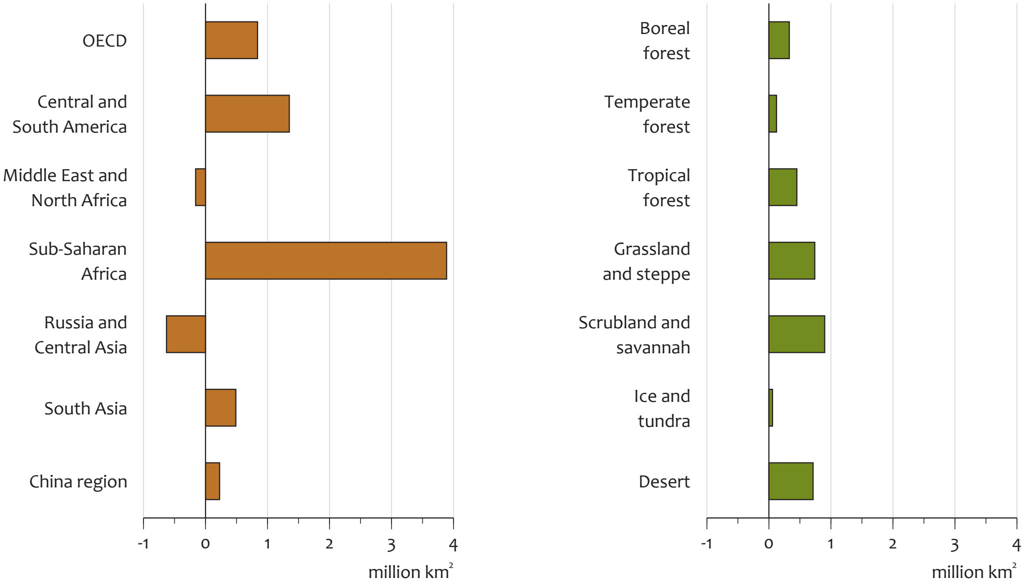
The scenarios in this report assume continued increase in agricultural yields, also in the baseline scenario sketched in Chapter 3. This may be overly optimistic and much discussion abounds on the future of agricultural yields.

Large potential benefits to global biodiversity from increased agricultural yields come with a high degree of complexity in implementation. New leaps in yield improvements are commonly understood not to be hindered by technological feasibility. Solutions are mostly based on the introduction of new high-yielding or

Figure 4.13 **Change in natural area and wilderness compared to baseline scenario, 2050**

Closing the yield gap;
Natural area per region

Closing the yield gap;
Wilderness per biome



The natural and wilderness area in 2050 would increase as a result of improving agricultural productivity.

Box 4.4 Balancing production intensity and environmental impacts

Closing the yield gap means producing more on the same tract of land, not solely through increased inputs, but also by improving management practices and indirect determinants of productivity such as education and access to credit and capital. Intensification through increased external inputs such as water, energy and fertiliser can create a trade-off with mostly local environmental quality. Sustainable agricultural intensification relies on balanced inputs and more use of ecosystem services while maintaining a higher level of ecosystem integrity. A review of research presented in IAASTD (2009, p. 385), the framework provided by Keating et al. (2010) and the position paper by (Brussaard et al., 2010) demonstrate that many agricultural systems have scope for considerable yield improvement with little or even positive impact on the environment. For example, conservation agriculture that combines no-till with residue retention and crop rotation increases yields by conserving soil, water and nutrients, hence restoring soil health and preventing off-site environmental impacts. The effectiveness and aptness of specific measures, however, depends on local environmental and social conditions, and even widely acclaimed systems such as conservation agriculture have their limits (Giller et al., 2009).

more resistant varieties or breeds, and practices to enhance water and nutrient use efficiency, soil health or pest and weed control. However, these improvements are difficult to achieve because: i) solutions must be extensively tried, tested and adapted to local conditions before taken up in farmers' operational routine; and ii) sustainable yield improvements usually require changes to production systems that are unattractive or difficult to implement by individual farmers under current social, institutional and political conditions (Box 4.4). None of these conditions can be addressed by simple top-down regulations. Most improvements refer to long-term processes in which many diverse interests play a role.

Yield increases may accelerate agricultural expansion locally

Allocation through world market prices would reduce agricultural pressure at the global level. But improving yields at local level could make further land conversion more attractive given abundant infrastructure and as long as marketing opportunities exist (see for instance, Schnepf et al., 2001). Furthermore, in areas with abundant suitable land, land prices will remain relatively low and thus partly remove the incentive to invest in sustainable intensification (Lambin et al., 2001). These observed effects emphasize the need to combine efforts to increase yields with policies on land-use planning and conservation.

The option delivers benefits for other policy issues

The benefits of closing the yield gaps in different regions are manifold. Closing the gaps would enable higher production on existing agricultural lands, a requirement to feed a growing world population. It would also reduce pressure from agricultural expansion on remaining natural areas, increase competitiveness of developing countries in agricultural markets, contribute to food security, compensate for production losses from soil degradation, and reduce the costs of climate change mitigation.

Improved food availability and better farming conditions are important benefits especially in regions with the widest yield gaps, such as in most countries in Sub-Saharan Africa (see also Chapter 6). This option also results in a small reduction in CO_2 concentration compared to the baseline scenario.

4.5 Reducing post-harvest losses in the food chain

- Reducing post-harvest losses in the food supply chain are projected to result in lower food prices, leading to increased consumption, especially in developing countries, and particularly of livestock products.
- The rebound effects of lower prices lead to only a modest reduction in land use for agriculture and livestock. Investments to enhance productivity are also dampened. As a consequence, biodiversity gains would also be modest.

Losses in supply chains are large for manifold reasons

Post-harvest losses are caused by numerous factors, such as harvest inefficiencies (e.g., poor timing), poor harvest conditions (e.g., too wet), losses during transport, or deterioration during storage on-farm, on-market, or after purchase by consumers. Data on these losses are limited with relatively few studies

Fruit and vegetables disposed of by supermarkets may be still edible.

published, and estimates range between 2 and 23% from production to retail sites for developed countries, and up to 50% for developing countries (Lundqvist, 2009). Losses in developing countries are presumed to be highest during harvest and storage, but tend to occur further down the supply chain in high-income countries (Kader, 2005; Lundqvist, 2009). A Swedish inquiry into losses in food service institutions reported that over one fifth of food is lost between preparation and consumption (Engström and Carlsson-Kanyama, 2004). In the USA, losses by consumers were estimated at 25% of edible food by (Kantor et al., 1997). Nelleman et al., (2009) cite even higher figures, for example, some 40% of global fish landings are lost through discards, post-harvest loss and spoilage; waste of 30% of all food in the USA; and 32% of all food purchased at household level in the United Kingdom , of which 61% could be avoided.

Option: Cutting post-harvest losses by half in the food supply chain

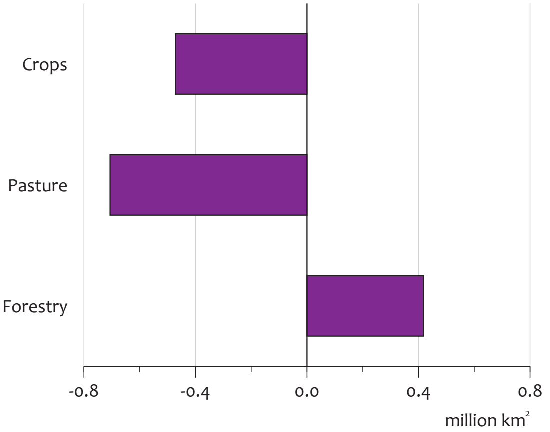
This option assumes a gradual reduction in post-harvest losses in food supply chains worldwide by 15% of total food supplies, which would roughly correspond to halving the estimated present losses. In the model suite used, this is mimicked by gradually adjusting the price and income elasticity curves. No distinction is made between different types of losses (e.g., during harvest inefficiency, pre-marketing or post-marketing storage) or type of foodstuff. Additional costs to implement the assumed measures are not taken into account. The option is based on a current joint study on sustainable food supply by PBL, LEI and IFPRI.

Results

The direct effect would be that less additional production is needed to meet increasing food demand, resulting in a reduced expansion of agricultural land use (Figure 4.14). The effect on land use, however, is much less than the expected 15%

Change in global land use compared to baseline scenario, 2050 **Figure 4.14**

Reducing post-harvest losses



When post-harvest losses are reduced, less land is required for crops and pasture by 2050. This also results in less agricultural expansion into forested areas, a process from which wood is usually obtained. This would lead to more regular forestry (see Box 5.1).

reduction. The models used account for the following rebound effects: i) decrease in food and land price; ii) increased food consumption due to lower prices; iii) lower yields due to a lack of price incentives.

These rebound effects would partly negate the net effects on land use: land expansion would be reduced modestly by almost 0.5 million km² of cropland and 0.7 million km² of pasture. This is less than one sixth of the reduction that could be achieved if reduction in post-harvest losses were to translate fully to reduction in agricultural area. Consequently the option gains are modest (almost 5% prevented MSA loss; Figure 4.15). The total net gain in wilderness areas would be 0.4 million km², mainly in the temperate and tropical grasslands of OECD countries, Central and South America and Sub-Saharan Africa (Figure 4.16).

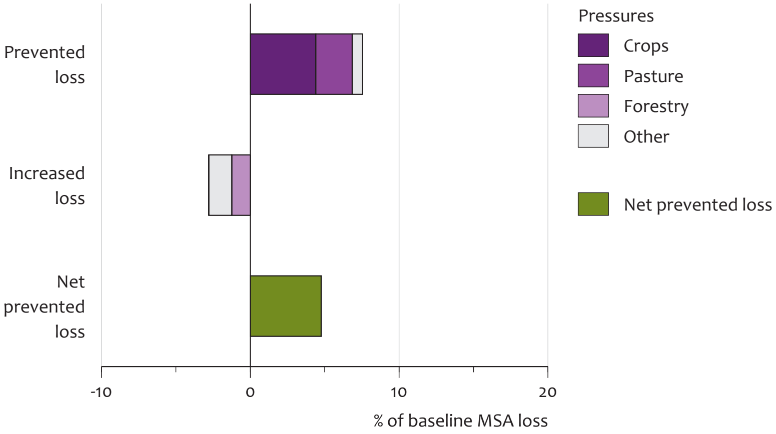
Discussion

Losses in the food chain cannot be eliminated completely, nor are all losses comparable. Food safety regulations limit the scope for reducing waste, especially for perishable products. Crop residues and waste are also often used as feed (e.g., for pigs) or as primary energy input.

The size of reported losses indicates that demand-side measures in the food chain could make the food chain more resource-efficient. A potential reduction of 10 to 15% of production assumed in this report does not seem excessive nor technically unattainable. The reduction potential differs between food types of food. Also, only a few estimates of losses are available, mostly referring to studies based on limited

Figure 4.15 **Prevented global MSA loss compared to baseline scenario, 2000 – 2050**

Reducing post-harvest losses



The prevented MSA loss from reducing post-harvest losses is modest and results mostly from reduced land-use for crops and pasture.

observations. More and standardised research is required on losses in the various parts of the food chain.

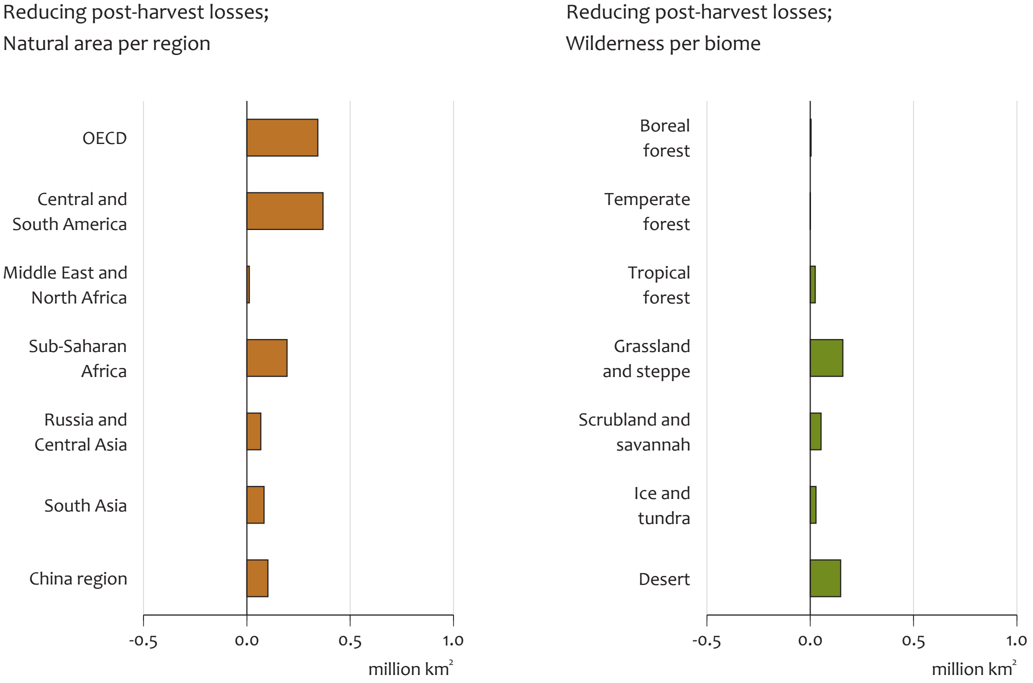
Feasibility

In developing countries, most supply chain losses occur during and after harvest on the farm, at local storage facilities, and during transportation to the nearest market. This presents scope for synergy in measures to improve yields. These include:

- Improvement of communal storage facilities in rural areas;
- Early warning systems for example, weather forecasts indicating poor harvesting conditions;
- Improvement of infrastructure and marketing facilities;
- Enhanced logistics to prevent unnecessary delays in getting produce to the market;
- Training and capacity-building on planning and management practices.

In developed countries, the balance of losses tips to the commercialisation and consumption phase. Food safety regulations are tight and producers maintain high certainty margins on dates up until when taste and quality of food products are guaranteed. While fixed expiration dates are necessary to guarantee the food safety of perishable products, consumers often perceive best-before dates as maximum dates. There is little research on the potential gains of better scrutiny of best-before dates and of changing consumer behaviour in developed countries towards less food spoiling. Other potential measures include improved technologies to lengthen the consumption period of products (such as pasteurisation or improved storage at store and household levels).

Change in natural area and wilderness compared to baseline scenario, 2050 **Figure 4.16**



Reducing post-harvest losses leads to small increases in natural and wilderness areas.

Despite past and present efforts to reduce food waste by private sector and government, there is still scope for significant reductions. For instance, the benefits of reductions may be deemed small (in financial, social or environmental costs prevented) or the instrumentation may be too complex with many actors, scales, conflicting interests, and the variety of issues to address.

Investments needed to attain loss reduction also add to production, storage and transaction costs, which may not be economically justified in an environment of declining prices. Therefore, the feasibility and effectiveness of this option partly depends on other options, such as protection options, that make available land scarce and stimulate resource efficiency.

4.6 Changing diets

- Reducing meat consumption in developed countries to ‘healthy’ levels would also reduce global agricultural land area by almost 25% in 2050 compared to the baseline (from 40 to 31 million km^2), comprising mostly of abandoned pasture.
- As a result, biodiversity loss could be reduced significantly provided abandoned lands are allowed to regenerate to their natural state.

Less meat consumption can lead to major reduction in global agricultural area.

- Reduction in livestock production would also benefit climate change mitigation through reduced emissions from deforestation, re-growth of natural vegetation, and reduced CH_4 and N_2O emissions from agricultural sources.

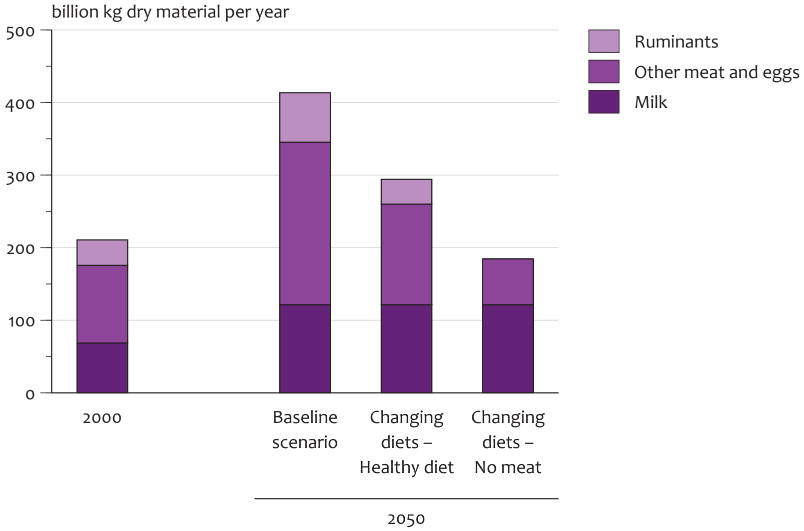
Effect of livestock sector on climate and biodiversity

The livestock sector has attracted much attention as a major contributor to global GHG emissions and land use. According to FAO, the sector accounts for 18% of GHG emissions and for 80% of total anthropogenic land use (Steinfeld et al., 2006). Demand for meat and dairy products will significantly increase with growing population and wealth. Consequently, a shift to a less meat-intensive diet could have multiple benefits including reduced biodiversity loss from land conversion and could contribute significantly to climate change mitigation. The climate benefits arise from reducing methane and nitrous oxide emissions from livestock, as well as carbon sequestration through re-growth of natural vegetation on land used for agricultural and livestock production. Reduced consumption of red meat and pork in wealthy regions is also suggested to be beneficial to human health. There could also be drawbacks. Involuntary reduction of consumption (e.g., through price mechanisms) would reduce people's choice, and would impact on livestock farmers and countries with a high stake in exporting livestock products.

Options with reduced meat consumption

Under the baseline scenario, GHG emissions from land use increase from 11 Gt CO_2 eq/yr in 2000 to 12 Gt CO_2 eq/yr by 2030 and 2050 (Stehfest et al., 2009), and total GHG emissions from 41 Gt CO_2 eq to 72 Gt CO_2 eq (78% increase). In the same period, livestock production doubles, mainly driven by population growth and increasing per capita meat consumption (Figure 4.17). Increasing efficiency in crop and livestock production, and a gradual shift in consumption from ruminant meat

Global livestock production **Figure 4.17**



Changing diets to less meat consumption would significantly reduce livestock production by 2050.

to pork and poultry results in an agricultural land expansion of about 4%, which is much less than the increase in production. Along with the increased livestock production, methane emissions from beef and milk production, and N_2O emissions from animal manure will increase, as well as emissions from the production of additional feed crops.

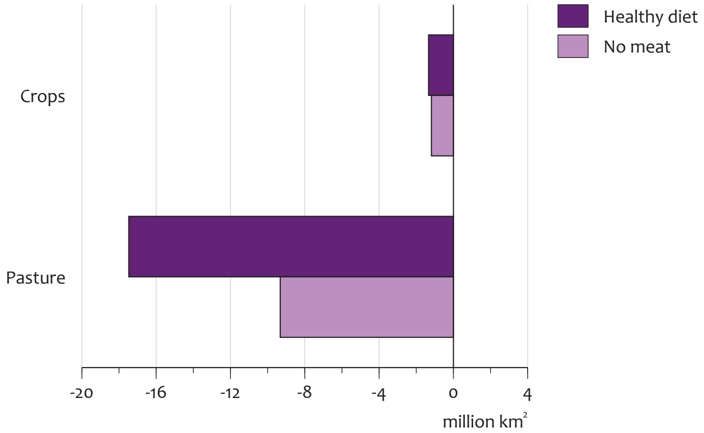
The dietary change options quantify the impacts of dietary transition from substituting animal products with plant-based proteins (Stehfest et al., 2009). The following two options are analysed:

1. Healthy diet: A shift is assumed to a more healthier diet (derived from the so-called Willet diet; Willett, 2001) based on daily consumption of beef, pork and poultry/eggs of 10, 10 and 44 g per person, respectively (Stehfest et al., 2009). World fish consumption from wild catches is assumed to be constant after 2000, and consumption of milk and dairy products follows the baseline scenario (Stehfest et al., 2009). These assumptions indicate that some regions with currently low meat consumption exceed the consumption projected in the baseline because it also assumed that these diets are to be achieved in developing countries.
2. No-meat diet assumes complete substitution of meat with plant-based proteins. This rather extreme option is calculated only as a sensitivity analysis.

In both cases, the dietary change starts in 2010 and is assumed to be completed by 2030, and remains level up to 2050. Meat protein is substituted with proteins from pulses and soybean in all variants to ensure protein intake equal to the baseline

Figure 4.18 **Change in global land use compared to baseline scenario, 2050**

Changing diets



Changing diets to less meat consumption would have considerable effect on pasture areas by 2050.

scenario, or higher in regions where meat consumption according to the Willet diet is higher than the baseline scenario.

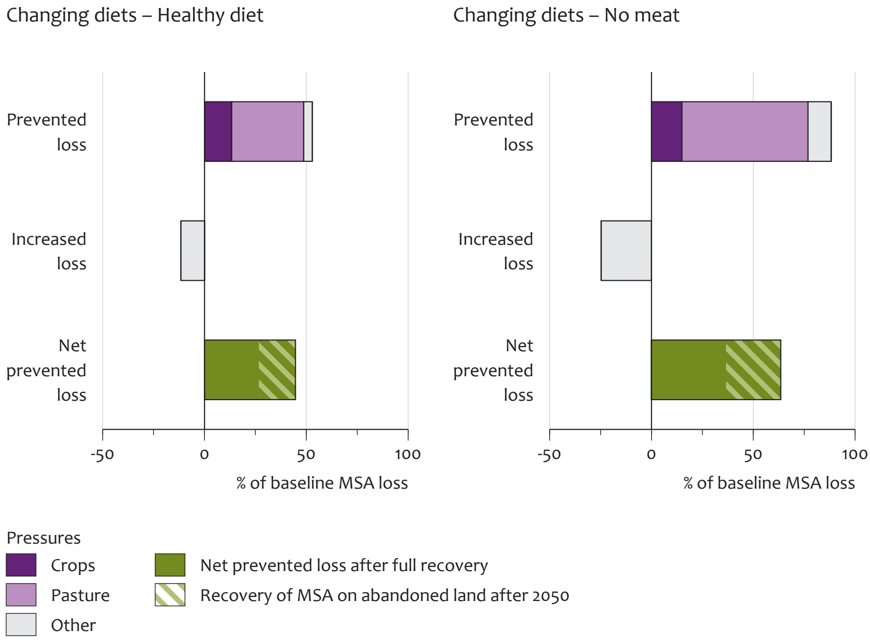
Results

The Healthy diet option leads to substantial decrease in global pastureland by almost 45% (over 9 million km²) on the baseline scenario for 2050, and a 10% decrease in global cropland (1.2 million km²; Figure 4.18). The No-meat option would lead to an even higher reduction in pasture, and to a small additional decrease in cropland. The relatively small effect of both options on cropland is caused by substitution of meat protein with pulses, which require almost as much land area per unit protein as do pork or poultry. However, GHG emissions between 2000 and 2050 are about 20% lower under the Healthy diet option than in the baseline scenario. As a result, GHG concentrations, temperature rise and MSA loss from climate change are slightly lower in 2050 (see also Section 6.2).

Overall, the reduction in anthropogenic land use greatly benefits biodiversity. Under the healthy diet option, MSA loss would ultimately be reduced by about 2.5 percent points (preventing over 40% of the MSA loss projected in the baseline; Figure 4.19) and almost 4 percent points of MSA in the No-meat option (or over 60% MSA loss prevented), provided the abandoned land is left to fully recover its natural state. By 2050 the already realised gains are 1.4 and 2.2 percent points, respectively. Full recovery takes more time.

The largest gains in biodiversity under the Healthy diet option occur in the OECD countries and in Central and South America, followed by China, Russian and Central Asia, and Sub-Saharan Africa. Temperate forest and grassland show the largest

Prevented global MSA loss compared to baseline scenario, 2000 – 2050 **Figure 4.19**



Net prevented MSA loss from changing diets is significant, but is partly achieved only after 2050 because time is needed for abandoned lands to recover to a more natural state.

gain, followed by tropical grassland and forest (Figure 4.20). These region- and biome-related results mostly reflect where pastureland would be abandoned. The slight increase in cropland in Central and South America is due to additional cropping of pulses and soybean to replace animal protein. Aquatic biodiversity shows less eutrophication in most regions (Section 6.3).

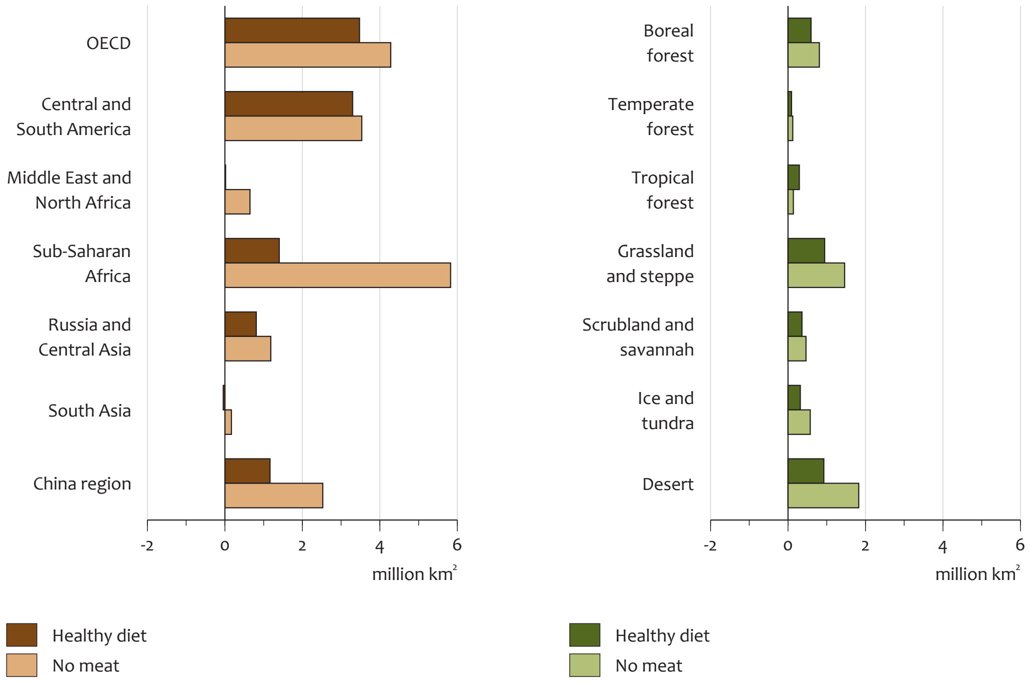
Discussion

Secondary effects of the diet changes, such as health improvements, changes in gross domestic product (GDP), and in demographic growth have not been considered, nor have the agro-economic consequences of transition costs and land prices. These might offset some of the gains discussed. The results assume recovery of natural vegetation in the abandoned lands by 2050 but whether full potential recovery is achieved depends onwhether these areas are left to recover or used for alternative uses.

Feasibility: Diet changes possible through agricultural price increases or changes in preferences

Altering habits and preferences are difficult to achieve, politically and practically. Meat consumption may be reduced because of changes in consumer preferences, and higher meat prices. Preferences can shift, for instance, because of increased knowledge about healthy levels of meat consumption (see for instance, Moreira

Figure 4.20 **Change in natural area and wilderness compared to baseline scenario, 2050**



Changing diets; Natural area per region

Changing diets; Wilderness per biome

Under the two diet options, the largest gains in natural areas by 2050 are in OECD countries, South and Central America and Sub-Saharan Africa. The largest gains in wilderness area are in grassland and savannah systems, and in other marginal systems partly used for grazing.

and Padrao, 2004), or social acceptance of non-meat substitutes. Price might change because of the externalities in meat consumption, specifically the high land-use footprint and contribution to GHG emissions. Fiscal instruments can internalise these costs in the price of meat products. Wise et al. (2009), for instance, show that internalising costs of GHG emissions can drive changes in dietary composition, especially reducing beef consumption, which is most carbon intensive. Other studies stress that no major changes can be expected through price mechanisms (Smil, 2002).

Impacts on livestock farmers who will face income losses could be a political barrier to low-meat diets. Regionally, meat exporting countries would suffer economic losses, although large and sudden shifts to lower meat consumption seem highly unlikely.

Highly productive forest plantations reduce loss of primary forest in the long term.

4.7 Improving forest management

- Establishing highly productive forest plantations can lower the pressures of logging on semi-natural forests. This would reduce loss of primary forest area and total forest biodiversity loss may be reduced, especially where plantations can be established without affecting natural forests.
- Reduced impact logging (RIL) may increase biodiversity in timber-producing semi-natural forests, especially in the tropics. RIL also provides a modest increase in the total carbon storage and better forest recovery.
- Plantations are efficient for producing wood but have relatively low biodiversity value. The availability of abandoned agricultural land for plantations largely determines the net biodiversity effect. This factor is external to the forestry sector.

Introduction

Under continuation of the current forest-use regime, forests may not be able to supply all future human needs in several world regions. Deforestation remains high in many countries (FAO, 2001, 2010), and agricultural expansion is seen as the main cause. Sustainable use of natural resources such as forests is therefore an important part of the Convention on Biodiversity (UN, 1993). Responsible establishment and management of ‘planted forests’ can reduce pressure on the extent of native forests and the goods and services provided by them (Carle and Holmgren, 2008). In this study, only options in the forestry sector for production of timber, paper and firewood have been considered. Halting deforestation and limiting agricultural expansion, which is external to the forestry sector, are covered by other options.

Improving forest management

Two variants with improved forest management were analysed. Possibilities for reducing biodiversity loss in natural and planted forests are explored under continuation of wood production. In the IMAGE model, three simplified forest management types (together referred to as forestry) have been implemented: intensive plantation forestry; selective logging of individual trees (mostly in tropical countries), and clear-cutting and re-growth in secondary forests (mostly in boreal and temperate regions).

The option variants combine elements of sustainable forest management with the use of intensively managed plantations, namely:

- Changing conventional selective logging practices for more efficient forest use. By applying pre- and post-harvest techniques (here collectively termed as Reduced Impact Logging - RIL), the logging impact on the remaining forest stand is reduced, and simultaneously forest re-growth after logging and carbon storage are enhanced (Putz et al., 2008a; Putz et al., 2008b);
- Establishing intensively managed forest plantations increases productivity. The planting scenarios are based on FAO projections and represent plausible developments (Brown, 2000). The establishment scenarios will result in a considerable share of future global wood production from plantations. This, in turn, creates possibilities to reduce pressure on semi-natural forests from current forestry practices (Carle and Holmgren, 2008). Plantations can be established in all climatic zones, but growth rates are highest in the tropics.

The two option variants each have different proportions of the three simplified forest management types (see Figure 4.21):

1. Moderate Ambition option with partial RIL practices in tropical forests and establishing plantations to supply 25% of global wood demand by 2050;
2. High Ambition option with full implementation of RIL practices and establishing plantations to supply 40% of global wood demand.

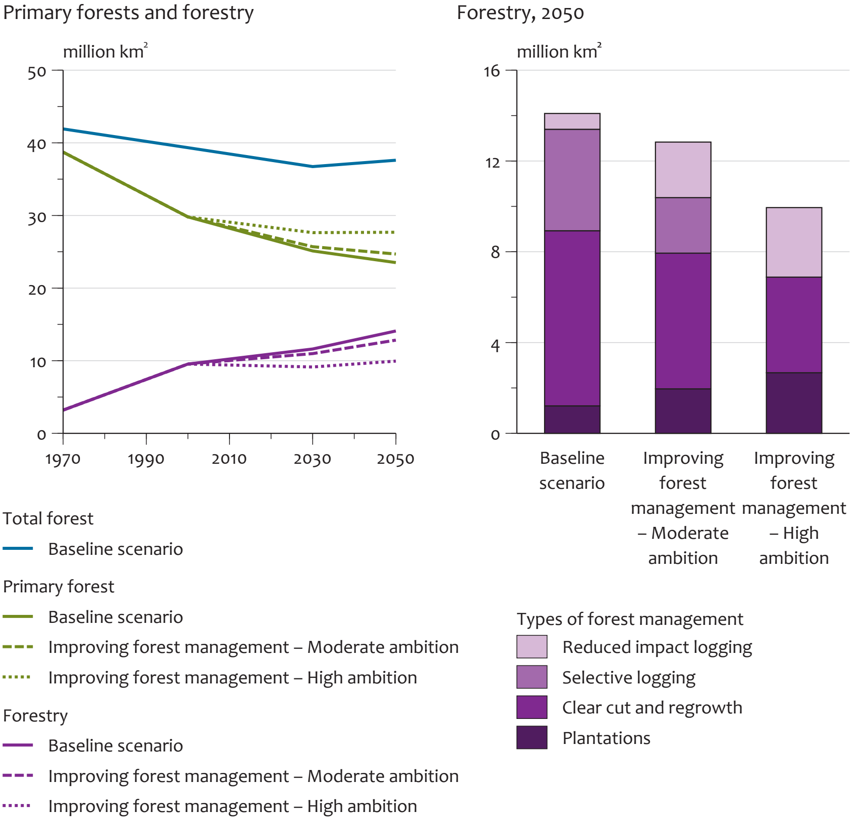
Plantation establishment continues up to 2050, while RIL measures are assumed to be implemented completely from 2010 onwards. Consumption-oriented options (such as material recycling and dematerialisation) that reduce wood use are not included.

Results: baseline development

The baseline used for this option used a demand and supply scenario quantified by the European Forest Institute-Global Trade Model (EFI-GTM; Kallio et al., 2004), based on the SRES B2 storylines (Arets et al., 2008). This is combined with the demand for traditional wood-fuel energy from TIMER (van Vuuren et al., 2007) and the OECD baseline scenario for other non-forest sectors (see Chapter 3).

In the absence of stimulating forestry policies, the total forestry area would increase from 9.5 million km^2 in 2000 to 14 million km^2 in 2050, just over one third of the global forest area. Within this scenario, plantation areas are assumed to increase slightly from about 1.1 to 1.2 million km^2 by 2050. Undisturbed forests (without forestry activities) would decrease in area from almost 30 million km^2 in 2000 to 24 million km^2 by 2050 (Figure 4.21). The total forest area is also influenced by expanding agriculture (see Chapter 3).

Forests and forestry **Figure 4.21**



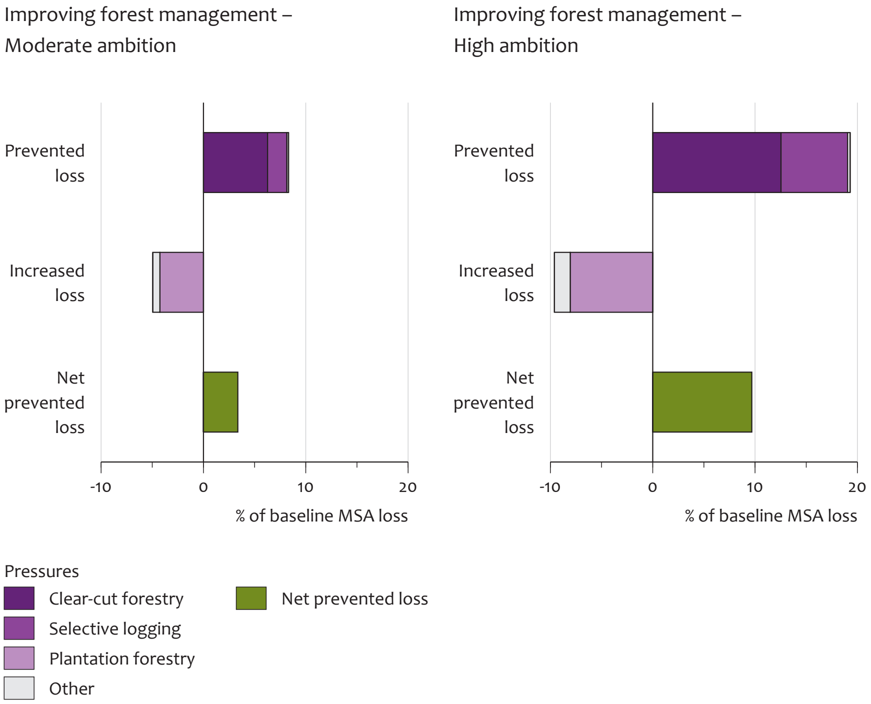
The two improved forestry options have different proportions of forest management types compared to the baseline scenario for 2050. In these options, the area of unused forest increases relative to the baseline.

Global biodiversity loss in terms of MSA due to forestry would amount 1.2 percent point on a total baseline loss of about 9 percent points. Further losses in forest biodiversity result from deforestation due to agricultural expansion. During conversion, part of the biomass removed will be used in timber production, but the exact amount is uncertain. To avoid double counting, biodiversity loss from conversion has not been attributed here to forestry, but to land use and habitat change for agriculture.

Results: option effects

The High Ambition option would reduce the amount of land used for wood production by one third in 2050 or about from 10 to instead of 14 million km² (Figure 4.21). With such a reduction on total forestry area and the assumed positive effects of RIL, total MSA loss from forestry would be 0.9 percent point less in 2050 (which means 10% prevented MSA loss; Figure 4.22).

Figure 4.22 **Prevented global MSA loss compared to baseline scenario, 2000 – 2050**



The prevented MSA loss in the Moderate and High Ambitions for improved forestry results from improved conditions in semi-natural forest used for clear cutting and selective logging. Establishing forest plantations leads to additional MSA loss.

In the Moderate Ambition option, the forestry area expands by more than 3 million km² and MSA loss is now about 0.3 percent point less (3% prevented MSA loss). Most gains come from the increase in primary forests, being one of the most species-rich environments of the world.

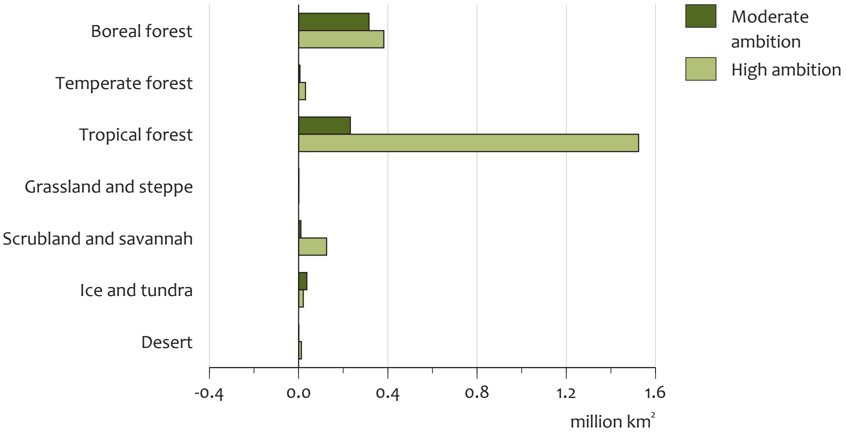
Opportunities for plantations and RIL differ between regions. RIL is primarily implemented in South America, Sub-Saharan Africa and in Asia and improves conventional selective logging. In the other regions, clear-cutting in semi-natural and natural forest can be considerably reduced by establishing intensively managed plantations.

As a result, the wilderness area (high quality in terms of MSA) is higher in both the Moderate and High Ambition options compared to the baseline in 2050 (Figure 4.23). Boreal and tropical forests especially benefit from improved forest management, while temperate forests show only a slight effect. This is due to the fact that temperate secondary forests with clear-cut and re-growth cycles are highly productive, with only small potential for further in improvement in production.

Change in wilderness compared to baseline scenario, 2050

Figure 4.23

Improving forest management



Increases in wilderness area by 2050 in the High and Moderate Ambitions for improved forest are mostly in boreal and tropical forests.

In the baseline scenario by 2050, total carbon storage in forests is about 2100 Gt CO_2, while in the High Ambition option, this is 40 Gt CO_2 higher, mostly in living biomass. This means that there is an annual extra accumulation of 0.7 Gt CO_2/yr during this period, which is partly the result of RIL which causes less damage to the forest biomass. In a study on climate change mitigation, the difference in GHG emissions between a baseline and a representative 450 ppm mitigation pathway amounted about 900 Gt CO_2 between 2000 and 2050 (17.6 Gt CO_2 /yr; Figure 4.24). Thus, the High Ambition option contributes 4% to this mitigation pathway, and is only a temporary effect that can not be continued indefinitely. Preventing deforestation holds a further and larger potential (Section 6.2).

Discussion

Strategy for improvements

The role of used forests in conserving biodiversity has been discussed by (Barlow et al., 2007). They concluded that secondary forests and plantations can provide complementary conservation services but primary forest contains irreplaceable elements of forest biodiversity. This notion supports the strategy in the options of increasing productivity in plantations that have a relatively low biodiversity value and increasing the area of unused forests. By carefully selecting land for establishing plantations, trade-offs can be reduced and synergies with carbon storage served.

Uncertainties

It is not known how much wood (including firewood) is obtained from forest conversion, which is a process driven mainly by agricultural expansion. In this

process, part of the wood removed will be used to meet regional demand. But this potential supply is neither treated explicitly nor fully in the present model version. As a consequence, the total area for forestry is probably underestimated.
Wood supply from forest conversion cannot continue because it jeopardises the wood supply potential of forests in the long term. The High Ambition option shows that the combination of plantations and RIL has the potential to meet global demand for industrial wood from a limited forest area.

Further, proportion of traditional fuelwood obtained from forestry is not known exactly. A large part of this woody biomass is collected informally outside regular forests and not produced in industrial forest concessions. The presented analysis focuses on forested biomes, and not on biomes with sparse tree vegetation such as tropical savannahs. Informal fuelwood collection in developing countries exerts pressure on wooded lands and leads to further ecosystem degradation. Thus, establishing plantations specifically for fuelwood production is a promising option for further analysis .

Improved forests often have many benefits for forest biodiversity (e.g., van Kuijk et al., 2009). However, the benefits from RIL techniques in terms of MSA values are not known, and not possible to quantify. A modest improvement of 10 percent points of MSA for RIL is assumed compared to conventional selective logging. More comparative experimental studies and monitoring in tropical forests are required to quantify the anticipated positive effects.

The Forest Resource Assessment 2005 (FAO, 2006) estimated that about one third of the total forest area has a productive function. This study also arrived at a similar proportion for harvested forests in 2050. But the FRA2005 estimated the designated purpose without further indication on already performed or planned future harvest. Better monitoring of present and past harvested area is required to improve the modelled trends. Deforestation rates are not compared here with other studies because they mostly depend on agricultural development.

Feasibility

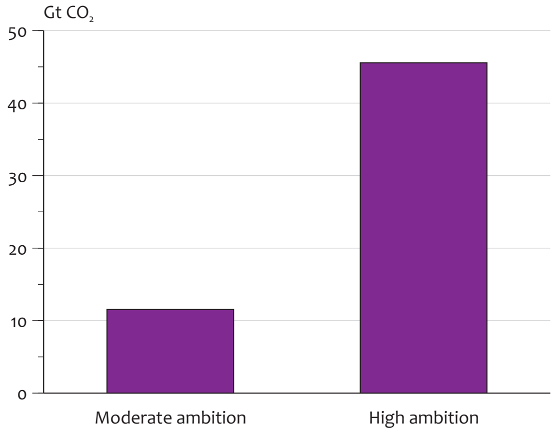
Sound forest governance and multi-stakeholder processes are needed to profit from the potential benefits of planted forests (Carle and Holmgren, 2008). Putting the potential of plantations in place requires the establishment of well-planned timber and fuelwood plantations and preferably not in existing forests. The availability of land for reforestation is a central issue in effective implementation, and depends on using abandoned agricultural lands.

Improved forest management, such as applying RIL practices, requires training of forest workers worldwide. This may achieved by promoting and applying forest certifications schemes worldwide that demand good forest management. A stimulus for implementation may be higher financial yields of improved management (Putz et al., 2008b).

Further, supporting policies are needed to protect semi-natural forest no longer required for wood production from other land-use change pressures. Otherwise, the potential benefits of the option will not be achieved. Combining sustainable

Change in carbon in the biosphere compared to baseline scenario, 2050 **Figure 4.24**

Improving forest management



Improving forestry management would lead to more carbon stored in living and dead forest biomas.

forest management (SFM) with policies on REDD and protected areas may provide a solution (Venter et al., 2009). Although such solutions have to take account of many different governance issues (Laurance, 2008; Phelps et al., 2010).

Certification schemes[1] allow public and private purchasers of timber to know the production circumstances of wood products. However, government measures that set standards for imported timber often run into conflict with trade regulation because such schemes focus on the production circumstances. As a result, demand for sustainably produced timber over non-certified timber is based on buyer preferences, pressure from environmental organisations, and green public procurement.

Barriers to sustainable production include: i) higher costs of production due to higher management and certification costs; ii) price competition with non-sustainable timber; and iii) lower production per hectare as certification schemes require set-aside areas for conservation and less felling per hectare to reduce environmental impact. The sustainable production of tropical hardwoods sees a large gap in production costs, which can be attributed to the long growth periods before a harvest. The shift to RIL in the option is largely in the main tropical hardwood exporting regions of South America, Sub-Saharan Africa and Asia.

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1) Such as FSC (Forest Stewardship Council) and PEFC (Programme for Endorsement of Forest Certification schemes)

Clean production of aquaculture in stead of capture fisheries helps to restore natural fish stocks.

4.8 Reducing marine fishing efforts

- Restoring fish stocks to maximum sustainable yield levels requires immediate reduction in current levels of wild catches. This would allow recovery over the following 20 to 30 years in turn leading to a more than 30% increase in future catch volume, and no further loss of fish biodiversity.
- Additional aquaculture to supplement the temporary deficit in fish supply would lead to a negligible amount of extra land use for producing crops for fish feed, compared to other agricultural developments explored in this study.

Introduction

Production from marine capture fisheries has been stagnant since the late 1980s (Pauly et al., 2005). Currently, about 27% of fish populations are overexploited or depleted throughout the world (FAO, 2009) and future catches will be below the maximum sustainable levels and of less commercial value (Pauly et al., 2003). Because of overexploitation, the effort needed to catch a given amount of fish is steadily increasing.

Baseline

In the baseline scenario, global demand for fish is expected to increase, largely driven by developing countries, and enabled by the purchasing power of a growing middle class. The annual fish demand (and hence supply) will increase from the 2004 level of almost 140 million tonnes to almost 190 million tonnes by 2030, and to 227 million tonnes by 2050, according to projections based on the Global Orchestration (GO) scenario from the Millennium Ecosystem Assessment (Cork et al., 2005). Capture fisheries will not be able to contribute sufficient to cover the increased demand.

In the baseline scenario, the estimated level of fishing in 2004 was kept constant for all fishing fleets. The predicted net result is a decline in total catches to around 60 million tonnes by 2050 from around 80 million tonnes in 2004 (Figure 4.25). Catches reduce by more than two-thirds in high commercial value large-fish populations, in most areas. The marine depletion index (DI)[2)] is projected to fall far below 2004 levels for the 15 distinguished FAO marine areas (Annex B).

The baseline scenario for aquaculture follows the projections of the Global Orchestration scenario, compiled by (Overbeek et al., in press) for finfish, and by (Pawlowski et al., in press) for shellfish. These projections were combined with the baseline assumptions for marine catches. To calculate land use for aquaculture feed, data were used on the development of feed conversion ratios (FCRs) and fractions of fishmeal and fish oil (as percentage of feed weight). Accounting for productivity growth in crop production, the total agricultural land use for fish feed in the baseline scenario was calculated at 0.10 million km^2 in 2000 to 0.22 and 0.23 million km^2 by 2030 and 2050, respectively.

Options

The key issue in obtaining sustainable fisheries is to temporarily limit fishing capacity. As a theoretical exercise, a restoration option is considered in which fishing is reduced so that stocks can restore to a sustainable level. Lower catches are assumed to be compensated by increases in aquaculture to meet a growing global demand for protein. The development of conversion ratios and fractions of fishmeal and fish oil for aquaculture feed are assumed to be identical to the baseline. It is expected that 20 to 30 years after the effort reduction, marine catches will be higher than in the baseline scenario, and achieved with lower effort.

Three options were considered:

1. High Ambition (HA): stocks are restored to produce the maximum sustainable yield. This is theoretically the largest yield for a fish population over an indefinite period. Return to maximum sustainable yield level calls for steep reduction of fishing effort. This is achieved in this variant by immediately reducing the fishing effort of different fleets.
2. High Ambition with Ramp down (HAR) is similar to the previous variant, but the reduction in effort take places gradually over a ten year period.
3. Moderate Ambition (MA) with the fishing effort reduced to an intermediate level between the current effort and maximum sustainable yield.

All options include additional aquaculture to compensate for temporary losses in marine fish catches. This aquaculture involves herbivore species or fish species that are largely vegetarian.

Results

The initial catches in all options are lower than in the baseline scenario. The options show that more sustainable catches lead to considerable improvements in biodiversity of living marine resources, and additional feed production has a small effect.

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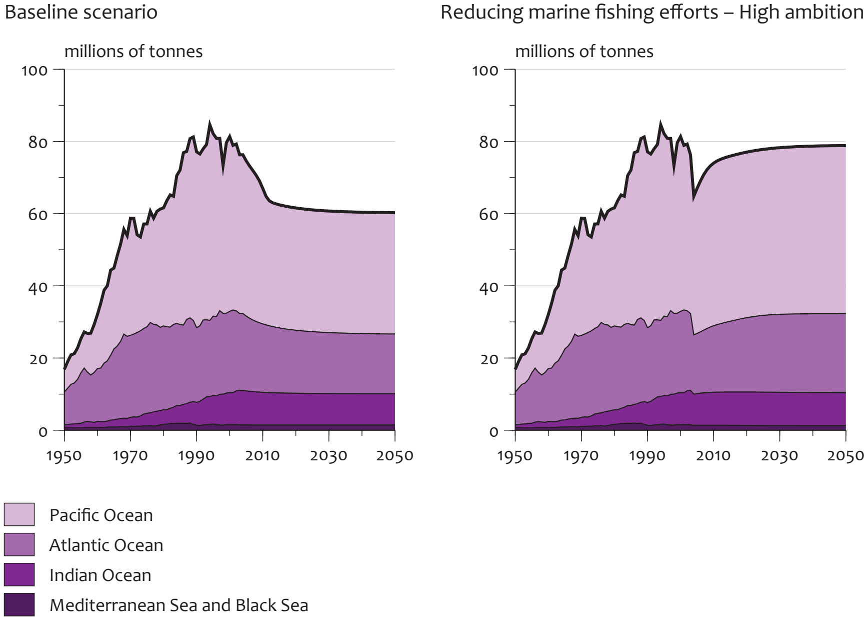
2) The Depletion Index (DI) is an indicator for marine biodiversity, based on the average relative change in stocks of fish populations (weighted stock size). See Chapter 2 for further explanation.

Figure 4.25 **Marine catches per region**



Baseline scenario

Reducing marine fishing efforts – High ambition

In the baseline, marine catches are lower in 2050. Temporarily reducing the fishing effort would allow marine catches to be restored to higher levels.

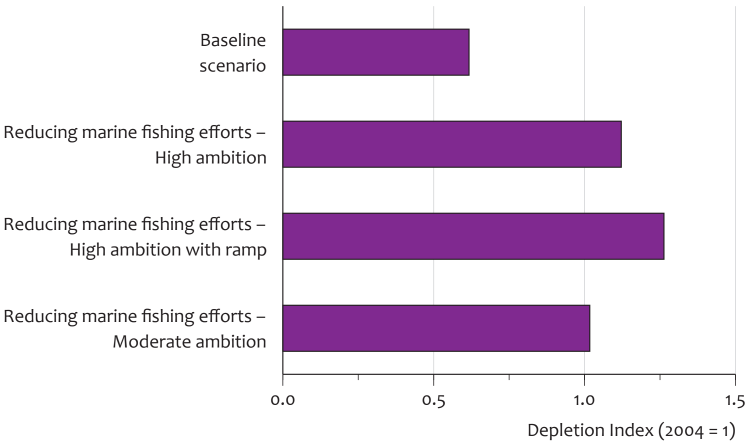
In the High Ambition option:

- Catches decrease immediately by about 12 million tonnes and recover over the following 20 to 30 years, eventually returning to slightly below 80 million tonnes per year (20 million more than in the baseline scenario; Figure 4.25). Optimal effort translates to around 20 million tonnes extra per year.
- From 2004 onwards, the marine depletion index (DI) remains stable or increases slightly up to 2050, which is a clear improvement compared to the baseline (Figure 4.26). Larger commercially interesting species remain stable or even decrease slightly in some regions compared to 2004 levels (Figure 4.27).
- The additional area required for feed in aquaculture will increase the total agricultural area by 0.3% compared to the baseline. Restoration of stocks quickly leads to higher sustainable yields and decreases the need for aquaculture and feed.
- The changes in crop area have a negligible effect on global MSA: -0.03 percent point in the first ten years and +0.02 percent point by 2050 (slightly positive, as increased catches lead to less need for aquaculture).

The High Ambition with Ramp down option:

- Shows similar but less pronounced results. Catches recover to levels slightly above 70 million tonnes, but may be lower because some functional groups may not recover at all due to the low stocks or irreversible changes in community structure reached after the ten year 'ramp down'. The DI is slightly higher by 2050 than in the High Ambition option (Figure 4.26).

Relative global biomass of marine fish stocks, 2050 **Figure 4.26**



The Marine Depletion index (weighted stock indicator for fish populations) in 2050 is higher in the options than in the baseline, and equal to or higher than the 2004 levels.

The Moderate Ambition option:

- Shows similar but less pronounced results. Catches recover to levels slightly above 65 million tonnes. The DI increases by only a few percent between 2004 and 2050 (Figure 4.26).

Discussion

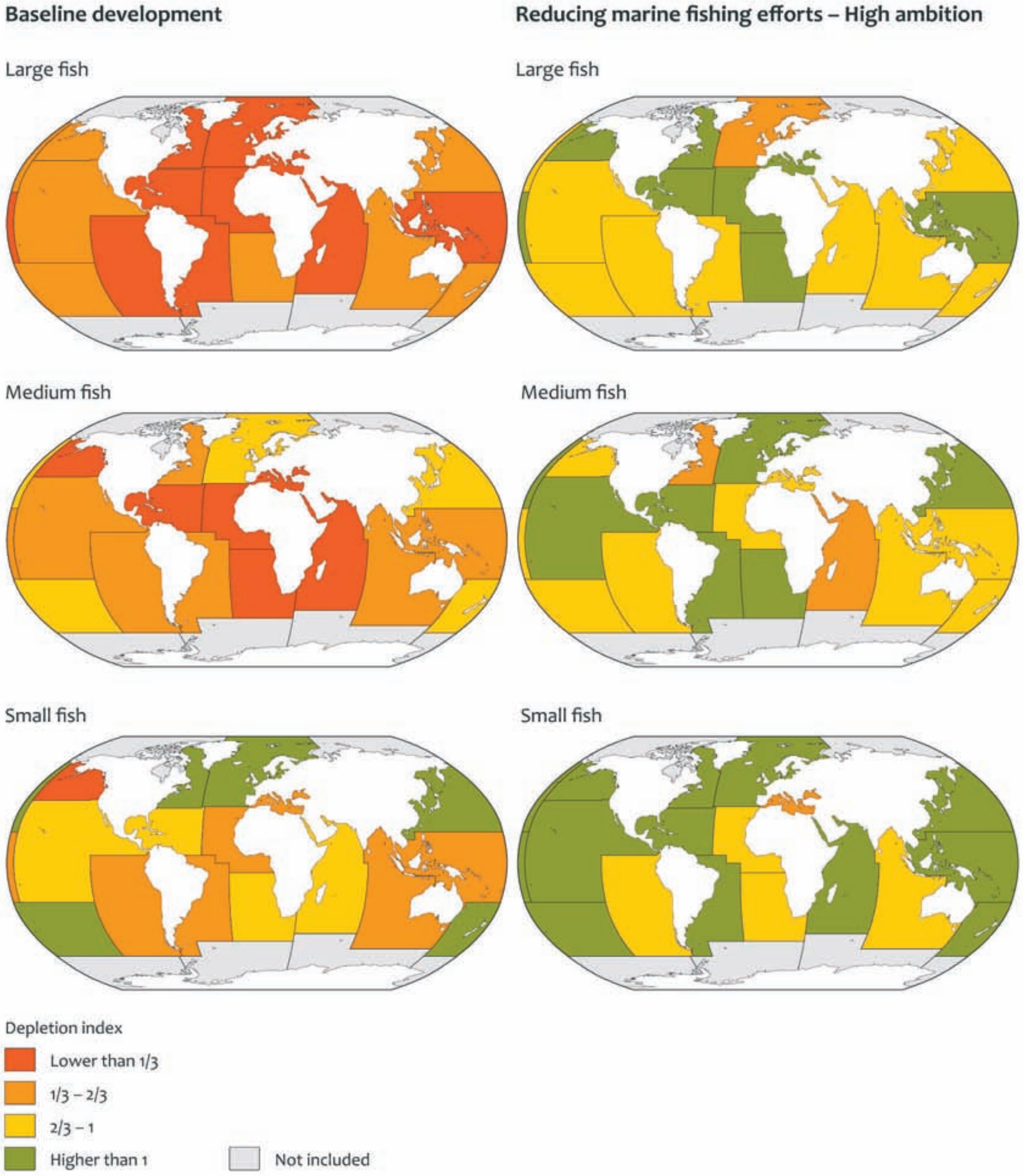
Uncertainties

There is considerable uncertainty in the fishery model predictions, and further improvements are needed. Nevertheless, these scenarios provide useful insights into the magnitude of possible changes in catches. In calculating the overall DI, the strong decrease in large fish is partly masked by the strong increase in small fish in some regions. Land use for feed crop production was calculated with world average production efficiencies, although there are big differences in crop production at the regional level. This may influence the outcomes when aquaculture occurs in a small number of regions only. The concept of maximum sustainable yield (MSY) is used as the optimum level of fisheries exploitation, but current research on managing fisheries within an ecosystem framework question this (Mora et al., 2009).

All options consider the land use required for fish feed but do not include the effects from:

- GHG emissions from energy use in fleet fuel, feed production and fish farming;
- Eutrophication and pollution from antibiotics and other chemical products in coastal areas, rivers and marshlands;
- Biodiversity loss in mangroves and coastal zones;
- Freshwater use for controlling the salt level in aquaculture basins.

Figure 4.27 **Relative biomass of fish groups, 2050 compared to 2004**



The Marine Depletion Index (weighted stock indicator for fish populations) by 2050 in the High Ambition option is higher especially for large and medium-sized fish populations.

Feasibility

Limiting fishing capacity (quota and ship horsepower) may be feasible in developed countries given the political will to limit fishery permits. However, it will be difficult to implement in countries where fishing operations are dominated by dispersed, small-scale activities, and would have significant impacts on those depending on fisheries for their food and livelihoods. Marine capture fisheries are an important component of food security and income in coastal nations. The annual direct contribution of these fisheries to the global economy is estimated at USD 85 billion, and USD 380 billion when secondary economic activities are included (Dyck and Sumaila, 2009).

Reducing fishing efforts calls for fisheries management at local, national, and regional scale. In areas where fisheries management is effective, stock rebuilding on a local scale is likely to be successful using a variety of instruments such as effort reductions, quota limits, and area and/or time closures. Fishery rebuilding where management is ineffective or non-existent will require a concerted effort nationally and internationally, including income alternatives to support displaced fishers in their livelihoods.

The analyses presented here suggest that delays in effort reduction, aimed at rebuilding fisheries may directly impair the economic viability of fisheries. There are major challenges in rebuilding fisheries. Effort must be reduced and not simply displaced to other areas. Measures must be put in place to address the short-term economic and catch losses associated with long-term fisheries rebuilding. The fishing industry receives fuel and capacity building subsidies in the order of USD 25-29 billion annually (Sumaila et al., 2010), corresponding to around 30% of the first-hand value. These subsidies serve to maintain fishing capacity and fisheries that are non-profitable without them. The removal of fishery subsidies is likely to have short-term effects in reducing fishing capacity and effort.

Aquaculture

Production in aquaculture grows in the baseline scenario steadily with long-term annual growth of 3%. The options, and especially the High Ambition scenario, require fast growth up to 15% in aquaculture in the first year of the relapse in catches. Such growth rates of global aquaculture are not unrealistic in view of the historic growth rate of almost 7% per year in the period 1970 to 2006, although growth has slackened in the most recent years (FAO, 2009). This would imply that swift changes from marine catches to aquaculture production are feasible. Aquaculture has considerable and often local implications for the environment.

Aquaculture will make increasing claims on resources such as land, water and energy and has to compete with agriculture for those resources. Efficiency of resource utilisation in aquaculture could be improved by further integrating fisheries and agriculture, or by improved technical solutions and management practices (Bostock et al., 2010).

A main technical challenge lies in cutting the requirements for fishmeal and fish oil as feed for farmed fish. Solutions could come from replacing fishmeal and oil with more vegetable ingredients, an improvement in the feed conversion rate, and a shift from production of carnivore fish to more omnivore/herbivore fish species. Developments in alternative feed, such as algae, baits or feed based on methane, are in initial stages and have their own barriers and adverse effects (Rood et al., 2006). Since production costs of alternatives for fish feed based on wild catches are relatively high, an increase in prices of fish oil and fishmeal would make the introduction of alternatives more likely.

4.9 Mitigating climate change

- Climate change is expected to be an increasingly important threat to biodiversity in the future. By 2100 (beyond the study horizon of 2050), average global temperature rise without climate policy might be in the order of 3 to 5 °C above the pre-industrial level. Stringent climate policy might limit this increase to 2 °C. In the coming decades, however, the differences between scenarios with and without climate policy are likely to be much smaller.
- Up to 2050, climate change is responsible for about one third of the total projected baseline biodiversity loss. Implementation of stringent climate policy may prevent about 10% of the predicted total biodiversity loss.
- For reducing GHG emissions, leading ultimately to 450 ppm CO_2 atmospheric concentrations, several measures are available (such as energy efficiency, carbon capture and storage, and renewable energy). Bio-energy may also contribute to GHG emission reduction, but scenario analysis shows that this measure might involve trade-offs with biodiversity because most bio-energy crops require land and water.
- The net impact of climate policy with bio-energy (prevented climate change versus negative land use impacts) depends on the type of bio-energy used and the period considered. The impacts on biodiversity of land-intensive crops are high; impacts of using residues (agriculture or forestry), second generation bio-energy or use of degraded lands are much lower. Several factors influence the net results and its uncertainty, such as climate change sensitivity, bio-energy production efficiency, and also feedbacks of increasing land scarcity on agricultural productivity.
- To minimise or reduce biodiversity loss through bio-energy use, strict biodiversity criteria need to be applied to bio-energy (beyond those already included in legislation), and both direct and indirect effects should be monitored.

Introduction

Climate change is related to biodiversity loss in several ways: 1) climate change is one of the drivers of biodiversity loss (Leemans and Eickhout, 2004; Thomas et al., 2004; van Vuuren et al., 2006; IPCC, 2007; Jetz et al., 2007). 2) loss of natural ecosystems usually coincides with release of carbon into the atmosphere and reduces the uptake of carbon; and 3) climate change mitigation or adaptation may exert a direct impact on biodiversity via increased land or water use, thus increasing pressure on natural areas. The most relevant land-use changes in climate policy measures may come from bio-energy, but reforestation (carbon sinks) may also contribute to competing land claims. Impacts from water use are associated with bio-energy, but also with hydropower, especially large-scale dam systems.

Solar energy in New Mexico contributes to mitigate climate change.

Most models that examine mitigation scenarios identify bio-energy as an important element of the response portfolio. This is partly because of its role in replacing oil in transport, and partly due to possible use of bio-energy in power plants in combination with carbon capture and storage (van Vuuren et al., 2010). Other studies have warned against excessive use of bio-energy because vast land areas for bio-energy production may lead to considerable carbon and biodiversity loss (ten Brink, 2007; Sala et al., 2009). The crucial factors in this context are the type of bio-energy (residues, energy crops, wood/grass products), and the degree of indirect effects from displaced agricultural production (Searchinger et al., 2008; van Oorschot et al., 2010). Even if direct land use for bio-energy can be controlled by sustainability criteria, bio-energy production could still contribute to land scarcity and possibly force agricultural activities to expand into natural areas. However, land scarcity may also stimulate agricultural developments that lead to higher productivity in both bio-energy and food crops.

Assessment of climate policy and bio-energy

Quantitative assessment of negative and positive effects of bio-energy could shed more light on the trade-offs (Sala et al., 2009). The interactions between climate change, climate change mitigation and biodiversity loss are complex and beset with uncertainty. For instance, crucial uncertainties include climate sensitivity (degree of warming for an increase in GHG concentrations; Figure 4.28), and the uncertain relationship between climate change and biodiversity losses. Here, some of these relationships are examined with available scenario studies without fully accounting for the uncertainties involved. A full account of all aspects of climate policy and bio-energy is not provided. More detailed information can be found elsewhere: on stringent mitigation scenarios (van Vuuren and Faber, 2009; Edenhofer, 2010, Clarke, 2010) on potentials for bio-energy (Hoogwijk et al., 2005; Dornburg et al., 2010; van Vuuren et al., 2010; Behringer, 2008) and on indirect effects (Searchinger et al., 2008; van Oorschot et al., 2010).

The Copenhagen Accord for international climate policy indicates that a possible objective for international climate policy is to limit the average global temperature increase to a maximum of 2 °C on pre-industrial levels. To have a more than 50% probability of achieving this target, GHG concentrations would need to be limited to 450 ppm CO_2 eq (Meinshausen, 2006). The impacts of climate policies aiming at such targets (Bakkes et al., 2008) have been considered, and the effects of different climate policy strategies in 2050. The effects of climate change mitigation are examined in three options, namely:

1. Without bio-energy use;
2. With ambitious bio-energy use (based on woody bio-fuels, but without additional policies to limit biodiversity impacts);
3. With bio-energy use and assuming a significant improvement in agricultural productivity improvement.

The first option is a basic variant that shows the potential for biodiversity from successful climate change mitigation, while the other options serve as sensitivity runs, in which trade-offs are explored.

Baseline scenario

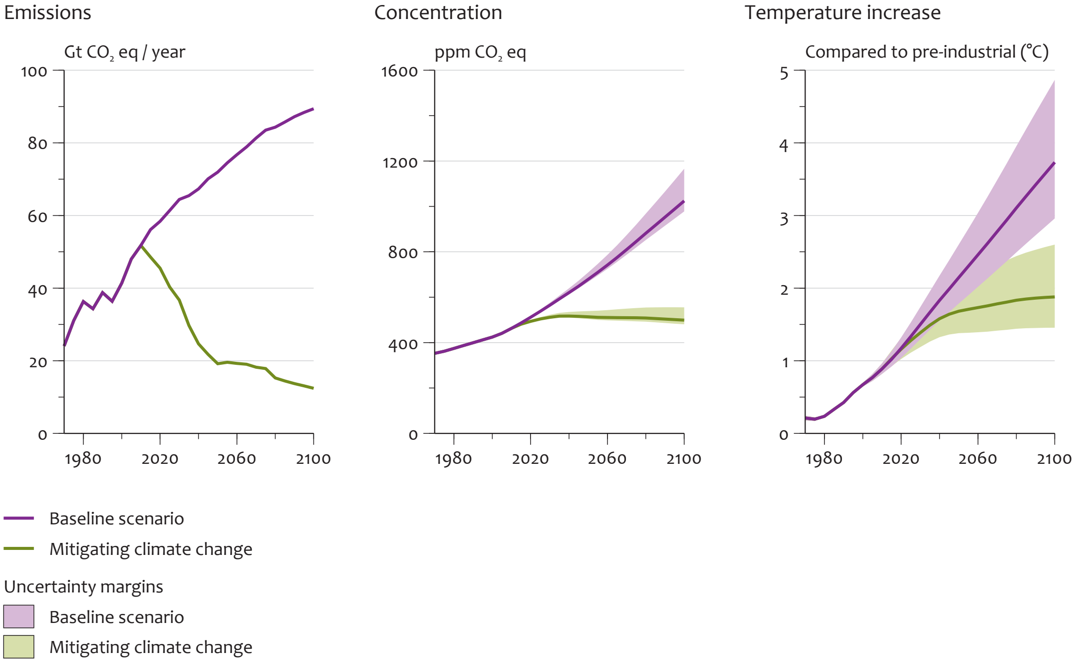
Under the baseline scenario, mean global temperature would increase to nearly 2.5 °C above pre-industrial levels in 2050 and to nearly 4 °C in 2100 (Figure 4.28). It is likely that bio-energy is used. In the baseline scenario, the total agricultural area increases from 37.5 million km² in 2000 to 44.5 million km², in 2050. The bio-energy share is modest (0.5 million km² by 2050), because there are no incentives after 2010 to increase energy supply from renewable biomass. The total biodiversity loss in 2050 in the OECD baseline scenario amounts to almost 9 percent points of MSA, and climate change is responsible for about one third (Chapter 2).

Options

All options explored reduce GHG emissions to about 25 Gt CO_2 eq/yr in 2050, targeting stabilisation of GHG concentrations at 450 ppm CO_2 eq after 2100:

- ad 1: Climate change mitigation: In this option, GHG emissions are assumed to be reduced by a mix of energy efficiency, renewable energy, nuclear power and carbon capture and storage but without bio-energy. Excluding bio-energy makes the technology mix more expensive (e.g., photovoltaic cells and wind power).
- ad 2: Bio-energy intensive mitigation: Climate change mitigation is achieved on the basis of the lowest mitigation costs, which includes ambitious use of bio-energy. Under that condition, bio-energy becomes important in the total mitigation mix leading to about 170 EJ of bio-energy use by 2050. Traditional energy (fuelwood) supplies 40 EJ, while the remaining 130 EJ is mostly woody bio-energy (for power generation and second generation) and residues (about 25% of energy demand).
- ad 3: Mitigation with compact agriculture assumes the same bio-energy intensive mitigation scenario as in the previous option but with simultaneous and rapid improvement in agricultural productivity. This would make it possible to produce bio-energy without large-scale conversion of natural areas, which would otherwise lead to increased GHG emissions from land-use change.

Global greenhouse gas emissions, concentration and temperature change **Figure 4.28**



Greenhouse gas emissions can be effectively reduced by means of mitigation policies to lower levels than projected greenhouse gas concentrations and temperature in the baseline. There are considerable uncertainties in future projections of climate change due to uncertainties in the carbon cycle and climate sensitivity (ranges based on van Vuuren et al., 2008).

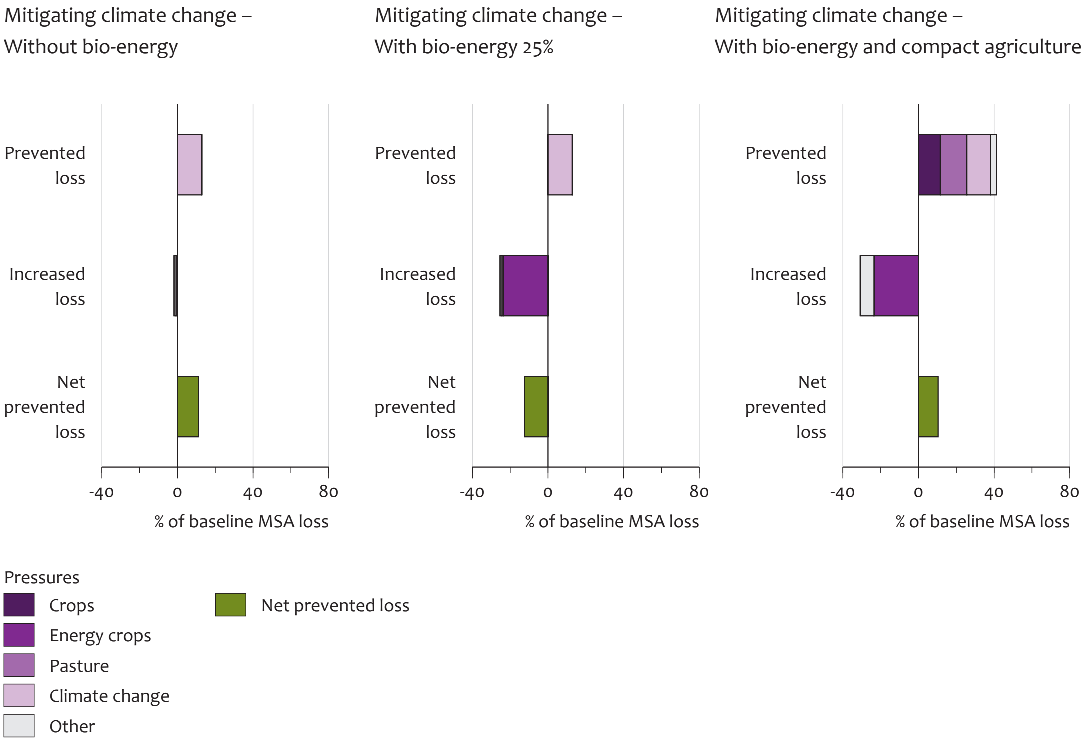
Results

Climate change mitigation leads to less biodiversity loss in terms of MSA in 2050. Compared to the baseline, MSA loss is reduced by 1 percent point in 2050 (about 10% prevented MSA loss; Figure 4.29). As a result of inertia in the climate system, the full effects of the mitigation scenario will only unfold slowly over time.
As in several other studies, the MSA effects of bio-energy intensive mitigation are negative over the period up to 2050 (10% increased MSA loss; Figure 4.29). However, the net effects of using bio-energy will become more favourable over time with the number of harvest cycles and amount of bio-energy grown , but depends on the type of bio-energy and land use assumed. Nevertheless, the results indicate important trade-offs and risks from ambitious bio-energy use both in time and space.

The last mitigation scenario shows that trade-offs and associated negative effects could be largely prevented with simultaneous improvement in agricultural productivity.

Climate change mitigation without bio-energy use has an especially positive impact on the biodiversity of boreal forests, and on scrublands and savannahs (Figure 4.30).

Figure 4.29 **Prevented global MSA loss compared to baseline scenario, 2000 – 2050**



Climate policy can reduce future MSA loss. Large-scale bio-energy use, however, may reverse this trend depending on how it is implemented (energy demand is equal for all options). This trade-off can be minimised with simultaneous improvements in agricultural productivity.

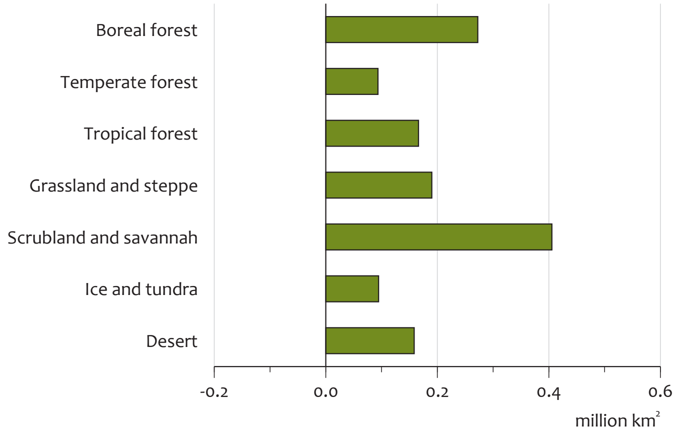
With intensive bio-energy use, the net negative effects would affect mostly scrubland and savannah because bio-energy crops are preferably grown in these habitats.

Uncertainties

Uncertainties in the net outcome of the different mitigation options are considerable and caused by uncertainties in the natural system (average climate sensitivity; projected biodiversity loss due to climate change) and also the type of bio-energy assumed in alternative mitigation scenarios. Several scenario studies (Fisher, 2007; van Vuuren et al., 2010) indicate the difficulty of achieving low climate stabilisation targets without bio-energy use. An important issue, therefore, is how to implement bio-energy while minimising the impact on biodiversity. Contributing factors include: i) use of residues; ii) bio-energy production with an efficient and positive energy yield (second generation); iii) production of bio-energy on degraded areas; and iv) whether ambitious bio-energy production can be implemented together with improvement in agricultural productivity. The impact of these factors have been analysed elsewhere but further research is needed to reduce

Change in wilderness compared to baseline scenario, 2050 **Figure 4.30**

Mitigating climate change – Without bio-energy



Implementing climate change mitigation without using bio-energy results in increases of wilderness area in almost all biomes, with the highest increases in boreal forests and scrubland and savannah.

uncertainties. Models used in most studies have limitations, for instance with respect to accounting for the multiple products in bio-energy production chains.

Feasibility

Over the last few years, a large number of model studies have looked into the feasibility of reaching GHG emissions profiles required for achieving a 2°C target with a high probability (Clarke, 2010; van Vuuren et al., 2007b; Edenhofer et al., 2010; Rao, 2008). Assuming that it is possible to reduce emissions in all countries and in all sectors, most models indicate this is technically feasible at mitigation costs in the order of maximum a few percent of GDP. However, at present, it seems very unlikely that all countries will fully participate in climate policy in the next one or two decades. At best, countries might take on emission reduction targets differentiated for levels of development - with many developing countries joining international regimes later. As such, the feasibility of achieving the 2 °C from a political and governance perspective might be much more difficult. Several studies have shown that if the participation of developing countries is delayed by more than a few decades, targets cannot be reached anymore within the model timeframes (van Vliet, 2009; Clarke, 2010).

Projected energy use in 2050 varies from 600 to 1000 EJ/yr (Domburg et al., 2006). Present ambitions in the EU and USA on energy policy and climate change mitigation include the use of bio-energy from different sources. The European Union has formulated sustainability criteria to prevent the possible negative effects of increased land use and conversion of natural ecosystems (EU, 2009; article 17.3).

These criteria prescribe minimum carbon efficiency, and exclude the use of natural areas and areas of high biodiversity value.

There is still much discussion about the indirect effects of increased bio-energy production caused by displacement of agricultural production to natural areas (Fargione et al., 2008; Searchinger et al., 2008). Indirect effects can be modelled but are difficult to monitor in practice. It is even more difficult to place the responsibility for indirect effects onto a single stakeholder (firms that produce bio-energy) because indirect effects are caused by global interacting markets (Ros et al., 2010). At present, different policy arrangements on indirect effects are explored in a European multi-stakeholder consultation process.

4.10 Overview of option effects

This section provides a summary of the effects of options compared on the indicators of natural area, wilderness area, and mean species abundance (MSA). We concentrate on terrestrial biodiversity. However, there are some caveats to bear in mind when comparing the effects of the options to reduce biodiversity loss. They are briefly mentioned at the end of this section (see also Chapter 7).

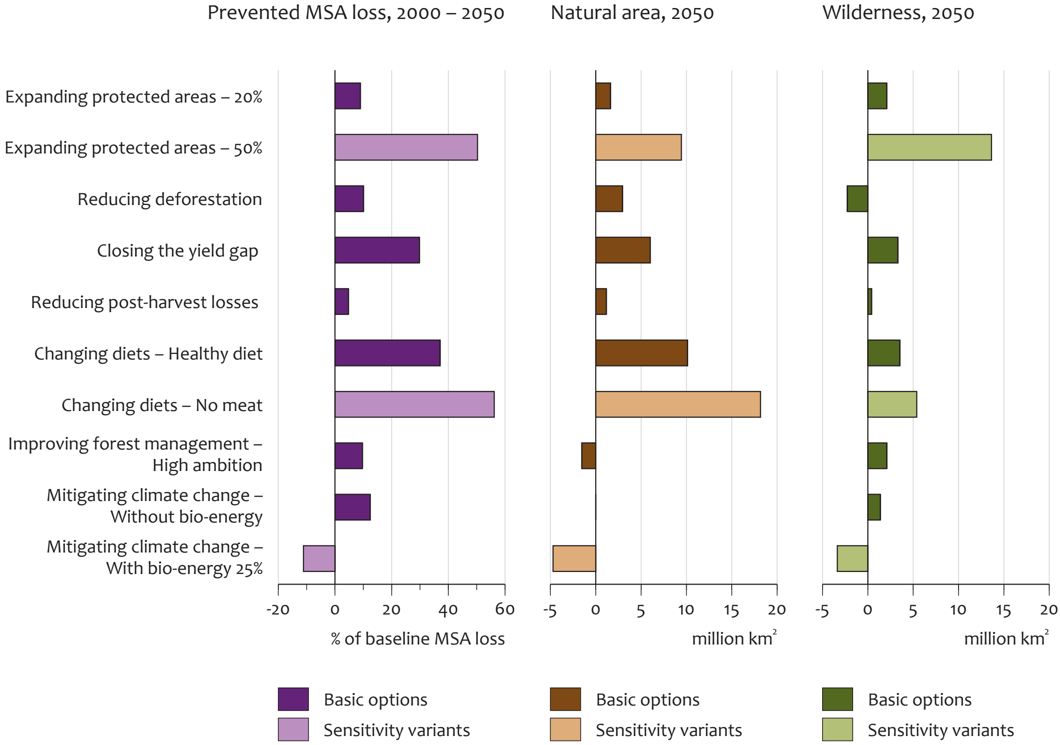
Most of the options considered in this chapter show a net positive effect on global biodiversity in terms of MSA natural area and wilderness. However, from the overview (Figure 4.31). It is clear that none of the options will be able to bring further biodiversity loss to a halt. While this implies that there is 'no silver bullet' for bringing biodiversity loss to a halt, we could determine an acceptable level of biodiversity, below which it is not to deteriorate any further.

Most options show a prevented MSA loss of around 10%, while closing the yield gap and a dietary shift could prevent more than 30%. All basic options, but one, increase the extent of natural area, and all but one increase the wilderness area. For natural area, a dietary change would yield the strongest savings (about 10 million km^2). For wilderness, the climate change option without bio-energy would have the largest effect (8 million km^2). However, like for the MSA indicator, much of the baseline’s loss cannot be reduced.

Options address drivers of biodiversity loss in various ways

The main drivers of biodiversity loss introduced in Section 3.1 are: i) expansion of agricultural area and associated change of habitats, ii) overexploitation of natural habitats (e.g., grazing and logging); iii) pollution (e.g., eutrophication), iv) invasive species and v) climate change. All but invasive species are mitigated by one or more of the options presented but in different ways and to different extents. Given these multiple pressures and distinct drivers, and the limited working range of each option, it is not surprising that no single option will be able to bring further biodiversity loss to a halt. Moreover, options often have trade-offs and rebounds, relieving one or more pressures only to see another increase, or see prices and demand for land respond. Thus, given the inability of one option to address all drivers of biodiversity loss, the 40% of prevented MSA loss and the gains in wilderness and natural area that would result from changing diets to healthier

Change in global biodiversity per option compared to baseline scenario **Figure 4.31**



Most of the basic options reduce losses in global biodiversity by 2050, on all three indicators MSA (left), natural area (middle), and wilderness area (right). Change in global biodiversity of options expanding protected areas and reducing deforestation by 2030.

levels is quite large. Part of that large effect is due to the ambition level set for the option, and another part results from changing consumption patterns instead of increasing efficiency with which a consumption pattern is satisfied.

Increased efficiency in economic sectors significantly reduces pressure

The options *Closing the yield gap*, *Reducing post-harvest losses*, *Improving forest management*, and *Reducing marine fishing efforts* all focus on production systems. Increasing production efficiency of crops, livestock, fish and also timber in the coming decades seems to contribute significantly to reducing future biodiversity loss. The extent to which the effect of these options overlap is explored in Chapter 5. Also, increasing production efficiencies may increase local impacts, as demonstrated by the eutrophication effects in the *Closing the yield gap* option. Global gains in efficiency and associated benefits for global biodiversity can imply large local impacts.

Benefits for climate change mitigation and food supply

Most options benefit climate change mitigation and food supply simultaneously while contributing to reducing biodiversity loss. Reduced conversion of natural habitats keeps carbon stocks and uptake capacity intact. A more efficient and less wasteful agriculture and food sector would contribute to stable food supply especially in developing countries. These effects are elaborated in Chapter 5.

Caveats when comparing the implications of the options for biodiversity

First, the level of implementation assumed for each option is not the technical maximum, but is a lower target that is ambitious but also more realistic (see Section 4.1). These targets have not been specifically selected for the purposes of this study and therefore differ in ambition level. Consequently, comparisons of the effects of the options on biodiversity must be made with due consideration to the level of implementation of each option.

Second, the possible effect of combining separate options cannot be estimated by simply adding up their individual scores. Options have implications for prices of land and commodities, allocation of agricultural production across regions and environmental pressures. A first attempt at combining options for identifying interactions and second-order effects is presented in Chapter 5.

Third, the three indicators presented focus on naturalness as representative of the state of biodiversity. They exclude rarity and risk of species extinction. Thus, it would be incorrect to state that a single option is better for biodiversity in all respects. This depends on the indicator used for or definition of biodiversity (see also Chapter 2).

4.11 Overview of the feasibility of options

In this report the analysis concentrates on issues of technical viability and performance of various options, implemented alone or in combination. Implementation costs were not estimated, neither in terms of direct (net) costs incurred by stakeholders, nor in the macro-economic terms GDP and welfare. For the combination of options the research team used its own judgement about the ambition levels of the included options (Chapter 5).

However, when considering measures to mitigate direct drivers of global biodiversity loss, more attention to issues of governance and diverging interests is necessary. This could on the one hand identify potential hurdles for implementation, and opportunities for implementation on the other hand (see for instance, Biermann et al., 2009). One way would be to assess the options on i) *technical feasibility* with consideration of relevant regional differences; ii) *in-built incentives* to what extent direct benefits can be expected for the actors involved; and iii) conflicting or coinciding interests outside the sectors in which an option is to be implemented. These aspects warrant further attention but are beyond the scope of this report.

Mainstreaming biodiversity and ecosystem services

One approach to reducing biodiversity loss is for the sectors to take into account the impacts on land use and biodiversity explicitly in decision making processes. This is called *mainstreaming* biodiversity and ecosystem services, moving biodiversity and ecosystem services concerns beyond their traditional biodiversity constituency and into related policy fields (sCBD, 2006; Kok et al., 2010; sCBD, 2010). It aims to make biodiversity a standard concern in the sectors that influence drivers of losses of biodiversity and environmental goods and services.

Mainstreaming biodiversity requires countries to put greater emphasis on policy coherence at national and international level, to ensure policy in one area does not increase the pressure on biodiversity unnecessarily. One way is to systematically proof policies for impact on biodiversity (sCBD, 2010). Another is to make valuation of ecosystem services in either monetary on non-monetary terms an integral part of decision-making on policies that impact ecosystems. Given that habitat loss and degradation is the largest pressure on biodiversity globally, land use planning policies are an important avenue to mainstream biodiversity concerns. Other avenues are consumer products and production systems, for instance through certification of product chains or by improved communication of consumer product footprint, and integration of biodiversity concerns in agricultural management. Trade-offs between policy fields will not disappear but mainstreaming biodiversity will help in an explicit treatment of these trade-offs, as well as using available synergies.

Benefits of mitigating indirect drivers are difficult to trace to specific locations

The effects of mitigating indirect drivers of biodiversity loss are more difficult to pinpoint at specific locations or ecosystems. In contrast, efforts to expand or improve protected areas are better able to show their benefits, for instance, by the numbers of species protected or ecosystems preserved. For example, it is not easy to trace or project where the environmental effects of a reduction in meat consumption or an increase in agricultural yields will exactly occur. This depends on a range of global, regional and not least local conditions: access to land, land prices, trade policies, capital and financing problems, labour costs and many others. This makes the benefits of policies that target direct drivers more elusive to pin down in terms of locations and number of endangered species saved. It also creates a responsibility gap and presents a governance issue. The same holds for improvements in more sustainable use of environmental goods and services, making it more difficult to promote and get public support for the required policies.

Results of a survey sent out to CBD national focal points

The focal points of the CBD parties were invited to respond to a survey, aimed at assessing perceptions on i) benefits to biodiversity, ii) desirability and iii) feasibility of the different options presented in this chapter. In total, eighteen questionnaires were returned with responses from all continents. Too few responses were received to make definite conclusions, or to investigate alternative option ambitions. The results seem to suggest that reducing meat consumption was evaluated low in terms of desirability and feasibility. In contrast, options that directly benefit forests, *Improving Forest Management* and *Reducing Deforestation*, scored high on perceived benefits to biodiversity as well as on desirability and feasibility. Other options, such as E*xpansion of Protected Areas* showed no clear pattern for perceived benefits to biodiversity desirability and feasibility (see also Annex A).

Combining options for reducing biodiversity loss

5

5.1 Design of the combination of options

The single options for protecting biodiversity compiled in Chapter 4 can significantly reduce biodiversity loss, but none of them can reduce biodiversity loss to zero for various reasons. Some biodiversity loss, for instance due to climate change, cannot be prevented. In addition, all options are not immediately effective but implemented over a period of time, and their effect is reduced by feedbacks and leakages. Most importantly, each option addresses only a single driver of biodiversity loss. Consequently, a smart strategy for reducing global biodiversity loss is needed that combines the most promising options. Such a strategy would prevent several of the side effects, feedbacks and leakages associated with the options could be prevented.

A combination of policies for reducing biodiversity loss has been designed and analysed. This combination should not be considered as an optimal mix of policies, but as an initial proposal that could be followed by further analysis and iterations in dialogue with policy makers. It is used to estimate the effect of ambitious yet feasible measures for reducing biodiversity loss. Additionally, this combination is used to analyse synergies and trade-offs between options.

In choosing the implementation level for the combination of options, the principle 'ambitious yet feasible' has been followed consistently across the options (Table 5.1). As cost curves and technical potentials are not available for the measures, this expert-based approach was considered the only possible way to combine the options. At our request, the secretariat of the Convention on Biological Diversity conducted an official survey on the desirability and feasibility of options for the Parties (Notification No. 2010-055). However, the 18 responses received were insufficient to build a second stakeholder-based combination of options (Annex A).

Seven options selected

The seven options included in the combination are presented in Table 5.1. It is assumed that changes in policy induce shifts in multiple sectors, reducing the

Combination of options and the assumptions and motivation for the implementation level

Table 5.1

	Assumption	Motivation
Expanding protected areas for 1) biodiversity and 2) carbon stocks	Globally, 20% of protected area covering a representative selection of the Earth's ecosystems, with a focus threatened and endemic species. In addition, protection of 9% of the global land area, containing carbon-rich vegetation in which forestry is allowed. This leads to a total of 29% in protected area.	A political target of 10% protection per biome has been agreed upon (CBD 2004; Decision VII/30). Currently, the CBD discusses to increase the target to 15-20% (GBO-3; sCBD, 2010).
3) Increasing agricultural productivity	Baseline yield improvement are increased by 50% (in OECD countries to a maximum increase of 1.5% per year).	The International Assessment on Agricultural Science and Technology Development (IAASTD, 2008) indicated that such an increase would be possible, based on increased investment in agricultural science and knowledge.
4) Reducing post-harvest losses	Worldwide agricultural losses are assumed to be reduced by one third (from 20 to 13%).	Assessed to be an achievable level, requiring reduction in losses at household level in developed countries, and mostly during storage in developing countries.
5) Changing diets to less meat consumption	Worldwide, consumption patterns slowly converge to a level of 50% above the consumption level suggested by a supposedly healthy diet (Section 4.6).	Historical evidence show limited ability to induce lifestyle changes through policies. Therefore, achieving a level of 50% above consumption level recommended for health reasons was implemented.
6) Improving forest management	Forest plantations are expanded to meet about 50% of timber demand by 2050. In addition, almost all selective logging is assumed to be based on Reduced Impact Logging (RIL).	Brown (2000) suggested that about 50% coverage of demand through wood plantation would be consistent with a high ambition level (see also Arets et al., 2010).
7) Mitigating climate change	2 °C / 450 ppm CO_2 eq concentration target, with additional bio-energy grown only on abandoned agricultural land.	International climate policy is currently considering limiting climate change to 2 °C, corresponding to 450 ppm CO_2 eq, for median climate sensitivity. This target is difficult to achieve without bio-energy use.

pressure of the major drivers of biodiversity loss. All options are assumed to be gradually implemented over the period 2010 to 2030.

Protected areas are assumed to expand significantly, both to conserve *biodiversity* and to protect their natural *carbon stock*. Furthermore, higher improvement in *agricultural productivity* than in the baseline is assumed as a result of increased investment in agricultural research and dissemination of knowledge and technology. The combination of options also assumes *reduction in post-harvest losses* across the globe, and diets are assumed to change, specifically with regard to meat content. In addition, *forestry* is assumed to switch to more sustainable practices in those areas where timber is harvested from natural forests, and to more intensive forestry plantations. Finally, the combination of options assumes ambitious climate policy, corresponding to the 2 °C target and achieved with low contribution of biofuels.

Degree of implementation: ambitious yet feasible

As described above, the principle of 'ambitious yet feasible' has been applied consistently in all options. Criteria used in setting the target for each policy option include: 1) existing international policies (e.g., on climate change); 2) indication in the literature of achievable levels (e.g., closing the yield gap); and finally 3) expert judgement on implementation levels of a similar ambition. The degree to which each option has been implemented in the combination of options is presented in Table 5.1. To follow similar ambition in all options, the implementation levels are sometimes different from those presented in Chapter 4. The reasons for selecting a particular degree of implementation are also explained.

Starting from a baseline scenario, the different options for protecting biodiversity have been introduced stepwise in the order shown in Table 5.1. The individual steps allow for analysis of the effect of each additional option. The analysis uses a slightly updated baseline scenario on that described in Chapter 3 (Box 3.1) including a post-banking-crisis economic baseline. However, baseline projections are little affected by this update.

Restoration of wild fish populations was identified in Chapter 4 as being of considerable benefit to marine biodiversity. This option has not been included in the combination because of the very limited interplay of its effects with the other options. However, it is an important element in efforts to restore marine biodiversity. It was shown to have a significant beneficial effect on catches, and could improve aspects of future food production, food security, and employment in fisheries (see Section 4.8).

5.2 Global biodiversity under the combination of options

Starting from a baseline scenario, the effect of the combination of options on global biodiversity was analysed in terms of mean species abundance (MSA), natural area and wilderness. As described above, the combination of options is not necessarily the best possible strategy for reducing biodiversity loss, but rather an

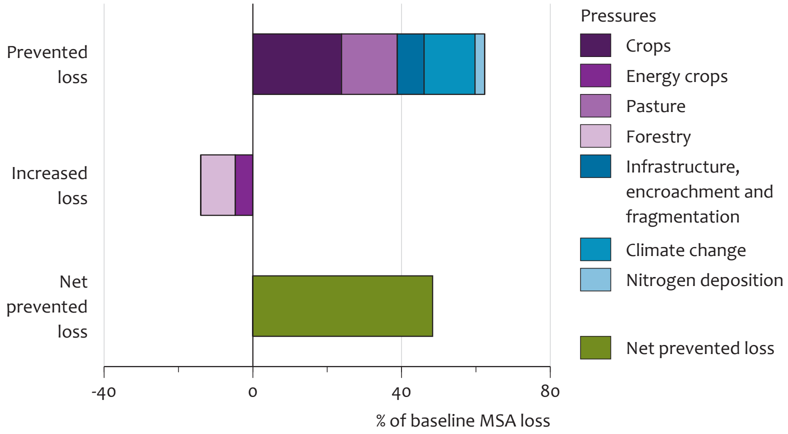
Box 5.1: Deforestation for agricultural use

To understand the land-use dynamics in forest biomes, developments in the agricultural and forestry sectors need to be analysed. When forest conversion to agricultural use takes place (deforestation), the tree biomass removed is used to meet regional wood demand. In addition, agricultural expansion will also preferably occur in areas cleared earlier by timber harvesting because these areas are more accessible. The entanglement of deforestation processes, timber exploitation and agricultural expansion has been documented extensively (FAO, 2001; Rodrigues et al., 2009; Achard, 2002; Geist and Lambin, 2009). In the IMAGE model, this is dealt with by applying similar suitability maps to the allocation of timber harvest and agricultural expansion. As a result

In the baseline, about 26% of global expansion in agricultural land occurs on primary grasslands and forests, the remainder on land previously cleared by timber harvesting. With reduction in agricultural expansion in the combination of options, wood supply from converted forests also decreases. As a result, more area is cleared only for timber harvesting, and thus the effect on biodiversity loss is attributed to forestry alone. Due to this effect, the impacts on forestry of the combination of options are larger than in the baseline scenario, even though improved forest management has been applied (see forestry option in Section 4.7).

Prevented global MSA loss compared to baseline scenario, 2000 – 2050 **Figure 5.1**

Combination of options



With a combination of options, MSA loss between 2000 and 2050 under the baseline is reduced by about 50%.

initial compilation of options and implementation levels. In that sense, the results are specific to our modelling approach, occurring under the chosen option settings.

Biodiversity loss in terms of MSA will be reduced by about 50%

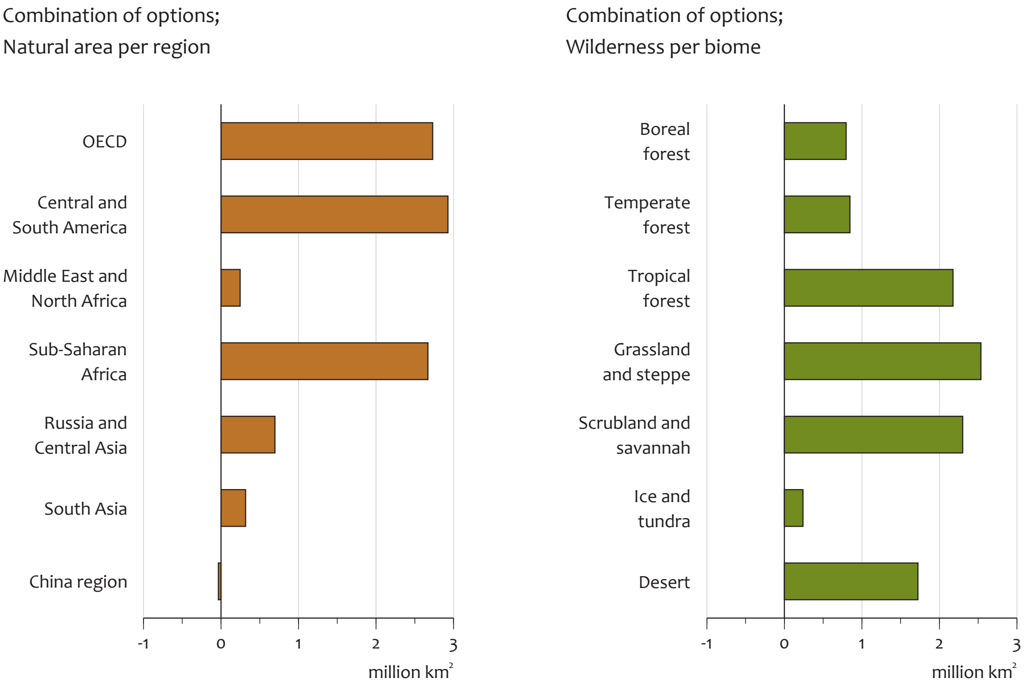
The combination of options prevents global MSA loss by about 50% compared with the baseline over the period 2000 to 2050 (Figure 5.1). This is about 60% of the loss from 2010 onwards and is more than resulting from any realistic single option (Section 4.10). This prevented MSA loss is to a large extent achieved by reducing land expansion for crops and grazing (resulting from options 1-5), and by reducing climate change. Cropland area, which is projected to increase in the baseline scenario by 5.5 million km², would increase by 2 million km² in the combination of options (for reference: Brazil is some 8.5 million km² in area). The projected MSA loss due to climate change in the baseline scenario (over the period 2000-2030) can be reduced by about two thirds in this combination of options. As part of climate policy, additional biofuels on abandoned land lead to some additional loss in MSA.

Despite strong measures in forest management (Reduced Impact Logging and forest plantations), there is an apparent increase in forestry impact. This counter-intuitive effect appears to be a side effect of successful measures against agricultural expansion. Less agricultural expansion forces the wood sector to increase production from ‘real forestry’ instead of one-off clearing practices (see Box 5.1).

Effects on Ecosystem Extent

The combination of options would strongly reduce the losses in the total natural area by 2000 and 2050, resulting in an additional 10 million km² of natural area in 2050 compared to the baseline (Figure 5.2). Thereby, global natural area in the

Figure 5.2 **Change in natural area and wilderness compared to baseline scenario, 2050**



The total natural and wilderness areas increases by 10 and 11 million km² under the combination of options by 2050, compared to the baseline.

combination of options is back at 2000 levels, though regional. Most savings would occur in OECD countries, South America, and Sub-Saharan Africa. The area of highly intact nature would increase even further by about 11 million km² in 2050 compared with the baseline, preventing 60% that would have occurred in the baseline. Here, the largest absolute improvement would occur in grassland and savannah systems followed by tropical forests and then other forest systems. The increase in wilderness area in desert systems is mostly related to the reduced impact of climate change and nitrogen deposition there.

The combination of options cannot halt biodiversity loss

Some of the projected biodiversity loss in the baseline cannot be prevented. For instance, not all biodiversity loss caused by climate change can be prevented because the mean global temperature will still increase even under ambitious climate policy. Furthermore, a substantial contribution to the projected biodiversity loss in the baseline comes from infrastructure and fragmentation (Figure 5.3). This study does not include measures to specifically reduce these pressures, and the resulting MSA loss is thus not reduced compared to the baseline. In reality, developed countries might be able to reduce the impact of additional infrastructure compared to baseline development, but this is less likely in low-income countries, given the expansion of infrastructure required for development.

The effects of the options differ over time

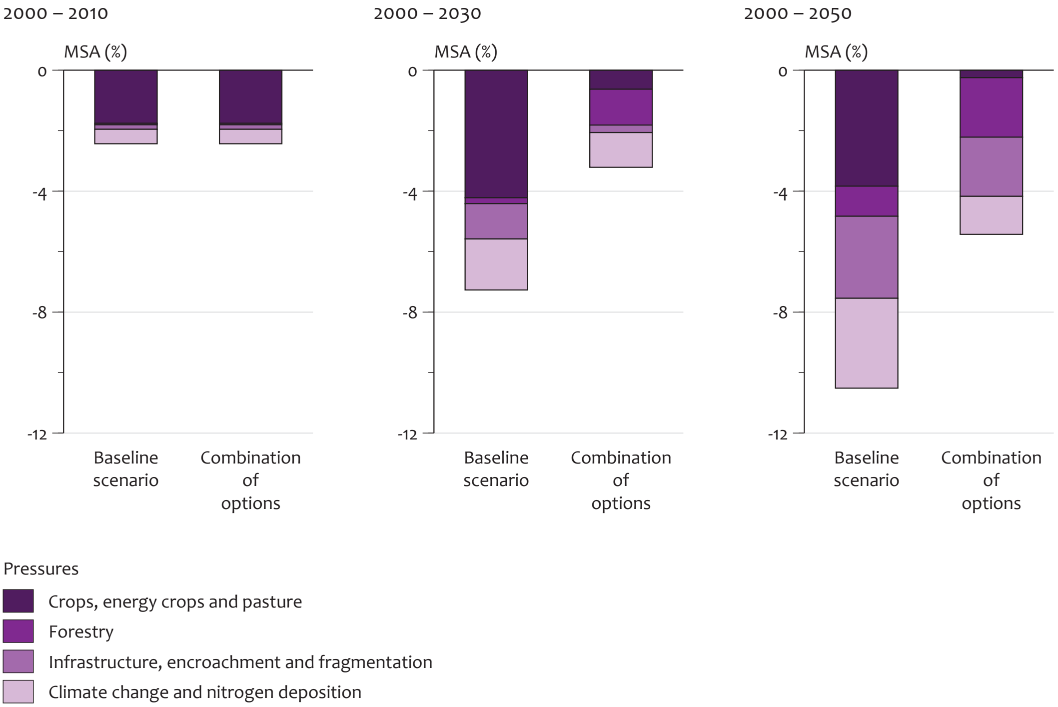
Pressures on biodiversity and the effects of options develop differently over time. In the baseline, pressure from cropland and pasture expansion increases most strongly up until 2030, and thereafter levels off, while pressure from forestry and climate change continue to increase between 2030 and 2050 (Figure 5.3). Consequently, options that limit agricultural expansion need timely implementation because restoration later will not lead to complete recovery of biodiversity, and is also expected to be more costly. These options (expanding protected areas, increasing productivity, reducing waste, and dietary transition) would all have an immediate effect from a technical point of view, but take many years to implement (see Chapter 4). Conversely, the benefits for biodiversity from climate change mitigation only become effective after a considerable time lag due to inertia in the climate system, and will continue increasing beyond 2050. Likewise, the shift to more sustainable forestry would only benefit biodiversity after some time, because new but highly efficient forestry plantations take decades to grow. Therefore, early implementation is crucial for all options related to agricultural expansion, forestry and climate policy.

Losses are not distributed equally across regions and biomes

Projected biodiversity losses in the baseline scenario as well as in the combination of options are not distributed equally over regions and biomes. In 2010, the extent of natural area has already been reduced, most strongly in Sub-Saharan Africa, South Asia, and China. These regions will see further loss up until 2050 under the baseline, most strongly in Sub-Saharan Africa (Figure 5.4). The apparent small reduction in natural area for all regions together is because they contain vast areas of ecosystems that are not under pressure from land-use change, such as deserts, polar, and tundra, and large parts of the boreal forests. Under the combination of options, the largest relative gains in natural areas are achieved in Sub-Saharan Africa, South America, and OECD countries. Considering the extent of pristine ecosystems (wilderness; Figure 5.4), large proportions have already been lost in 2010 in savannah and grassland systems, as well as in forests, with less than 15% of temperate forests left. Under the baseline, further loss is again strongest in these ecosystems. This is caused by the main macro drivers of population growth and economic development increasing most in regions where the prevailing biomes used for agricultural expansion are tropical grassland, shrubs or forests. The combination of options would significantly limit further loss of these systems.

Under the combination of options, much of the remaining reduction in natural and wilderness areas occurs in the savannah systems of Sub-Saharan Africa (Figure 5.4). This region is projected to see the largest increase in demand for agricultural products for which increasing yields cannot compensate. Agricultural expansion is large in this area and comes at the cost of grassland and savannah, especially because forests have preferential protection because of their carbon content, and are under less pressure because they are less suited for agriculture and are less accessible. The largest gain in natural area under the combination of options is in OECD countries and South America. This is partly related to higher meat consumption and extensive pasture in South America. Thus, dietary transition has the largest effect, causing a strong decrease in agricultural area.

Figure 5.3 **Pressures driving global biodiversity loss**



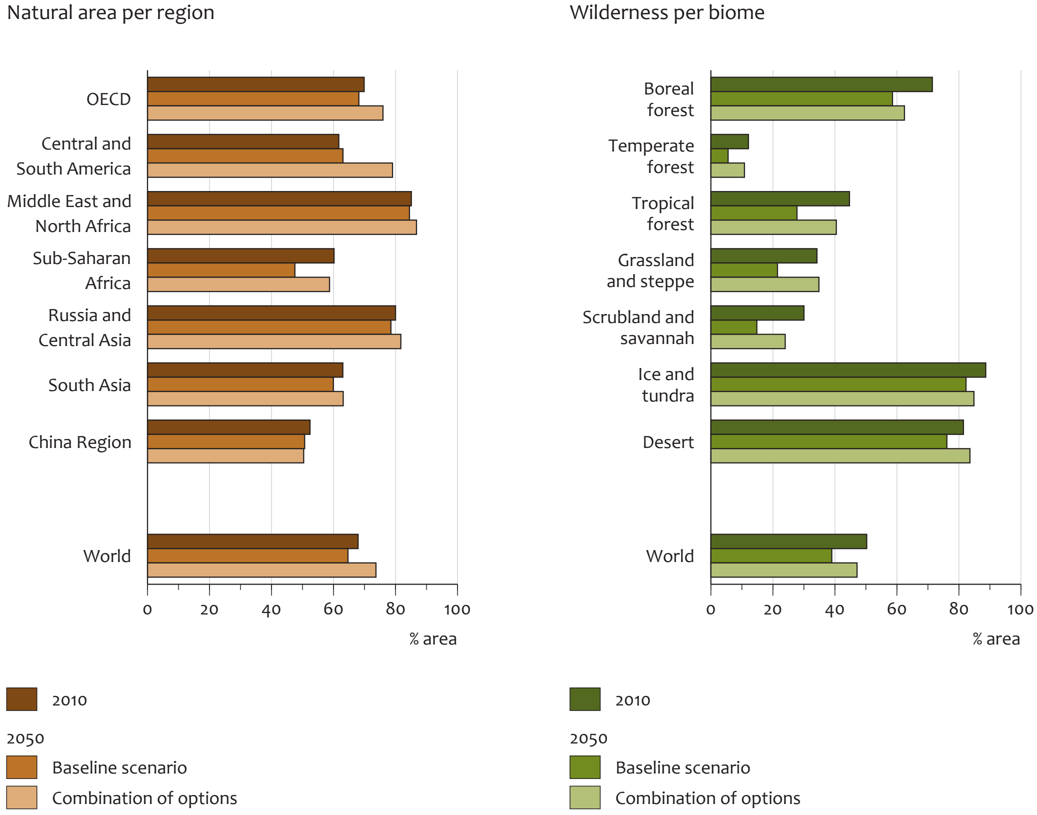
Pressures on MSA change differently over time, and are differently affected by the combination of options: (i) While agricultural expansion has the largest impact up until 2030 in the baseline, climate changes is an important driver even beyond 2050. (ii) The combination of options almost prevents crop and grassland expansion by 2050, and reduces pressure from climate change by two thirds, but no measures are taken to reduce pressure from infrastructure and fragmentation.

In addition to differences on an aggregated level, biodiversity will differ between areas within regions and biomes (Figure 5.5). The used models allocate land-use and other pressures on a fine scale (see Annex B), but these results are more uncertain due to imperfect allocation rules.

Measures are supplementary: one could prevent feedbacks of another

The single options showed that benefits may leak away as higher agricultural productivity or reduced post-harvest losses lead to a decrease in land and commodity prices, and finally to an increase in consumption (Sections 4.4 and 4.5). Yet, ambitious protection scenarios would increase land scarcity and commodity prices, and thus reduce consumption and affect food security (Section 4.3). The combination of options reduces these effects because measures that increase prices of land and commodities (expansion of protected areas for biodiversity and REDD) are combined with measures that decrease these prices (productivity increase, reduced post-harvest losses and dietary change). While land prices strongly increase when

Share of natural area and wilderness **Figure 5.4**


Natural area per region

Wilderness per biome

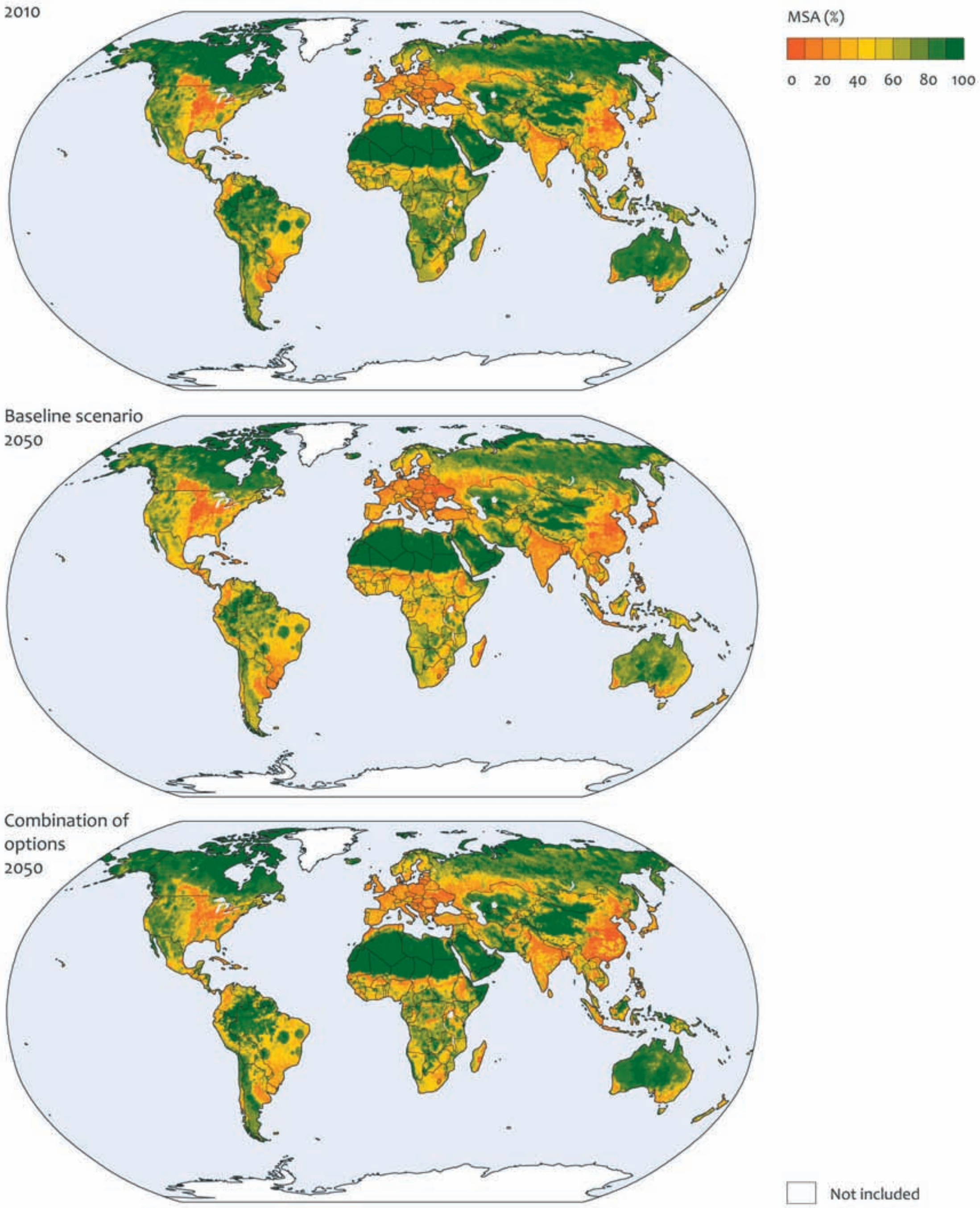
Under the combination of options by 2050 the largest gains are in natural areas in OECD countries, Central and South America, and Sub-Saharan Africa, and the largest gains in wilderness area are in temperate and tropical forests, and in grassland and savannah systems.

introducing extended protected areas, land prices again fall under the subsequent options (Figure 5.6). Complementary, food consumption first decreases under the high land prices, and then increases again (see also Section 6.1). Consequently, the effect of leakages and feedbacks can be reduced by the combination of options, and strong shocks on the agricultural markets and in food prices can be prevented.

Relative contribution of options to reducing agricultural area

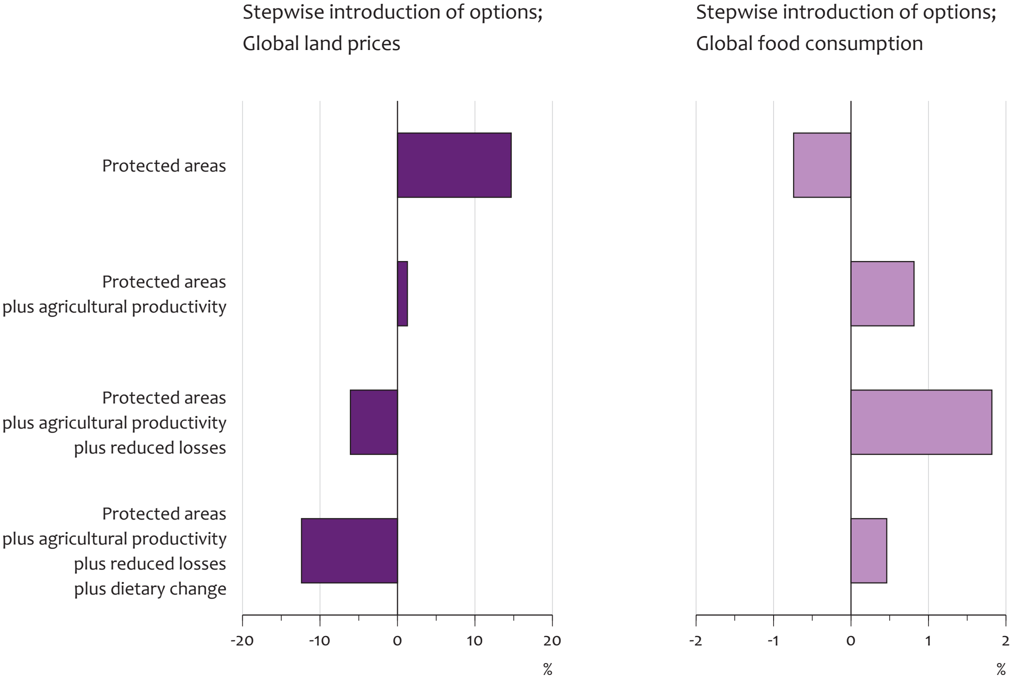
The first four options in the combination all lead to a reduction in agricultural area. In order to compare their relative contribution, changes in agricultural area were analysed during stepwise introduction starting from the baseline (Figure 5.8). The largest additional effect on reducing cropland area is achieved by increased agricultural productivity, saving more that 1.5 million km², followed by further 1 million km² due to reduced post-harvest losses. By far the largest reduction in grassland area is achieved by the dietary change, because grazing livestock numbers (cattle, sheep and goat) are reduced. The decrease in meat consumption leads to a reduction in

Figure 5.5 **Terrestrial Mean Species Abundance**



Global maps of terrestrial mean species abundance (MSA) for the baseline in 2010 (top) and 2050 (middle), and for the combination of options in 2050 (bottom).

Change in land prices and food consumption compared to baseline scenario, 2030 **Figure 5.6**



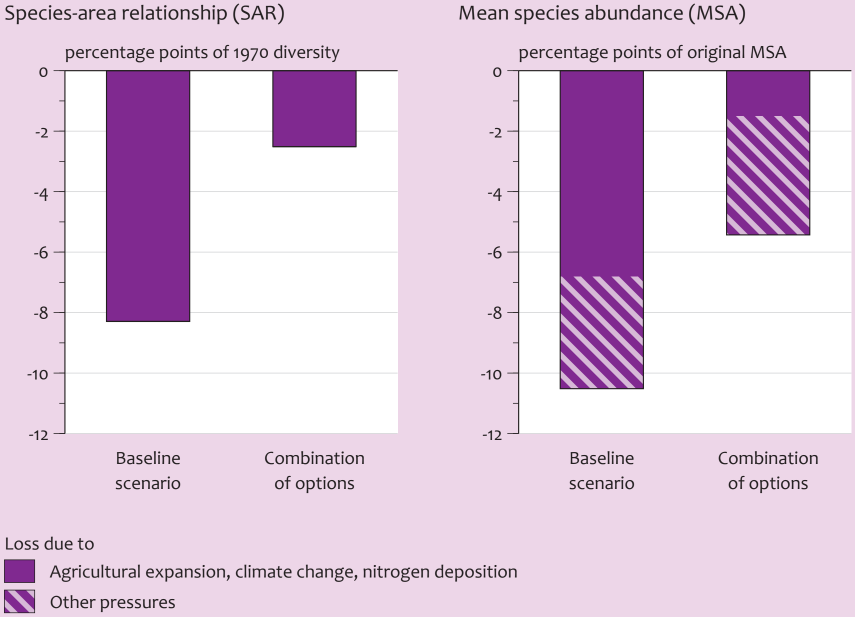
In the combination, the options have different effects on land prices and consumption. While extended protected areas increase land prices and reduce consumption, the subsequent improvement in agricultural efficiency and dietary change decrease land prices and lead to an increase in consumption.

Box 5.2: Loss of vascular plant diversity

In addition to the MSA biodiversity indicators, the SAR-based biodiversity indicator, developed by van Vuuren et al. (2006), was used to assess trends in potential loss of vascular plant diversity on a global scale (Chapter 2).

Similar to the MSA indicator, the SAR indicator shows further decline of biodiversity over time under the baseline scenario (Figure 5.7). The main driver for this is habitat conversion (land-use change), but climate change and nitrogen deposition also reduce plant diversity. The decline in the 2010-2050 period is very similar to that of the 1970-2000 period (not shown), resulting in an additional 8 percent points of all vascular plant species to become threatened with extinction in 2050. The combination of options would significantly reduce the decline to slightly more than 2 percent points.

Figure 5.7 **Change in global biodiversity, 2000 – 2050**

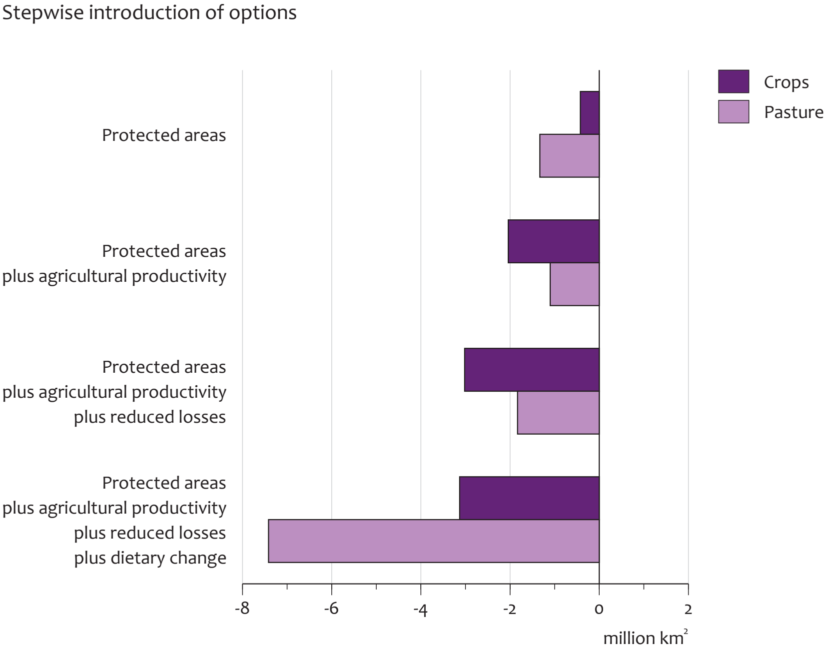


The MSA and SAR indicators give similar results when focusing only on the pressures covered by both indicators (agricultural expansion, climate change and nitrogen deposition).

Thus, the prevented loss in the SAR based indicator (about 70%) is higher than the prevented loss as measured with the MSA indicator (about 50%). This is partly related to the different underlying concepts (plant diversity across biomes versus ecosystem intactness). Most importantly, however, this difference is caused by the fact that SAR does not cover the pressures infrastructure development, forestry and the consequences of fragmentation and encroachment, while they are included in the MSA indicator. If the MSA results for only habitat loss, climate change and nitrogen-deposition are compared to the SAR results, the outcomes become much more similar (Figure 5.7). For the other remaining MSA pressures, we can note again that they are hardly reduced in the combination of options, as for instance no options to reduce the impact of infrastructure are readily available that could be implemented in the present model-framework (see also Figure 5.3 and Chapter 7).

In the development of biodiversity indicators for scenario studies it is important to include all relevant pressures for biodiversity loss, and thus, SAR-based indicators should be extended in the future (Laurance, 2006). So far, however, we can conclude that MSA and SAR give similar results when focusing only on the pressures covered by both indicators.

Change in agricultural area compared to baseline scenario, 2030 **Figure 5.8**



The area of cropland and pasture in 2050 (compared to the baseline) is gradually reduced with stepwise introduction of options.

feed crop demand, but is partly compensated by additional food crop consumption. Therefore, there is little change in cropland area in this option. Increasing protected areas for biodiversity and their carbon stocks at the chosen implementation level reduces total agricultural land by about 2 million km^2 and affects the location of additional area across biomes (see also Sections 4.2 and 4.3).

Biodiversity measures contribute to climate change mitigation

The combination of options assumes the introduction of measures that limit climate change to 2 °C or 450 ppm CO_2 eq concentration. This reduction comes partly from the land-use related measures introduced to reduce biodiversity loss. The combination of options would reduce the cumulative CO_2 emissions from land-use change by about 60 Pg CO_2 over the period 2010 to 2050 (see Section 6.2). The remaining emission reduction necessary to reach the 2 °C target is still large, and is mostly achieved by reducing emissions from the energy sector. However, part of the contribution comes from an increase in bio-energy use. The controversy about bio-energy use and impact on biodiversity is briefly discussed in Section 4.9. The bio-energy use in the combination of options is limited, and only allowed on abandoned agriculture land, thus preventing bio-energy to impact on current nature areas. There is still a trade-off as the same land could have been used for reforestation or left to recover to its natural state.

6

Effects on poverty, water, climate change and competing claims

This chapter discusses cross-cutting issues, and shows the relevance of options for food availability and long-term human development, climate change, and inland water quality. The last section elaborates on increasing competing claims on land.

6.1 Impacts on food availability and long-term human development

- Options for reducing biodiversity loss may go hand-in-hand with rural development and improved food availability. The combination of options would result in a global increase in food availability and reduction in food prices, hence increased progress towards eradicating hunger and mitigating related health issues. However, these effects will vary greatly between regions and between different groups of people within regions; and strongly depend on how the options are implemented. This implies that measures to reduce biodiversity loss and to promote human development require a concerted approach.

In 2000, the international community made a commitment to the Millennium Development Goals (MDGs). Since then, the MDGs have been the leading agenda for international policy on development and sustainable poverty reduction. This series of quantitative and time-bound targets are directed to reducing extreme poverty and hunger, to improving basic services for people such as health care, education and ensuring a healthy environment, and to creating a global partnership to enable these goals to be achieved. One of the targets is reducing biodiversity loss. As many options for reducing biodiversity loss imply changes in agricultural production and income, they also impact human development, poverty, hunger and health. Therefore, the link between biodiversity and agriculture is relevant to this study.

The target year for the MDGs is 2015. However, underlying long-term dynamics, including feedbacks and trade-offs with the environment, require an integrated, long-term perspective to designing policies. If not, then MDG achievements may not be sustainable beyond 2015 (Bourguignon et al., 2008). Analysis with the GISMO model shows that progress towards many of the MDGs can be expected, also beyond 2015. Yet, this progress is not sufficient to achieve all targets in all regions (PBL, 2009). By far the greatest progress is expected in East Asia, where high economic growth facilitates rapid development. In contrast, poverty will become more concentrated in Sub-Saharan Africa and South Asia and will increasingly become not only rural but also an urban problem. Despite the projected increase in global food production by 2015, 700 million people will still be living on less than the minimum required dietary energy consumption, most of them living in Sub-Saharan Africa and South Asia. Towards 2030, the situation will improve little, mainly because of the ongoing rapid increase in population in food-insecure countries.

Reducing child mortality might be one of the most difficult targets to achieve. In 2004, approximately 53% of all child mortality was related to under-nutrition (WHO, 2009). Without additional policy, Sub-Saharan Africa will not reach its 2015 target (not even by 2030) with under-nutrition being the major determinant. Just as in today's world of 'hunger amidst plenty', increasing global food production will not be sufficient to achieve the MDG targets on hunger and health. Poverty reduction and more stable food prices are also required, especially in the most food-deprived regions (UN Millennium Project, 2005).

The impact of the combination of options for reducing biodiversity loss (Chapter 5) on global and regional food security in 2030 is presented in Figure 6.1. Globally, the combination of options increases food security (decreasing food prices and increasing consumption), thus increasing progress towards eradicating extreme hunger and mitigating related health issues. Closing the yield gap, reducing post-harvest losses and changing diets decrease land and food prices and improve food availability. Expanding protected areas and reducing deforestation increase land and food prices and decrease food availability.

In most regions food security improves, with the largest improvements in South Asia. Sub-Saharan Africa and Latin America profit far less due to large negative impacts from expanding protected areas and reducing deforestation. Both regions have large potential for these options. Closing the yield gap, reducing post-harvest losses and changing diets all have positive impacts on food security, and offset the negative effect for Sub-Saharan Africa and Latin America. However, the effect for Sub-Saharan Africa is relatively small because their economies are less integrated into the global market and thus do not profit greatly from decreasing world market prices. China is confronted with overall negative impacts on total consumption, which is the result of changing diets, where the shift to less meat is not fully compensated by increased consumption of crops. As China is projected to have a high level of food consumption in 2030, this does not greatly impact on their overall food security.

However, these regional impacts are rather crude and aggregated. At the local level, these effects could vary significantly and depend strongly on economic factors, as well as on social and institutional factors and on how the options are introduced. Location-specific measures largely determine the social and economic benefits for various groups of people. Most poor and under-nourished people live in rural areas and depend on farming for their livelihoods (Cervantes-Godoy and Dewbre, 2010). They are mainly subsistence farmers who also earn some cash by

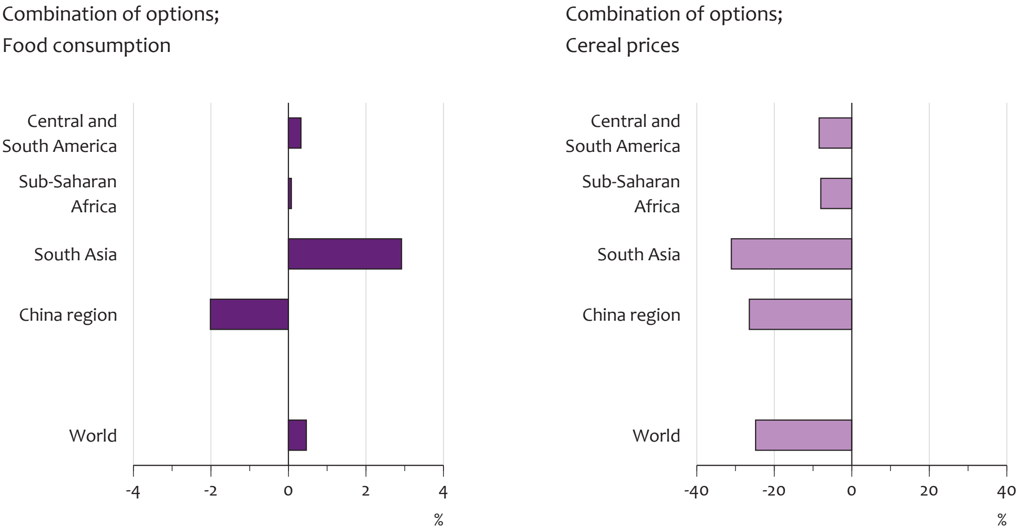
Improving food security is a key to sustainable development.

selling part of their produce. In general, these farmers are negatively affected by decreasing food prices. This holds even more so for commercial farmers. Landless agricultural workers do not automatically benefit from increasing food prices, but when prices decrease they are more vulnerable to loss of income. The urban poor generally depend entirely on the market for food and thus benefit from decreasing food prices. Hence, at country level and even more at local levels, the effects of the options on poverty and hunger need to be analysed with regard to different types of producers and consumers.

The list below provides an indication of the main effects of the individual options on various groups. As the set of models cannot be used to address poverty impacts in such detail, a qualitative indication is given that is very rough and by definition incomplete:

- *Expanding protected areas* and *reducing deforestation* will impose additional limits to expansion of agricultural land and generally increase food prices and decrease food availability, especially in areas with high REDD potential. In addition, communities directly affected would face restrictions in their development opportunities. Commercial producers outside the protected areas could benefit from higher prices as well as from environmental services provided by the protected areas.
- *Closing the yield gap* through productivity-increasing technologies will decrease food prices and increase food availability, especially in regions where yield gaps are widest. How farmers are affected largely depends on their access to the new technologies and how well they are connected to the market. More technologically advanced farmers and their employees might benefit, whereas other farmers and farm workers might be driven further into poverty as a consequence of lower product prices and possibly fewer on-farm jobs.

Change in food consumption and cereal prices compared to baseline scenario, 2030 **Figure 6.1**



The combination of options increases food security at the global level, which is the result of decreasing food prices and consequently increasing consumption.

- *Reducing post-harvest losses* will decrease food prices and increase food availability. The impacts of reducing losses in the food supply chain depend greatly on the location (on-farm losses or losses further down the supply chain) and whether a region is a net importer or exporter of food. Reducing on-farm losses will have similar effects as closing the yield gap. The untapped potential to reap the benefits is particularly large in developing countries dominated by small-scale farming. Reduced losses further down the supply chain will benefit retailers and/or consumers, while producers will face lower prices for their produce. These effects would be small, as long as demand is high and agricultural expansion is kept in check, for instance by protecting areas and reducing deforestation.
- *Changing diets* will lead to a decline in the demand for feed cereals, many of which are also suited for food mainly in wealthy countries and major food or feed exporting countries. These effects will partly spill over to other countries, with lower food prices and increased food availability for those importing food. Overall, the incomes of producers will decline. Rich countries and countries with large agricultural exports will have to restructure their agriculture and agri-business sectors. However, the effect will probably be small in the rural areas of the poorest nations that are shielded from world market effects by logistic barriers.

The diversity in effects implies that measures to reduce biodiversity loss, enhance access to food, and alleviate poverty require a concerted approach. Region-specific accompanying measures would be needed to prevent partial failure in any of these areas, which would eventually undermine progress in the others. For example,

A robust energy system includes a broad portfolio of energy sources and improved efficiency.

substantial reduction in deforestation and expansion of protected areas seems only viable if food availability is enhanced by increased yields and reduced losses. The reverse is also true: there is no incentive to reduce food losses and close yield gaps if abundant land for agriculture is available (Lobell et al., 2009) or when consumers do not have the purchasing power to buy food at affordable prices.

6.2 Impacts on carbon fluxes and climate change

- The combination of options would reduce the cumulative CO_2 emissions from land-use change by about 20%, in contributing to the 2 °C climate target. Abandoned agricultural area (0.8 million km^2 by 2050) could be left to recover, thus adding to the carbon stock when land cover has re-grown. The options for sensitivity analysis (not included in the combination of options) may individually contribute 15 to 30% in required CO_2 emission reductions for achieving the 2 °C climate target. Effects on emissions of non-CO_2 gases might contribute a further reduction of 10%.

Impacts of single options

Several of the individual options also influence climate change, mostly by reducing greenhouse gas emissions from land-use change (Table 6.1). Vegetation in general, and forests in particular, form important carbon stocks. Globally, forests store

Expected option-related impacts on greenhouse gas emissions in the period from 2000 to 2050 **Table 6.1**

Options	Expected impact on climate change
Expanding protected areas	Positive impact on carbon balance if carbon-rich ecosystems are protected.
Reducing deforestation	Positive impact on carbon balance as a result of prevented deforestation.
Closing the yield gap	Positive impact on carbon balance as a result of prevented deforestation/ reforestation. Possible negative impact on N_2O balance due to higher fertiliser use.
Reducing post-harvest losses	Positive impact on carbon balance as a result of prevented deforestation/ reforestation.
Changing diets	Positive impact on carbon balance as a result of prevented deforestation/ reforestation and reducing non-CO_2 emissions from livestock.
Improving forest management	Diverse impacts on carbon stocks and time dependent. Net impact is small to moderate.
Mitigating climate change (with and without of bio-energy)	Leads by definition to large decrease in greenhouse gas emissions. Specific contribution of bio-energy depends on policies, fossil-fuel prices and technology.
Reducing wild fish capture	Possible indirect impacts via dietary changes (replacement of reduced fish consumption.

about half of the total terrestrial carbon (above and underground; van Minnen, 2008; van Minnen et al., 2009). Deforestation currently contributes about 20% of the total annual CO_2 emissions.

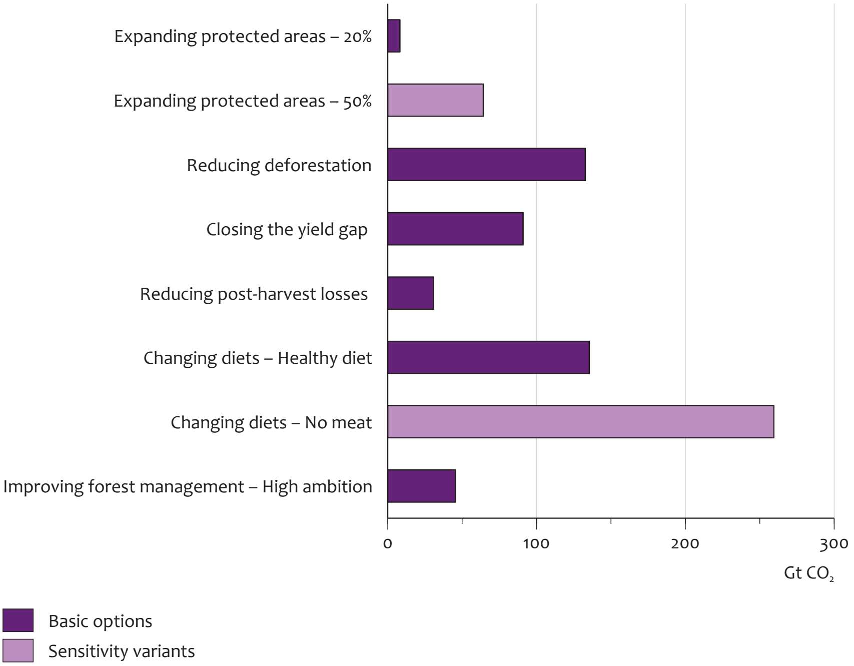
There are several dynamic relationships between land-use changes and carbon fluxes. Firstly, land-use change directly causes greenhouse gas *emissions* due to emissions directly associated with deforestation, known as anthropogenic emissions. In the baseline scenario, deforestation leads to significant sources of CO_2 emissions. Secondly, land-use change also influences total *uptake* of CO_2 by natural vegetation. Currently, the total natural biosphere is an important *net* sink (i.e. including deforestation). This results from elevated atmospheric CO_2 concentration (carbon fertilisation), but probably also from nitrogen fertilisation and earlier disturbance of natural areas. According to IMAGE-model calculations, the natural biomass will continue to act as a net sink in the baseline – leading to a net uptake of CO_2 (net carbon flux) by the biosphere (of about 200 Gt CO_2).

The options influence anthropogenic and natural emissions. The first occurs through deforestation and afforestation and its contribution tends to become smaller over time. For instance in afforestation, the carbon uptake takes place during the growing stage of the forest and ends after forests reach a mature state. Secondly, an increase in natural areas also implies an increase in natural uptake by ecosystems. The differences between the options for 'natural' carbon flux are relatively small. This implies that changes in the net carbon uptake are almost completely related to direct anthropogenic impacts.

This section focuses on increasing productivity, changing diets, decreasing deforestation, and improving forest management (Figure 6.2). These options could reduce land-use related CO_2 emissions by over 300 Gt CO_2 between 2000 and 2050 (no-meat option). Several options would reduce emissions by around 100-130 Gt

Figure 6.2 **Change in carbon in the biosphere compared to baseline scenario, 2050**

Per option



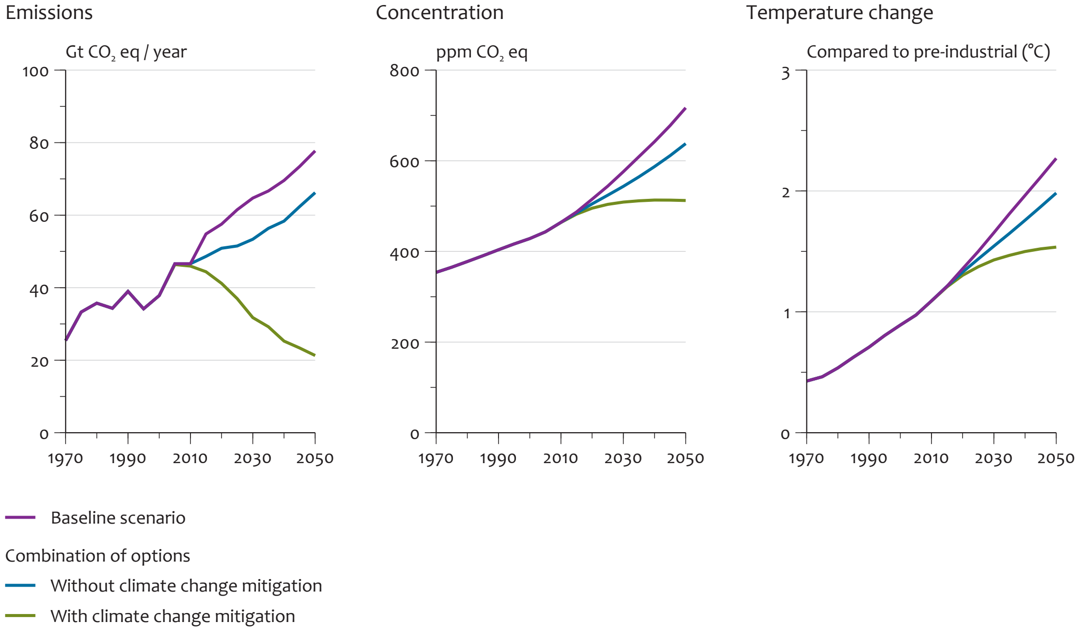
Most options lead to an additional net uptake of CO2 by the biosphere compared to the baseline. Change in carbon in the biosphere of options expanding protected areas and reducing deforestation by 2030.

CO_2 (improved productivity, healthy diet, deforestation reduction). The impact of improved forest management would be between 10 and 40 Gt CO_2. In terms of atmospheric concentration, this equals a range of 0 to 25 ppm CO_2.

The importance of these carbon fluxes can be shown by comparing them to the total emission reductions required to limit the increase in global mean temperature to 2 °C (with a probability of more than 50%). In typical baseline scenarios, the expected total greenhouse gas emissions in the 2000-2050 period is 2750 to 3000 Gt CO_2 eq. For a 2 °C scenario, these emissions need to be reduced to around 1800 Gt CO_2 eq, a reduction of 900 Gt CO_2 eq or 35% of cumulative emissions. This implies that the impacts on CO_2 emissions may be equal to up to 30% (no-meat option) or 15 to 20% (options included in the 100-150 Gt CO_2 range) of the required emission reductions.

Some options (changing diets changes and reducing post-harvest losses) also decrease the non-CO_2 emissions associated with agriculture, such as methane emissions from rice and livestock and nitrous oxide emissions from fertiliser use.

Global greenhouse gas emissions, concentration and temperature change **Figure 6.3**



Even without explicit climate policy the combination of options leads to a reduction of greenhouse gases compared to baseline. However, this reduction is not sufficient to achieve the 2 °C target.

These contributions can also be substantial. The impacts on non-CO_2 gases might involve a further 180 Gt CO_2 eq (10%) in the case of the dietary change scenario (Stehfest et al., 2009). In contrast, productivity increase may also lead to higher emissions if it coincides with a reduction in fertiliser efficiency.

In some cases, there might be a trade-off between biodiversity protection and climate change policy. Forest protection provides a substantial reduction in cumulative carbon emissions. As a consequence, agriculture expands mostly in non-forested land with often lower soil productivity, resulting in larger expansion and larger habitat loss.

Stehfest et al. (2009) assessed the prevented costs under 'explicit climate policy' as a result of dietary changes. Mitigation cost was found to be between 50 and 70% less, over the 2000-2050 period (about 0.3 to 0.5% of GDP instead of 1%). The numbers are relatively high because the dietary measures avoid the high costs range of the more conventional measures.

Impact of the combination of options

In order to identify the co-benefits of the combination of options, reduction in greenhouse gas emissions of all land-use related measures1) was compared with the emission reduction from 'conventional climate policy' to achieve the 2 °C climate target. The latter is the 'bio-energy-poor climate change mitigation option' included in the combination of options. This combination would reduce the cumulative emissions of CO_2 from land-use change by about 100 Gt CO_2 over the 2010-2030 period, and by 220 Gt CO_2 over the 2010-2050 period. This is about 20% of the required emission reduction to achieve the 2 °C climate target and corresponds to a reduction in CO_2 concentration of 30 ppm.

About 80% of the emission reduction in the combination of options would come from specific climate policy to reduce emissions from the energy sector and from an increase in bio-energy use. The controversy about bio-energy use and the impact on biodiversity is briefly discussed in Section 4.9. Bio-energy use in the combination of options is limited, and crops can only to be grown on abandoned agricultural land. This avoids any impact of bio-energy on current nature areas. However, there is still a trade-off as the same land could have been used as well for nature recovery or reforestation.

The combination of options reduces demand for agricultural land, even leading to an absolute net decrease of 0.8 million km^2 by 2050. These areas could be left to revert to their natural state, adding to the carbon stock when regrowing. This 'free space' would also create space to produce bio-energy.

6.3 Impact on water quality and aquatic biodiversity

- Increased agricultural productivity is expected to result in a net reduction in aquatic eutrophication worldwide compared with the baseline. This is due to a positive balance between increased nutrient loading from intensified agriculture on the one hand, and decreased loading from prevented agricultural expansion and increased crop nutrient-use efficiency on the other.

An overview is given of the major impacts on water quality and aquatic biodiversity of those options that show a significant effect. Only the effects of eutrophication on freshwater ecosystems (rivers, lakes and wetlands) are taken into account. River fragmentation, water abstraction, climate change and fisheries are not included in the analyses.

In the baseline scenario, biodiversity loss due to eutrophication will further increase, as a result of growing nutrient loads from urban wastewater and runoff from expanding and intensifying agriculture. These problems arise especially in highly populated areas in temperate and tropical regions. The developing regions in Africa and Asia are projected to experience the largest reduction in water quality (Figures 6.4 and 6.5).

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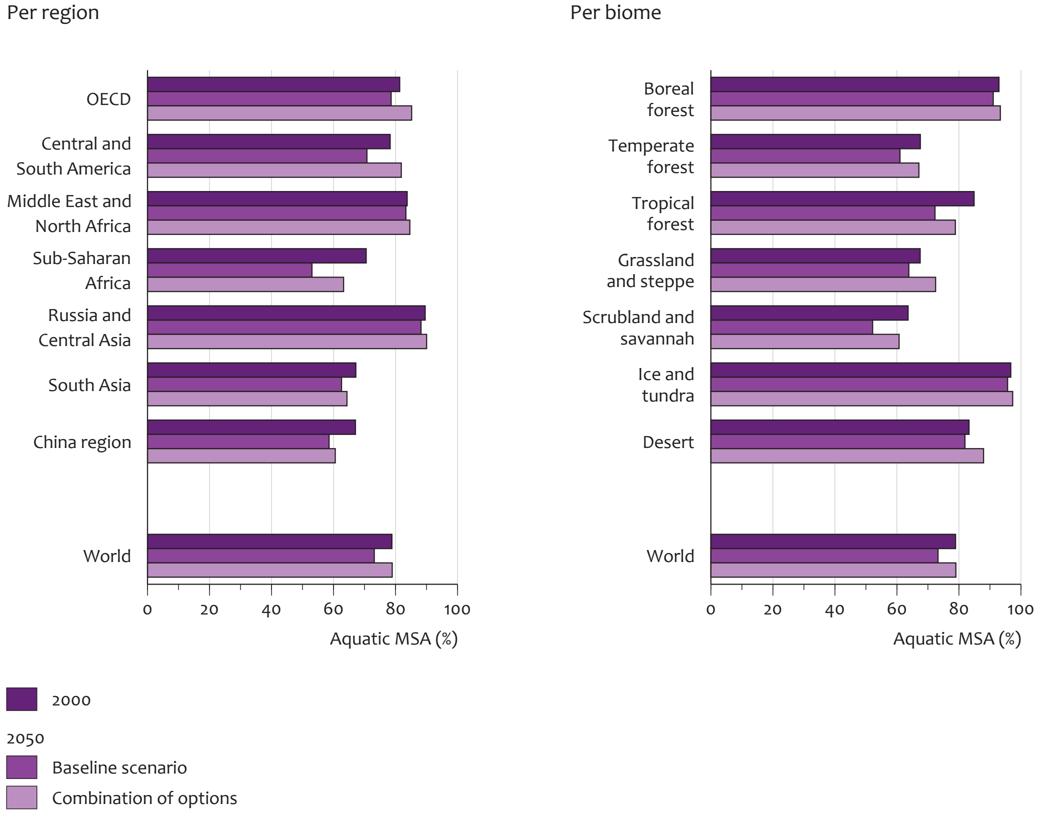
1) Dietary measures, productivity improvement, protection of ecosystems, reduced deforestation, and reduction in post-harvest losses.

Aquatic MSA in freshwater **Figure 6.4**

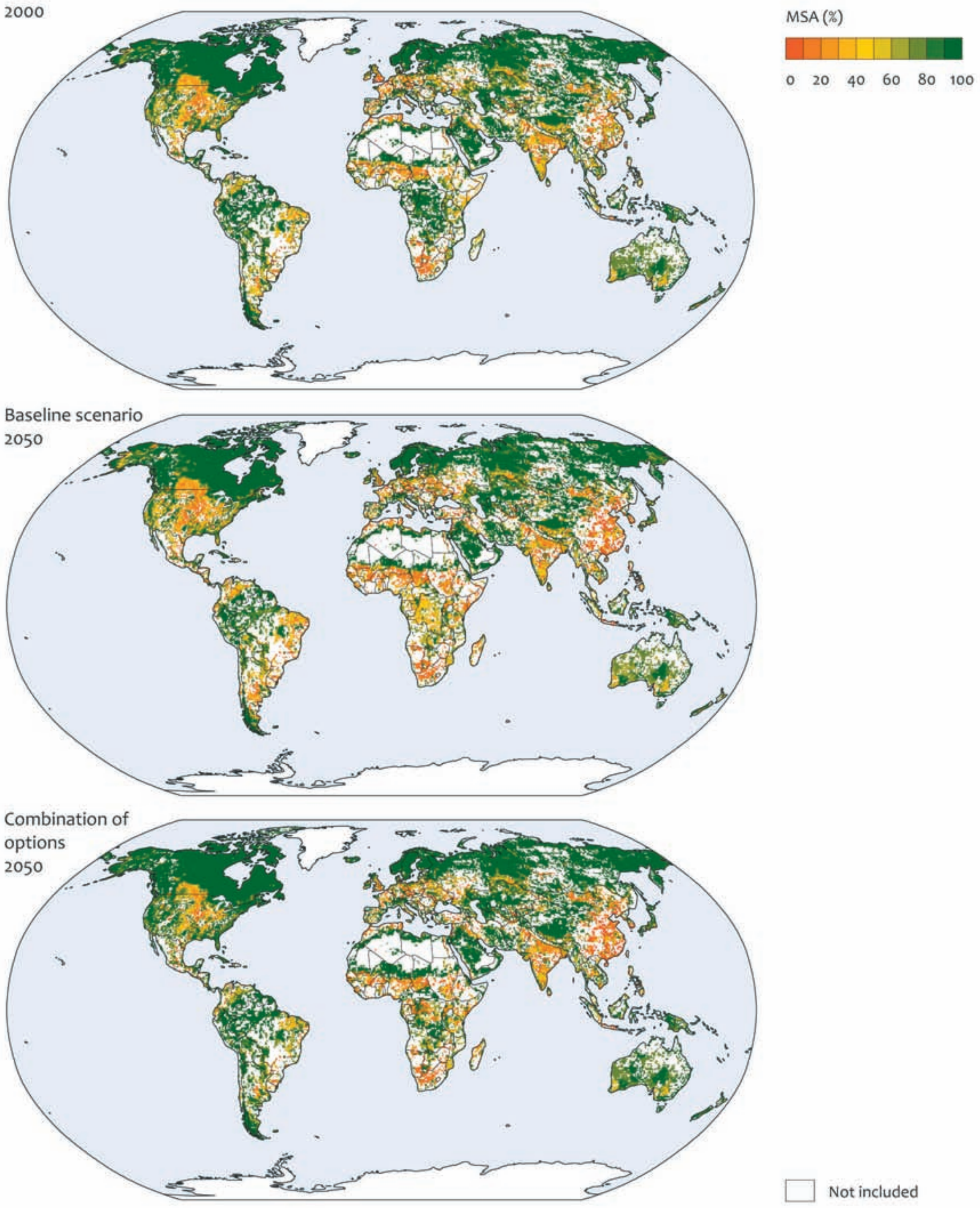


The combination of options would on average lead to less aquatic MSA loss from eutrophication in freshwater ecosystems compared to the baseline scenario

The option of closing the yield gap is expected to result in a net reduction in eutrophication effects worldwide compared to the loss in the baseline by 2050. This positive effect on average is the net result of different processes, involving the size of the agricultural area, agricultural productivity and nutrient use efficiency. In the industrialised countries, China and India, the productivity increase is assumed to be more nutrient efficient (IAASTD, 2009), with the use of nutrients per unit of product decreasing. The situation is different in most developing countries. The fertiliser use will have to increase rapidly in order to prevent land degradation by soil nutrient depletion. Here, the use of nutrients per unit of product is expected to increase.

In both developing and industrialised countries, production per unit area increases partly because of increasing fertiliser and manure inputs per hectare. Consequently, nutrient loads to freshwater also increase but from a relatively smaller agricultural area. If productivity increase stagnates (Chapter 3), expansion of extensive agriculture with a lower efficiency would lead to lower nutrient inputs per unit of

Figure 6.5 **Aquatic Mean Species Abundance**



2000

Baseline scenario 2050

Combination of options 2050

Spatial distribution of aquatic MSA in freshwater ecosystems as affected by eutrophication. Maps of 2000, baseline by 2050, and the combination of options by 2050.

Wastewater discharge into freshwater lake reduces its functions.

area, but larger total inputs for the total agricultural area and thus larger nutrient losses. In closing the yield gap, the balance of this trade-off may be negative locally, but when averaged on larger spatial scales, the outcome would be positive, according to model calculations. Stagnating agricultural productivity and hence agricultural expansion is expected to enlarge eutrophication effects compared to the baseline.

A dietary shift would have a positive impact in those regions where meat consumption is expected to decrease. However in Sub-Saharan Africa and South Asia, meat consumption is expected to increase following rising income levels. Eutrophication would climb correspondingly. Decreasing deforestation would have a positive influence on eutrophication levels because it would reduce losses from degraded forests. The combination of options would again on average lead to less biodiversity loss from eutrophication in freshwater ecosystems compared to the baseline scenario (Figure 6.4 and 6.5).

In the baseline scenario the risk of harmful algal blooms (HABs) in lakes would increase by more than half, especially in developing regions. HABs directly affect drinking water, health, recreational values, aquaculture, and coastal and lake fisheries. Pollution from substances other than nutrients that affect water quality and biodiversity are expected to increase as well, despite improvements in some developed regions (UNESCO, 2009) but these are not quantified here.

6.4 Competing claims on land

- The global available area might not be sufficient to accommodate all future demands from agriculture, forestry, bio-energy, biodiversity, and biotic carbon storage. These competing claims might present conflicts between different interests, and choices need to be made how to use the remaining land resources. One approach is to create additional claims, for instance for protected areas, and thus forcing the production sectors to increase their efficiency.

Humans have altered global land cover substantially, with about 40% of the land surface used for agriculture (including extensive grasslands). Future increase in population and wealth requires more production of food, fibre and timber, requiring more productive agricultural and forestry land. Additional demand for land emerges for bio-energy production that would increase energy security and support climate change mitigation. At the same time, agricultural land is lost due to soil degradation as a consequence of unsustainable management practices leading eventually to irreversible loss. Current productive agricultural land is also lost to expanding cities and infrastructure. Finally, strong calls for action are being made to protect significant parts of all ecosystems to conserve their biodiversity and to prevent exceeding uncertain critical levels that might lead to dramatic shifts in ecosystems, climate and water availability (sCBD, 2010; Rockstrom et al., 2009).

The physical land area and especially productive land is limited, and therefore the term ‘competing claims’ has been used recently to reflect the notion that these diverse claims compete for the scarce resource of land.

Much of this report illustrates current and future claims from agriculture, forestry, and climate policy, and the effects on land use and biodiversity. Most of the options discussed in Chapters 4 and 5 reduce biodiversity loss by reducing the claim from the agricultural and forestry sectors, or by imposing a claim for protected areas.

Here, we will reflect on the concept of ‘competing claims’. The claims are assessed in area requirements, and contrasted with the physical limitation of productive land, and emerging trade-offs and policy choices are illustrated.

Land resources and current and future claims

Physical limits

Of the 130 million km^2 of global land area (excluding Greenland and Antarctica), an estimated 63 million km^2 can be used for intensive agriculture and forestry (Table 6.2) and most of this area (40 million km^2) is already used for intensive agriculture and grazing. The largest remaining potential lies in tropical forests, and a much lower remaining amount in other forests and savannah systems. In addition to the 63 million km^2 of land suitable for intensive agriculture, a further 20 million km^2 of forest is estimated to be suitable for timber production but not for intensive agriculture. As the strongest competition is expected on land suitable for intensive agriculture, the study focused on the claims on these 63 million km^2 as well as on total claims (Table 6.2 and 6.3).

Area suitable for intensive agriculture and forestry, per biome in million km^2 **Table 6.2**

	Total Area[a]	Suitable for intensive agriculture & forestry (in brackets: currently in use)	Suitable for forestry, not for intensive agriculture (in brackets: currently in use)
Intensive agriculture (arable land)	15	15 (15)	
Intensive grazing grassland	25	25 (25)	
Extensive grasslands	10	0	0
Ice and tundra	10	0	0
Desert	15	0	0
Boreal forest (coniferous)	15	3	12 (4[b])
Tropical forest	15	12	3 (2[b])
Other forest (temperate and subtropical regions)	10	5	5 (4[b])
Other natural areas (such as savannah and steppe)	15	3	0
Total	130	63 (40)	20 (10)

Source: MNP (2006); FAO (2001a and 2006).

[a] Excluding Greenland and Antarctica.

[b] Not specified whether current forestry is in areas suited for intensive agricultural use.

Agriculture

Of the estimated 63 million km^2 of land suitable for intensive agriculture, almost 40 million km^2 is used by today's global population of 6.9 billion people (Table 6.3). An additional 10 million km^2 is used as extensive rangeland but cannot be used for more intensive agriculture because of its low productivity, for instance Mongolian steppes. By 2050, agricultural production is expected to double in order to feed 9 billion people with an increasingly meat and dairy oriented diet (see Chapter 3). In the past, about 70% of the increase in agricultural output had been achieved by increased yields with average global productivity increasing by 55% between 1970 and 2005.

Most scenario studies assume that this technological advance will continue at the same pace in the coming decades, and also this study's baseline (Chapter 3) estimates that average global productivity increases by 60%, limiting expansion of agricultural land to around 7 million km^2 until 2050. However, it is heavily debated whether strong improvements in crop productivity can be maintained given the many socioeconomic, environmental and institutional constraints (Section 4.4). Given the many uncertainties, the literature range for expansion of agricultural area up until 2050 lies roughly between 2 and 10 million km^2 (Table 6.2; see also Smith et al., 2010).

Forestry

Currently, about 10 million km^2 is used for timber production (Table 6.2). In addition to dedicated forestry, land clearance for agriculture or other purposes delivers a substantial quantity of wood but is very difficult to estimate (Arets et al., 2010). Consequently, the area required for forestry increases if agricultural expansion is reduced (see also Box 5.1). The area required by 2050 to meet global timber demand is estimated to range from 15 million km^2 to more than 20 million km^2. These estimates do not include all demands for traditional biofuels (e.g. wood for charcoal), which is very difficult to estimate. Part of this demand can be met by using woody vegetation outside intact forests, or can be collected from forests

Table 6.3 Amount of remaining land suitable for intensive agriculture

Additional claims by 2050 (million km^2; rough estimate)

Remaining amount of land suitable for intensive agriculture, in 2005	
63	land suitable for intensive agriculture (from Table 6.4.1)
- 40	in use: agricultural land (~15 arable, 25 pasture)
- 6	in use: protected areas per ecoregion
17	**remaining amount of land suitable for intensive agriculture**
Additional claims on land suitable for intensive agriculture, by 2050 (only including mutually exclusive claims)	
2-10	agricultural claim
0-10	energy crops claim
3-6	protected area (15 to 20% protected per ecoregion)
?	other ecosystem services (e.g. climate and water regulation)
?	remaining forestry claim
2-5	potentially lost due to degradation between 2010 and 2050
7-31	**claims by 2050 on land suitable for intensive agriculture**

without logging involved. But a part of the demand is certainly fulfilled by forestry and logging.

The estimated 20 million km^2 of forestry could be accommodated completely within the area suitable for forestry only, thus would thus not compete with intensive agriculture (Table 6.2). This would lead to continued decrease of undisturbed forest. However, productivity of boreal forests not suitable for intensive agriculture is low, and thus some remaining demand may have to be met on land suitable for intensive agriculture. One way of reducing the area required for forest production is to develop intensively managed plantations. This would require land that is also suitable for intensive agriculture, but may be a worthwhile trade-off, considering the high productivity of forest plantations. As the remaining forestry claim on land suitable for agricultural is very difficult to estimate, it is not specified further in Table 6.3.

Bio-energy

The claims on available land for bio-energy depend on political targets, the level and volatility of fossil-energy prices, and available technologies. Thus, estimates for 2050 vary widely, reaching as much as 5 million km^2 to more than 10 million km^2 (e.g. PBL, 2009; Wise et al, 2009; Table 6.3).

Biodiversity

Currently, about 14% of the global land area is protected, adding up to almost 20 million km^2, although the proportion of protected area varies considerably across ecoregions. Of the land suitable for intensive agriculture, about 6 million km^2 are currently protected (Table 6.3). To protect global biodiversity, the CBD is considering a target of 15 to 20% protected area per ecoregion (Stokstad, 2010), which would result in an additional 3 to 6 million km^2 required for nature conservation on land suitable for intensive agriculture.

Competing land claims of nature conservation, forestry, and agriculture.

Other ecosystem services

Next to the provisioning services (agriculture, forestry, bio-energy) and biodiversity listed above, various other ecosystem goods and services might need to be maintained and would then put a simultaneous claim on land. While cultural and recreational needs might be met under a 15% protection target of CBD, other claims such as climate regulation will require even larger areas to be in natural or close to natural state. For instance, large-scale loss of Amazon rainforest might destabilise the entire ecosystem and might severely affect climatic conditions in other parts of South America (Nepstad et al., 2008; Nobre and Borma, 2009). Likewise, the need to manage global carbon stocks places demands to maintain current forests as completely as possible (Section 4.3).

Urban expansion

Current urban areas are estimated to cover less than 1 million km^2 of the earth's surface (Table 6.3), but depending on the definition, the range is much wider from 0.5 to 3.5 million km^2 (Potere and Schneider, 2007). This area is expected to increase by about 1 million km^2 with increasing population and wealth. While this is only a small proportion of the total land surface, urban expansion will mostly take place close to existing cities, and thus often occupy the most productive croplands.

Other factors affecting availability and productivity of land

Degradation

Soil degradation reduces productivity of agricultural lands. Scherr and Yadav (2001) estimate irreversible loss of land suitable for agriculture at an annual rate of 0.1 to 0.2%. Over the next 40 years, this would result in a loss of 4 to 8% or about 2.5 to 5 million km^2 (Table 6.3). Productivity losses through less serious forms of soil degradation are much more widespread. According to the GLASOD study, 38%

of the world's 15 million km^2 of cropland was degraded due to human activities between 1945 and 1990 (Oldeman et al., 1991).

Climate Change

Like soil degradation, climate change can influence land productivity, and in fact agriculture and forestry are expected to be most affected in the coming decades (IPCC, 2007). However, the regional impacts may vary considerably with large and persistent uncertainty about changes in precipitation.

Scarcity of inputs such as phosphate and water

Despite increasing global demand for non-renewable phosphate rock in the short and longer term, and its critical role in food production, global phosphate scarcity has only recently been emerging in debates on global food security and global environmental change. The same is the case for water, which is not assumed to be a limiting factor in most scenarios.

Over the next decades, water demand is expected to increase from households, the energy sector, industry, agriculture and energy crops. Currently, food production accounts for 70 % of withdrawals from surface and groundwater sources. With this water, about 20 per cent of cropland (2.75 million km^2) is irrigated, accounting for 40% of crop production. Up until 2030, the area of irrigated land is estimated to increase annually by 0.6 % (CAWMA, 2007). Taking into account the significant opportunities to improve water per unit of crop efficiency, water used for irrigation is estimated to increase by 13% up to 2030 (360 km^3) but this amount is highly uncertain (OECD, 2008; UNESCO, 2009).

Multifunctional land use

In the above, we have discussed the physical claims on land per sector or demand category. However, there might be overlap in certain claims because the same area of land can be used for several purposes or contribute to several services. For instance, depending on its intensity, agriculture can accommodate certain remaining natural biodiversity and elements of agro-biodiversity. Forests may contribute to timber production, biodiversity, water regulation and climate regulation at the same time.

Confronting claims with physical limits of available land

As some types of land use might serve multiple functions, one needs to be careful in adding up the above claims. In Table 6.3 we have only included numbers for the services that are mutually exclusive, and put question marks for those which might be (partially) fulfilled within other claims, or for which there are no clear targets.

The above claims from different sectors and policy targets add up to an additional 7 to 31 million km^2 of productive land required in 2050, not including other ecosystem goods and services. This claim is facing a remaining amount of 17 million km^2 of available productive land. Depending on the various uncertainties, the diverse needs and ambitions might exceed the physical area available. Consequently, competition and conflicts between different interests will increase in the future, and important choices need to be made.

Competition – incentive for efficiency and optimal solutions

Given the competing claims elaborated above, it is evident that the available area might not be sufficient to accommodate all demands, and that conflicts between different interests will increase in the future. While competition might be regarded as a useful mechanism in increasing efficiency, and to finding optimal solutions, a solely competitive approach has important implications.

Firstly, some claims are less well represented in the economic system, with biodiversity and other supporting cultural and regulating ecosystem services being little represented at present. To rectify this situation (creating a 'level playing field'), attempts are made to value these services, to ultimately put a price on them, and to let them compete in the market process with, for instance, agriculture and forestry. While payment for maintaining carbon stocks (reducing emissions from deforestation and degradation, REDD) in Post-Kyoto Climate agreements might become a successful example, other services are extremely difficult to value, and might only be successfully integrated in the far future.

Secondly, some claims have higher priority than others, and thus should not be subject to market mechanisms under any circumstances. For instance, the conflict between increased biofuel production and its potential impact on food prices can be seen as the result of differing priorities. Although the extent of the effect is heavily debated, there seems to be consensus that 'food comes first', and that biofuel policies, although economically sensible, must not put food security under pressure. The global food system, however, is in fact much too complicated to be described in such simple terms. There are complex mechanisms between food prices and food security (poor farmers profit from high prices, poor citizens suffer from high prices), and increasing prices might not only threaten food security, but also stimulate innovation.

Choices to be made

Given the limited land resource, choices need to be made how to use this resource and consequently trade-offs between these services and policy targets emerge, as the physical land area is limited. The most important trade-offs between the services are:

- Biodiversity and climate change: large-scale bio-energy and carbon plantations have high local impact on biodiversity in the short term and uncertain climate and biodiversity benefits globally in the long term. However without climate mitigation, there are risks of ecosystem shifts, and food and water insecurity, in the longer term (Section 4.9).
- Food/timber production and biodiversity/carbon stocks: large-scale protected areas and the REDD programmes benefits both biodiversity and climate, but could increase land scarcity, increase commodity prices, and thus affect food security (Section 4.3).
- Compact, highly efficient agriculture and biodiversity. Productivity increases in agriculture might keep agricultural area compact (if combined with nature conservation measures, see Chapter 5) and thus reduce total loss in natural area.

However, this would have a larger negative impact on the remaining biodiversity in agricultural areas.

The single options (Chapter 4) and the combination of options (Chapter 5) can reduce biodiversity loss by two different approaches. One approach is an additional claim for protected areas, serving biodiversity and carbon stocks, and thus forcing the other claims by means of price and market mechanism to cover less area. The other approach is to increase efficiency so that the area needed to fulfil a certain demand is reduced, for instance yield increase, reduced losses, and improved forest management.

Increasing efficiency is a promising way to reduce the apparent competition between different land claims, and to ensure more services per land area are delivered. However, specific services, such as biodiversity, conservation of carbon stocks, or other non-market ecosystem services, need to be supported, for instance by payments or protection simultaneously in order to achieve the intended effect. Otherwise, price feedback may largely result in more consumption of market-based services.

7

Robustness of results

7.1 Conclusions

Without new policies worldwide biodiversity loss will continue is a *robust statement*. We believe that the present approach (method and indicators) is relevant and robust for the pressures and proposed reduction options to counteract these pressures. However, a different choice of indicator emphasising species numbers for example, could result in greater emphasis on changes in species-rich biomes in the tropics, and somewhat less emphasis on changes in deserts, tundra and temperate zones.

The options for reducing global biodiversity loss - expansion of agricultural land use, expanding infrastructure, forestry, increasing climate change, and capture fisheries – were identified in the analytical set-up of this study and therefore *conditional* but rather conventional options. The pressures targeted by the options are in line with the findings of the recent GBO3 that lists the main threats based on multiple indicators from the CBD indicator framework. The relative results of the options expressed in prevented biodiversity loss are *robust* against assumptions and uncertainties that affect both the baseline and options.

The map locations where pro-biodiversity options would have effects (world regions, biomes) are *plausible* but changing trade rules may influence these patterns and make the findings *conditional*.

That the combination of options cannot stop or reverse global biodiversity loss is a *robust* statement, given the problem framing and analyical set-up of this study. However, while the options analysed in this study include the key pro-biodiversity measures, they are not exhaustive. Which option contributes most to reducing biodiversity loss should not be judged from this study alone because the findings are *conditional* on the study set-up and the ambition level of individual options. However, the finding that an combination of options is needed is *robust*.

Options that serve multiple policy goals are attractive for their synergies, and will have a higher chance of delivering success. Connecting solutions to benefits for the sectors makes solutions more likely to be taken, such as health benefits of less meat-intensive diets. Finding such connections will make the implementation and feasibility of options more *plausible*.

The need for further prioritisation of areas to be protected is *robust*. In the absence of concerted action in the different sectors (or considering the amount of time it will take), protection is the only option to stop further degradation of ecosystems, and is needed to prevent irreversible loss. As such, it is a *no-regret* option that should be taken up soon in policy debates.

The policy window for these options before rather than after 2030 is *plausible*. In terms of probable friction costs, technology-based options emerge as least problematic while conflicting interests emerges as the most problematic aspect.

Using a model based on species-area relationships (SAR) showed less biodiversity decline in the combination of options. This was mostly the consequence of not having infrastructure as a pressure in the model. Excluding this pressure, both SAR and MSA approaches gave comparable relative results. Although preliminary and limited in scope, this comparison shows that the chosen indictor delivers *robust* results.

No integrated pressure-based models are currently available to model the number of threatened species populations in the future. With such models, other results may be obtained that could provide complementary results and insights.

7.2 Robustness and uncertainties

Analysis of robustness should shed light on two issues of interest to the policymakers:

- Whether the main conclusions of this study are robust against assumptions and methodological uncertainties in scenarios (baseline and options) and models;
- Whether the results would have been different if other approaches and methods had been used (other indicators, other models or frameworks).

There are numerous sources of uncertainty that influence the study findings, ranging from problem framing, indicator selection, data imprecision and variability, model uncertainties in parameters, cause-response relationships and conceptual structure, to scenario and option assumptions, and last but not least, the communication tools (Janssen et al., 2003). These sources cannot be analysed here in detail, as elaborate quantitative uncertainty analysis would be required (through Monte Carlo simulation and other methods). The sources of uncertainty thought to be most relevant for robustness are briefly discussed and, where possible, qualitative expert judgment is given of their impact on direction, size, and timing of the findings.

More information on involved uncertainties can be found in the OECD Environmental Outlook to 2030 (OECD, 2008), and the Crossroads scenario study for the Second Global Biodiversity Outlook (sCBD and PBL, 2007). These studies used largely the same suite of models, although with earlier versions.

7.3 Problem framing and study set-up

Problem framing

The biodiversity crisis can be framed in many ways, depending on the definition, importance and value of biodiversity (expressed by different indicators). Thus, the framing may range from irreversible species loss to putting the well-being of people at risk as essential (local) ecosystem services are lost.

A pressure-based approach is regarded as the interface between drivers of change and a range of sustainability and biodiversity issues, whatever definition is taken (Spangenberg, 2007). Our modelling framework views world biodiversity loss as essentially an issue of growing competition for limited and dwindling resources. Within this framework, several generally recognised human-induced pressures (Sala et al., 2000; sCBD, 2010) are responsible for ecosystem loss in extent and quality (degree to which they resemble their natural state; Bouwman et al., 2006; Alkemade et al., 2009). The model framework allows for integration and analysis of direct and indirect pressures on ecosystems and biodiversity. This enables analysis of options for reducing these pressures, and thus the formulation of relevant policy actions.

The approach takes human land-use as a central and pivotal point, from which relationships are drawn with biodiversity and with the delivery of essential goods and services (Braat and ten Brink, 2008; de Groot et al., 2010). Land-use, ecosystem extent and ecosystem quality are crucial for both MSA and ecosystem goods and services delivered. This approach builds on the concepts and interests in the CBD framework, Millennium Assessment and TEEB analyses. As such, it presents a valuable addition to assessment of future trends and targets for biodiversity and related issues.

Study set-up: baseline and options

Options are assessed by comparing a Business-As-Usual scenario with several solution- oriented scenarios. The results depend on the many assumptions on (autonomous) future developments in the presence and absence of additional policies beyond 2010. According to the OECD Outlook for 2030, baseline probability is skewed towards higher pressures on the environment that reflects the expectation of accelerated growth and consumption in dynamic new economies (Bakkes et al., 2008; OECD, 2008). Uncertainties in the future energy system stem from assumptions on lifestyle and technology. It is not easy to give a quantitative indication on the probability of these projected autonomous trends. However, several of the quantifiable and unquantifiable uncertainties are present in both the baseline and options (Table 7.1). Therefore, expressing the option effects relatively (as prevented baseline biodiversity loss, or prevented land-use expansion) is a more robust way of communicating the option effects.

An alternative set-up would be to formulate several scenarios with different levels of autonomous development, and explore the effects of the options on each of these 'alternative' baselines. Including, for instance, stronger autonomous efficiency in improvements in agriculture leaves less room for effects of further improvements in an option. Then, discussion focuses on projections of autonomous

Uncertainties in indirect drivers of biodiversity loss

Table 7.1

Population growth	Assumptions based on UN medium projection.
Economic growth	The direction (increase) is certain, but the size has considerably more uncertainty. Uncertainty skewed towards more environmental pressure from higher growth in industrialising countries. The current economic downturn is expected to have no significant effect on long-term economic trends.
Consumption growth	The direction (increase) is certain but the growth rate has considerable uncertainty, as it is a combination of economic development leading to more disposable income and demographic development.
Agricultural productivity	Assumptions based on FAO projections. Discussion about the ability to continue long-term productivity growth as assumed in the baseline scenario (which includes for instance the Green Revolution jump).
Energy use	Direction certain (growth) but developments in the energy system and energy mix are uncertain and depend on lifestyle, economic growth and technology.
Technology and labour productivity	Labour productivity assumed to converge towards (not necessarily reaching) long-term industrialised country average. Assumed trend includes large technological transitions (e.g., ICT) although their exact future timing is hard to predict.

improvements. But to focus on *potential* effects of policy actions, a relatively policy-poor baseline was selected to show the full potential of options.

Comparing options

The effects of individual options should be compared with caution. Firstly, their effect depends on the assumed ambition and level of implementation. Secondly, the impact of options is largely based on studies for which the underlying baseline scenarios vary. Thirdly, the list is not exhaustive. Options are conceivable which could not be integrated because of time constraints. The theoretical potential to limit biodiversity loss is thus greater than the options in this report. For instance, no options were included that counter the effects of infrastructure, or that reduce fibre and timber consumption.

The option comparison summarised in Figure 4.10.1 shows the relative and not the absolute impacts on biodiversity loss in MSA (left part) compared with the respective baselines. This figure should be interpreted as a coarse ranking of promising options.

Options combination

Setting the combination of options required choices on the options and implementation levels. The options included are relevant because they match the recommendations of the Third Global Biodiversity Outlook, and counteract several main pressures (sCBD, 2010).

The combination of options analysed is only one example of possible solution mixes, but indicates that concerted action is required to harvest the combined potential of options. Moreover, trade-offs and leakage to other ecosystems and regions can be avoided by combining and aligning them with other policy areas. However, concerted actions over different sectors are not easily achieved and may take a long time.

In the absence of concerted sectoral biodiversity policies, ecosystem degradation will continue. Losses of species and ecosystems are not easily reverted. It takes decades to a century or more for ecosystems to fully recover with high chances that abandoned land is used for purposes other than nature development. Therefore, expanding the protected area network deserves immediate attention in the policy arena and thus presents a no-regret action. This accentuates the need to prioritise areas that need further protection.

Temporal and spatial scales

The option assessment period extends to 2050. The biodiversity gains of climate change mitigation, sustainable forestry, and nature recovery on abandoned lands are likely to occur significantly beyond this time horizon. Long-term processes are involved in all options. Thus, the potential effects of the first two options are probably underestimated. Because of these long-term responses, the risk of losing ever more biodiversity in the absence of sectoral polices, and the higher chance of success when additional habitat loss is prevented, makes it highly likely that the period up to 2030 is crucial for effective policy interventions.

7.4 Indicator choice

In outlook studies, the choice of metric largely determines the results. The main characteristics of the mean species abundance indicator MSA (Alkemade et al., 2009), which is the central indicator in this study, are compared here with alternative indicators.

- A *pressure-based approach* is the interface between drivers of change and a range of sustainability and biodiversity issues, whatever definition is taken (Spangenberg, 2007). This would mean that results are relevant as long as the right pressures are included. The GBO3 focuses on: ’biodiversity protection, linking up with climate change policies to reduce the further loss of carbon-storing ecosystems, greater efficiency in the use of land, energy, fresh water and materials, strategic land use planning, the application of best practices in agriculture, sustainable forest management, sustainable fisheries, restoration of terrestrial and marine ecosystems, and better decisions for biodiversity in all sectors’.
- The MSA indicator is a measure of local *naturalness* of an ecosystem that is put to human use at different degrees of intensity. Loss of local species is referred to as extirpation, and many cases of local extirpation eventually result in complete disappearance of a species, which then becomes globally extinct. As local extirpation precedes global extinction, MSA provides a more sensitive indicator that can be regarded as an early-warning signal for extinction, on which appropriate and timely action can be taken.
- Another indicator often used is the *Living Planet Index* (LPI; Gregory et al., 2005; Loh et al., 2005) that uses multiple species groups to build a broad picture of biodiversity trends. LPI shows considerably faster downward trend over the period 1970-2010 (GBO3) than does MSA. This faster trend is the result of using a selection of species which is probably more sensitive to environmental changes than taking all species into account. Changes in the number and abundance of endemic species are expected to be similar to changes in threatened species. Both have generally small distribution areas (by definition), making them more vulnerable to habitat loss and other causes of homogenisation.

- As the MSA indicator is based on naturalness in general, it cannot reflect the specific effects of *expanding protected areas*. For the additional protection areas, maps were used that include specific hotspots based on species richness and uniqueness. Thus the option benefits are underestimated with the MSA indicator and the extent of natural area. To overcome this short-coming, a complementary indicator was included – representativeness of protected eco-regions - that gives the value of the protected area network for the 10% CBD sub-target (Coad et al., 2009). So for this option, complementary indicators are required.
- If an *indicator of extinct species* had been used, changes would have been similar to those for mean species abundance (MSA), but probably lagging behind. This follows logically from the statement that 'local extirpation precedes global extinction'. Consequences of too small or unsuitable habitats will not immediately lead to extinction, so this effect will unfold gradually in time. In an Outlook Study for the Millennium Assessment, plant species extinction was calculated using species-area relationships (SAR; van Vuuren et al., 2006). The results on the SAR indicator are formulated as 'increased risk of future extinction'. The results obtained were more or less similar to this study with important roles for habitat change and climate change. However, the SAR indicator does not cover all the pressures covered in the MSA method, most prominently the effect of infrastructure. For further discussion, see Box 5.2.
- Using naturalness as a biodiversity indicator implies *neutrality* between biomes. It is consistent with a sub-target of the CBD to protect and conserve a representative part of the diversity in all ecoregions. Further, using the natural state of biomes or ecosystems as the reference provides a more equitable comparison of regions in different stages of socio-economic development.
- If the biomes were *weighed* on species richness (weighed MSA), pressures operating in species-rich biomes (tropical forests and grasslands) would have been accentuated. In a previous assessment (sCBD and PBL, 2007), additional calculations were made with a weighted MSA (based on species richness figures per biome, from (Rodrigues et al., 2004; Kier et al., 2005; WWF, 2006). It showed that the impacts on biodiversity *at the global level* are more severe, because human impacts are larger in species-rich tropical and temperate zones than in species-poor boreal and polar regions. However, this is the case in both the baseline and policy options. And as the results are expressed preferably relatively (as prevented biodiversity loss), results would be more or less the same.
- The CBD indicator framework contains a set of complementary indicators as no indicator can cover all aspects. Each possible indicator illuminates a specific aspect of the multi-dimensional entity of biodiversity. Using other models with other biodiversity indicators may result in different insights and other assessments of the option effects. But currently, there are few integrated, global covering, pressure-based model frameworks (Leadley et al., 2010).

7.5 Implications for the robustness of the main findings

The robustness of the main findings of this study is assessed briefly. It is essentially a self-assessment and based on information provided elsewhere in the report:

- the problem framing and analytical approach (Introduction);

- the ensuing limitations and bias;
- the uncertainties associated with specific parts of the analysis, mentioned in Chapters 3, 4 and 5, and above;
- and builds on the published model descriptions (Annex B).

This section deals with some key aspects such as projected biodiversity loss and potential of the single options and the options combination. Key considerations leading to the various statements on robustness are summarised in Table 7.2. This takes advantage of a robustness assessment of the findings of the OECD Environmental Outlook to 2030, which used largely the same suite of models (Bakkes et al., 2008).

Table 7.2 **Considerations on the robustness of the main findings of this study**

Type of finding	Implications for robustness	Reasons
Without new policies, biodiversity loss will continue	The projected global trend of continued biodiversity loss towards 2050 under baseline conditions is robust. Underestimation of the rates of loss is more probable than overestimation. The absolute biodiversity values (in terms of MSA) are probably overestimated. The exact extent of loss per region is uncertain.	The loss continues a long-term trend for all three indicators at the global level. Most underlying drivers of change move to increased pressure on biodiversity between now and 2050. Not all known major pressures are presently included in the GLOBIO model (fire, invasive species, tourism, mining and soil erosion). The risks of abrupt changes are not included in the projections. The impacts of the broad category of infrastructure development are modelled very simply and therefore uncertain. The impacts of climate change have been modelled but the projections concern shifts larger than in the calibration period of the models and are thus imprecise. The projection of biodiversity loss would have been very similar (but probably less) if *species richness/species area curves* had been used as the central indicator instead of *mean species abundance*. If the Living Planet Index had been used as indicator, biodiversity losses would have been larger in view of the development of this index in the period since 1970.
Time: The window for effective action is before 2030	The finding that in all regions most of the projected biodiversity loss occurs before 2030 is plausible. The implication that options need to be implemented before 2030 is also plausible. The rate of biodiversity loss will subside after 2030 depends on assumptions on demographic development and cannot be taken for granted. This uncertainty is largest for Africa.	The underlying notion for quick action is that biodiversity is lost quickly and only slowly restored. The reduction in biodiversity loss after 2030 is dominated by a slowing down in land conversion for agricultural production. This hinges on price elasticities of food (red meat, in particular), levelling off of demographic growth and food consumption in the developed world, continued advances in agricultural productivity, and availability of sufficient fresh water. The potential increase in agricultural productivity is subject to discussion, just as the resulting impact on food prices and agricultural expansion. The margins for change in these factors are largest in Africa.
Potential effect of all options to 2050	On balance, the finding that the single options and the options combination analysed in this study cannot reverse the overall loss of biodiversity is robust, given the problem framing and analytical set-up of this study. The potentials can be either somewhat underestimated or overestimated. The options relate mostly to more efficient resource use in primary production sectors and only addresses the potential for reducing demand in case of human diet. Different options combinations are conceivable.	The gap between baseline loss and prevented loss remains wide. Various options are not included, particularly to counter infrastructure development. This means that the potential would be larger than this study shows. Infrastructure related effects correspond to approximately one quarter of 2010-2050 changes in the baseline. Scope for achieving the potential of the options through effective policy instrumentation is not part of the quantitative analysis. As the discussion in this report shows, reality on the ground will mean that only part of the potential can be achieved. Several pressures are not included. Incorporating more pressures in the models would increased baseline loss, for which additional options have to be analysed. Other options combinations are conceivable. The combination analysed has been designed to maximise the effect on global biodiversity loss. Other options and ambitions could provide alternative combinations, and there is no evidence that the combination analysed has the maximum effect.

Table 7.2 (continued)

Type of finding	Implications for robustness	Reasons
Spatial emphasis in the findings - regions, biomes	The overall pattern is plausible. In terms of regions, the largest potential for reducing biodiversity loss is in OECD countries and Africa; in terms of biomes, the largest potential is in tropical and grassland biomes.	The overall pattern conforms to earlier, partial studies. The future impacts without new policies are projected to be the greatest in biomes and regions suitable to human exploitation (grasslands, temperate and tropical forests) that could even be enhanced mediated by free trade. This is where the options in general have their largest potential. The study emphasises changes in biodiversity loss in temperate zones, deserts and tundra. This is a consequence of the vast areas that will be affected by climate change. Mitigation of clim ate change will have benefits for all biomes and not just these.
Scope for implementing the options	Technological options within sectors emerge as the least problematic, relative to options with conflicting interests. Of the various options, restoration of marine fish stocks is probably the most problematic. Opinions differ in the scope for changing trends in diet change, and probably the regional scope for achieving some of it in the next decades will also differ	Without quantitative cost analysis, the finding that technology is least problematic and conflicting interests are most problematic is plausible in the light of the broad-based assessments. It is in line with responses to the sCBD survey among the Parties, April 2010, as part of this study (see Annex A). Changing diet trends has been deemed beyond reality as well as a rational development in view of additional benefits. There are contrasting views on the appropriateness of policy instruments. For instance, this study quotes health benefits of moderating meat consumption but probably underrates countervailing incentives and habits.

Annex A Results of the CBD Policy Option Survey

Focal points of the CBP parties were invited to complete a survey (Notification No. 2010-055) to assess their perceptions on the impact, desirability and feasibility of different policy options to reduce biodiversity loss. Completed questionnaires were returned by representatives from a total of 18 countries with all continents represented. A number of questionnaires were partly completed and could not be included in the survey analysis. For each of the policy options, participants were asked to indicate:

- the rank in impact on nature conservation;
- the desirable extent to which the option should be implemented;
- the feasible extent to which the option should be implemented.

The first question, in which the different policy options were to be ordered according to their potential impact, was answered sufficiently by 15 country representatives (at least five options were ranked). For the second (desirability) and third (feasibility) question, answers from nine countries were included in the analysis.

Perception of the impact of each of the policy options differed somewhat from the outcome of the model predictions (Table A.1). Notably, the outcome of the survey suggests that the effect of dietary change, whether it be No meat or Healthy Diet was underestimated by the country representatives. The impact of improving forest management in reducing biodiversity loss seems to be generally overestimated.

The impact of the single options depends on the ambition level. For example, up to 50% expansion of protected areas mitigates biodiversity loss more than expansion of up to 20%, and complete substitution of all red meat has a greater effect than partial substitution. For most options, a rather large discrepancy is apparent between the ambition of the option at its full extent, and the desirable/feasible extent as indicated by the focal points. For example, the dietary change option, if implemented to its full extent (no meat), is predicted to have a relatively high impact. However, none of the parties desire full implementation and thus the ambition levels are relatively low. Full implementation is also considered to be difficult, resulting in low scores for feasibility. In general, the feasibility levels for the various options were not very different from the desired ambition levels. Results of the desirability and feasibility questions are presented in Table A.2.

Policy options ordered according to modelled impact (prevented MSA loss) and the ordered averages of the ranks for relative impact as allocated by the survey participants (n=15)

Table A.1

Modelled Impact (2030, 2050)	**Prevented loss**	**Perceived Impact**	**Average rank 1-9**
Changing diets (no meat; 2050)	56%	Improving forest management	7.2
Expanding protected areas (50%; 2030)	50%	Reducing deforestation	6.8
Changing diets (healthy; 2050)	37%	Expanding protected areas to 20% or 50%	6.6
Closing the yield gap (2050)	29%	Closing the yield gap	5.2
Mitigating climate change (no biofuel; 2050)	12%	Aquaculture fish partly replacing marine fisheries	5.0
Reducing deforestation (2030)	10%	Mitigating climate change (biofuel)	4.8
Improving forest management (2050)	9.7%	Changing diets (reducing consumption of meat)	4.6
Expanding protected areas (20%; 2030)	9.0%	Liberalising trade in agricultural products	3.7
Reducing post-harvest losses (2050)	4.8%	Reducing post-harvest losses	3.5
Mitigating climate change (biofuel; 2050)	-11%		

Averages of the desirable and feasible extent of implementation as scored by the survey participants (n=9)

Table A.2

Policy option	**Desirability 0-10**	**Feasibility 0-10**
Improving forest management	9.1	8.1
Reducing deforestation	8.9	7.3
Closing the yield gap	7.3	6.9
Aquaculture fish partly replacing marine fisheries	6.7	6.8
Protected Areas	6.7	6.4
Reducing losses	6.4	5.7
Mitigating climate change (biofuel)	5.4	5.6
Changing diets (reducing consumption of meat)	4.2	3.9
Liberalising trade in agricultural products	3.1	3.5

Annex B Methodology

A more elaborated description of models and concepts used, and information on regional classifications and delineation can be found in a separate web document, which can be accessed from the project's publication web page:
http://www.pbl.nl/en/publications/2010/Rethinking_Global_Biodiversity_Strategies.html

Additional information on the GLOBIO consortium, the GLOBIO model and global and regional assessments can be found on the website:
http://www.GLOBIO.info

Information on the IMAGE model can be found on the thematic web page:
http://www.pbl.nl/en/themasites/image/index.html

More information about the models and assessments involved, can be found at the following PBL web pages:

Models and Data
http://www.pbl.nl/en/dossiers/modelsanddata/index.html

Guidance on Uncertainty Assessment and Communication
http://leidraad.pbl.nl/

Climate Change
http://www.pbl.nl/en/dossiers/Climatechange/index.html

Biodiversity
http://www.pbl.nl/en/dossiers/Biodiversity/index.html

Glossary

Affected natural area is the extent of natural area impacted by human activities to a MSA lower than 80%, expressed in million km^2. This is complementary to *Wilderness areas* which are areas with a low degree of human influences, defined as the area with MSA higher than 80%, expressed in million km^2. The sum of affected natural area and wilderness area is natural area.

Agricultural land is the total of arable land and pastures.

Assessment frameworks provide a systematic structure for organising indicators so that, collectively, they paint a broad picture of the status and trends for a field of interest, in this case biodiversity. These consist of assessment principles (baselines), indicators (and underlying variables), and methods of aggregation.

Baselines are references or starting points for indicators and can be used to measure change from a certain date, state or trend, for instance, the extent to which an ecosystem deviates from the natural state or certain year. The chosen baseline strongly determines the meaning of the indicator.

Baseline scenario in this report is a societal development path without new policies and serves as a contrast to show the effects of one or more options.

Biodiversity is 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 (UNEP, 1993).

Biodiversity loss is the reduction of biodiversity caused by human-induced impacts. In this report, biodiversity loss is expressed in loss of natural area (NA), loss in mean species abundance (MSA) and loss of wilderness.

Bio-energy crops are grown specifically to produce energy. In this report, the term bio-energy encompasses all forms of modern energy from crops. This includes the use of specific crops (also wood) grown to produce energy but also the use of agricultural residues for commercial energy purposes, such as use in electric power plants or conversion to liquid biofuels. In this report, the effects of bio-energy only concerns crops grown to produce energy.

Biofuels encompasses a range of liquid fuels, mainly used in the transport sectors, and derived from biomass.

Biome is a generalised natural ecosystem type. Biomes are defined by soil types and climatic conditions. In the IMAGE model, 14 biomes are distinguished, based on a static natural vegetation model (Prentice et al., 1992).

Cultivated area is the area (in km^2) converted into arable land, grazing land, forestry plantations, infrastructure or built-up area.

Conversion of natural ecosystems is the almost complete replacement of a natural ecosystem by a man-made and managed ecosystem such as arable land, man-made pasture, infrastructure, forest plantations or built-up land.

Depletion Index (DI) is the average of the estimated biomass change since 1950 for each functional fish group weighted by the species richness.

Drivers-Pressure-State-Impact-Response assessment framework is an analytical framework which considers various different stages in the causal chain from drivers to effects. In this report, the following biodiversity-specific definitions are used:

> **Driving force or indirect drivers**: socio-economic factors which cause pressures
>
> **Pressures or direct drivers**: changes in the environment caused by humans which affect biodiversity
>
> **State**: condition of biological diversity and the abiotic environment as such
>
> **Impact**: change in ecosystem goods and services from biodiversity loss and consequently change in economic sectors, public health and/or livelihoods
>
> **Responses or policy options**: measures taken in order to change the state.

Ecoregion is "a relatively large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (WWF, 1999). The classification of Bailey (1998) is one of the most widely adopted. It is a hierarchical system with four levels: domains, divisions, provinces and sections. Olson and Dinerstein (2002) identified 238 terrestrial or aquatic ecoregions called the 'Global 200' that they considered to have priority for global conservation.

In this study, two types of ecoregion divisions are used. The 20% PA option covers a representative selection of the Earth's ecosystems (e.g., Olson et al., 2002) with a preference for areas with concentrations of threatened and endemic species (e.g., Orme et al., 2005; Rodrigues et al., 2004; Birdlife International 2005, Stattersfield et al., 1998). In the 50% and package option, 190 ecoregions are identified combining the IMAGE region and biome classification with a preference for those areas as far away as possible from human activities such as settlements and agriculture.

Ecosystem quality is an assessment of the state of an ecosystem expressed as a distance to a well-defined baseline state. In this report, ecosystem quality is calculated as the 'mean abundance of original species relative to their abundance in undisturbed ecosystems' (Alkemade et al., 2009).

Ecosystem extent is the area occupied by a certain ecosystem type. The extent of a natural ecosystem is one of the main indicators used in the study and derived from the CBD 2010-indicators. It is calculated by subtracting the converted area (agriculture, built-up area, infrastructure and forestry plantations) from the original extent of the biomes.

Ecosystem recovery takes place if cultivated land is taken out of production and returns to its natural state without human intervention, a process that could take decades or even centuries. It is a function in the GLOBIO model. Recovery of MSA on abandoned land has been mentioned in those options in which considerable recovery take place after 2050.

Extensive grassland is applied to marginal natural land used for extensive grazing (globally about 10 million km^2) such as the Mongolian steppes. The impact of extensive grazing on MSA is not implemented in the GLOBIO model.

Forest is an ecosystem with a cover of predominantly tree species. Forests are defined according to the global land cover database (GLC2000). 10 of the 22 land-cover types from the global GLC2000 database are denoted as forests (Bartholomé et al., 2005).

Forestry is the exploitation of forest for wood production (timber, pulp and fuelwood). These forests undergo some kind of harvesting and management activities. Such activities do not occur in primary forest. Three simplified forestry types are distinguished: i) intensively managed plantations using mostly planted exotic species; ii) clear-cutting and re-growth cycles with indigenous species, with or without assisted regeneration (semi-natural forests); and iii) selective logging where individual trees are harvested with varying harvest intensities (mostly in tropical forests).

Grassland is a natural biome dominated by grass species, irrespective of whether it is affected by human interventions. Grassland used for intensive livestock grazing is called a pasture.

Habitat type is a specific type of vegetation. Major habitat types as distinguished under the CBD are forest, tundra, grassland, desert, inland or marine waters, and agriculture.

High Quality natural area (NA-HQ) see wilderness

Homogenisation is a process of biodiversity loss which is characterised by the decrease in abundance of many species and the increase in abundance of a few other human-favoured species due to human interventions. As a result, different habitats are becoming more and more alike.

Hotspot is an area with a relative high species-richness. For practical reasons, species-richness can be based on one or more well-known taxonomic groups.

Indicators are quantitative measures which "imply a metric (i.e. distance from a goal, target, threshold, benchmark, etc.) against which some aspects of policy performance can be measured". It is the use of reference points, such as targets or benchmarks that distinguish indicators from statistics. Use of a reference point allows the reader to gauge the significance of the statistic for example, "the extent to which an objective is met" (UNEP, 1997).

Land cover is the way the terrestrial surface is covered by either natural ecosystems or by cultural systems. In GLOBIO, a system of 22 land-cover types is used taken from the GLC2000 database that contains data on the present land cover for the whole world (Bartholomé et al., 2005). In IMAGE, a system of 21 land-cover types is used, with 6 human dominated land-cover types, and 15 natural occurring land-cover types that are similar to biomes (and including ice).

Land-use is the way in which land is used for human needs. In this study, agriculture, forestry, urban and infrastructure are distinguished.

Mean Species Abundance is an indicator of biodiversity intactness and defined as the '*mean abundance of original species relative to their abundance in undisturbed ecosystems*', in short known as 'mean species abundance' (MSA; Alkemade et al., 2009).

MSA see: mean species abundance

MSA aquatic is an indicator of biodiversity in inland water ecosystems (lakes, rivers and wetlands) and is defined as mean species abundance.

MSA of usable land is the MSA value *of* all land excluding the low-productive areas - ice, tundra and desert - which are less suitable for production especially agriculture and forestry. It ranges from 100% to 0%.

Natural area (NA) is the original area of a biome minus the area converted for human use by agriculture (arable land and land for permanent grazing), forestry plantations, infrastructure and built-up area. Natural area includes both entirely intact and degraded areas. Natural areas are the sum of *affected natural areas* (MSA< 80%) and *wilderness area* (MSA >80%). The indicator is expressed in million km^2 (see ecosystem extent).

Option is a possible (bio-physical) change in a sector such as forestry, fishery, agriculture and energy production as compared to a development path without new policies (baseline scenario), such as lowering fishing effort and increasing the amount of forestry plantations.

Option package is a combination of two or more individual options superimposed on a baseline scenario, which is, in this study, a no new policies scenario.

Pasture is grassland managed for livestock grazing, often planted.

Production is the total quantity of a commodity produced, for example by a country in a specific year.

Productivity is an economic concept, indicating the output of a production process per unit input. Basic types of productivity are (i) land productivity (e.g., production per ha), (ii) labour productivity (production per labour-hour), and (iii) capital productivity (production per USD invested).

Plantation forestry is a forestry management system using planted endemic or exotic tree species, including activities that improve productivity. Mostly, homogeneous even-aged stands of planted exotic species are used.

Policy options*:* see option

Pressure*:* see driving force

Recovery: see ecosystem recovery

Reduced impact logging (RIL) is a form of selective logging in which a number of measures have been developed to minimise damage to the residual forest, and to promote future timber harvest.

Region is a geographical area used to divide the world into more or less homogeneous socio-political units. In IMAGE 2.4, a total of 26 regions are used to cover the whole terrestrial world (including Greenland and Antarctica). Greenland and Antarctica are excluded from the regional and global calculations in this report.

Scenarios are applied to explore possible futures in which particular factors and developments are considered as highly autonomous, and not to be influenced by the policy makers. Developments which can be influenced by policy measures are considered in this report as policy options. Options are superimposed on a baseline scenario. See also *driving force*.

Sector is an economic activity such as agriculture, forestry and fisheries.

Selective logging is a method in which only a relatively small number of tree species of economic importance are harvested. Damage to the remaining forest stand may be considerable and larger than the volume harvested (see also RIL and Forestry).

Semi-natural forest is forest harvested (applying clear cutting) followed by a re-growth phase using mostly indigenous species. Cutting cycles are longer than in plantations. Re-growth can be assisted by planting, seeding and other silviculture techniques. Wood production in temperate and boreal forest mostly takes place in semi-natural forest (See also Forestry).

Silviculture is the practice of controlling the establishment, growth, composition, health, and quality of forests to meet diverse needs and values of the many landowners, societies and cultures.

Single option is one possible (bio-physical) change in a sector such as forestry, fishery, agriculture and energy production as compared to a development path without new policies (baseline scenario). Examples are: i) lowering fishing effort, ii) increasing the amount of forestry plantations, or iii) increasing agricultural productivity.

Species abundance is the total number of individuals of a species in a particular area. It can be measured in various ways such as numbers of individuals, total biomass, distribution area and vegetation cover.

Species density is the abundance of a single species per spatial unit.

Species richness is the number of the species present in a particular area or spatial unit. As it is practically impossible to count all species, species richness is generally determined for selected taxonomic groups such as birds, mammals and vascular plants.

Targets often reflect tangible performance objectives developed through policy-planning processes. For example, a country has established a target of protecting at least 10% of each habitat type.

Under-nourishment is the prevalence of under-nourishment as applied in the MDG indicator framework (MDG 1) and defined as the number of people with a lower calorie-intake than is required to perform basic activities (on average around 1800-2100 kcal per person per day).

Usable land is all land excluding the low-productive areas such as ice, tundra and desert which are less suitable for production purposes, especially agriculture and forestry.

Yield is an agronomic concept. For crops, this is the amount produced per unit area, usually expressed in ton/ha at harvest. For livestock, it can also refer to the amount of meat per animal slaughtered.

Wilderness areas are natural areas with a low degree of human influences. These areas are mainly areas where large animals can roam freely and vegetation is untouched by humans. In this study, wilderness areas are defined as the natural area with high MSA values, arbitrarily set higher than 80% and expressed in million km^2.

References

Achard F (2002) Determination of deforestation rates of the world's humid tropical forests. Science 297:999-1002.

Alder J, Guénette S, Beblow J, Cheung W, and Christensen V (2007) Ecosystem-based global fishing policy scenarios. UBC Fisheries Centre, Vancouver.

Alkemade R, van Oorschot M, Miles L, Nellemann C, Bakkenes M, and ten Brink B (2009) GLOBIO3: A Framework to Investigate Options for Reducing Global Terrestrial Biodiversity Loss. Ecosystems 12:374-390.

Antweiler W, Copeland B, and Taylor MS (2001) Is free trade good for the environment? American Economic Review 91:877-908.

Arets EJMM, Palosuo T, Moiseyev A, Nabuurs GJ, Slimani D, Olsmat C, Laurijssen J, Mason B, McGowan D, and Vötter D (2008) Reference futures and scenarios for the European forestry wood chain. Deliverable 1.4.7 of EC FP6 project EFORWOOD. Alterra, Wageningen UR, Wageningen, The Netherlands.

Arets, EJMM, van der Meer PJ, Verwer CC, Nabuurs G-J, Hengeveld GM, Tolkamp GW, van Oorschot M (2010) Global wood production: Assessment of industrial round wood supply from different management systems in different global regions. Alterra-Rapport 1808. Alterra, Wageningen UR, Wageningen, The Netherlands

Balmford A and Whitten T (2003) Who should pay for tropical conservation, and how could the costs be met? Oryx 37:238-250.

Bakkes JA, Bosch PR, Bouwman AFE, den Elzen MGJ, Janssen PHM, Isaac M, Klein Goldewijk K, Kram T, de Leeuw FAAM, Olivier JGJ, van Oorschot MMP, Stehfest EE, van Vuuren DP, Bagnoli P, Chateau J, Corfee-Morlot J, and Kim YG (2008) Background report to the OECD Environmental Outlook to 2030. Overviews, details, and methodology of model-based analysis. PBL Report 500113001/2008, Bilthoven, The Netherlands.

Bakkenes M and ten Brink BJE (2009) A green development mechanism: biodiversity compensation on a global, regional and biome scale. PBL Report 55505003, Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Barbier EB (2000) Links between economic liberalization and rural resource degradation in the developing regions. Agricultural Economics 23:299-310.

Barlow J, Gardner TA, Araujo IS, Avila-Pires TC, Bonaldo AB, Costa JE, Esposito MC, Ferreira LV, Hawes J, Hernandez MIM, Hoogmoed MS, Leite RN, Lo-Man-Hung NF, Malcolm JR, Martins MB, Mestre LAM, Miranda-Santos R, Nunes-Gutjahr AL, Overal WL, Parry L, Peters SL, Ribeiro-Junior MA, da Silva MNA, da Silva-Motta C, and Peres CA (2007) Quantifying the biodiversity value of tropical primary, secondary, and plantation forests. PNAS 104:18555-18560.

Bartholomé E and Belward AS (2005) GLC2000: a new approach to global land cover mapping from Earth observation data. International Journal of Remote Sensing 26:1959 - 1977.

Behringer T and Lucht W (2008) Simulation nachhaltiger bioenergiepotentiale wissenschaftlicher beirat der bundesregierung globale umweltveränderungen. Berlin.

Biermann F, Pattberg P, and Zelli F (2010) Global climate governance beyond 2012. Cambridge University Press, Cambridge.

Bostock J, McAndrew B, Richards R, Jauncey K, Telfer T, Lorenzen K, Little D, Ross L, Handisyde N, Gatward I, and Corner R (2010) Aquaculture: global status and trends. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2897-2912.

Bourguignon F, Bénassy-Quéré A, Dercon S, Estache A, Gunning J, Kanbur R, Klasen S, Maxwell S, Platteau J, and Spadaro A (2008) Millennium Development Goals at Midpoint: Where do we stand and where do we need to go?

Bouwman AF, Kram T, and Klein Goldewijk K. (2006) Integrated modelling of global environmental change. An overview of IMAGE 2.4. Report 500110002, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Braat L and ten Brink P (2008) The Cost of Policy Inaction: The case of not meeting the 2010 biodiversity target. Wageningen/Brussels.

Brink BJE ten, Hosper SH, and Colijn F (1991) A quantitative method for description and assessment of ecosystems, the AMOEBA-approach. Marine pollution bulletin 23:265-270.

Brink BJE ten (2007) Indicators as communication tools. An evolution towards composite indicators. ALTERNet Ref: WPR2-2006-D3b, The Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Brink BJE ten, Van Vliet AJH, Heunks C, de Haan BJ, Pearce DW, and Howarth A (2000) Technical Report on Biodiversity in Europe: an integrated economic and environmental assessment. Report 481505019, RIVM, Bilthoven.

Brooks TM, Mittermeier RA, da Fonseca GAB, Gerlach J, Hoffmann M, Lamoreux JF, Mittermeier CG, Pilgrim JD, and Rodrigues ASL (2006) Global Biodiversity Conservation Priorities. Science 313:58-61.

Brown C (2000) The global outlook for future wood supply from forest plantations. FAO Working Paper, Rome.

Bruinsma J (2003) World Agriculture: towards 2015/2030. An FAO perspective. Earthscan, London & FAO, Rome.

Bruner AG, Gullison RE, and Balmford A (2004) Financial Costs and Shortfalls of Managing and Expanding Protected-Area Systems in Developing Countries. BioScience 54:1119-1126.

Brussaard L, Caron P, Campbell B, Lipper L, Mainka S, Rabbinge R, Babin D, and Pulleman M (2010) Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Current Opinion in Environmental Sustainability 2:34-42.

Butchart SHM, Walpole M, Collen B, van Strien A, Scharlemann JPW, Almond REA, Baillie JEM, Bomhard B, Brown C, Bruno J, Carpenter KE, Carr GM, Chanson J, Chenery AM, Csirke J, Davidson NC, Dentener F, Foster M, Galli A, Galloway JN, Genovesi P, Gregory RD, Hockings M, Kapos V, Lamarque J-F, Leverington F, Loh J, McGeoch MA, McRae L, Minasyan A, Morcillo MH, Oldfield TEE, Pauly D, Quader S, Revenga C, Sauer JR, Skolnik B, Spear D, Stanwell-Smith D, Stuart SN, Symes A, Tierney M, Tyrrell TD, Vie J-C, and Watson R (2010) Global Biodiversity: Indicators of Recent Declines. Science 328:1164-1168.

Carle J and Holmgren P (2008) Wood from Planted Forests. A global Outlook 2005-2030. Forest Products Journal 58:6-18.

CAWMA (2007) Water for food, water for life: a comprehensive assessment of water Management in Agriculture. Earthscan, London.

CBD (1992) Text of the convention on biological diversity. Retrieved April 15, 2010 from http://www.cbd.int/convention/convention.shtml

Cervantes-Godoy D and Dewbre J (2010) Economic Importance of Agriculture for Poverty Reduction. OECD Food, Agriculture and Fisheries Working Papers.

Clarke L, Edmonds J, Krey V, Richels R, Rose S, and Tavoni M (2010) International Climate Policy Architectures: Overview of the EMF 22 International Scenarios. Energy Economics 31(SUPPL. 2): S64-S81.

Clay J (2004) World agriculture and the environment. A commoditiy-by-commodity guide to impacts and practices. Island Press, Washington DC.

Coad L, Burgess ND, Loucks C, Fish L, Scharlemann JPW, Duarte L, and Besançon B. (2009) The ecological representativeness of the global protected areas estate in 2009: progress towards the CBD 2010 target. UNEP-WCMC, Cambridge, WWFUS and ECI, University of Oxford.

Cork S, Peterson G, and Petschel-Held G (2005) Four Scenarios. In: Carpenter SR, Pingali PL, Bennett EM, and Zurek MB (eds.). Millenium Ecosystem Assessment Board, Ecosystems and Human Well-being. Island Press, Washington, pp. 223-294.

Dixon J, Braun H-J, Kosina P, and Crouch J (eds.). (2009) Wheat Facts and Futures 2009. CIMMYT, Mexico, DF.

Dornburg V, van Vuuren D, van de Ven G, Langeveld H, Meeusen M, Banse M, van Oorschot M, Ros J, van den Born G-J, Aiking H, Londo M, Mozaffarian H, Verweij P, Lysen E, and Faaij A (2010) Bioenergy revisited: Key factors in global potentials of bioenergy. Energy & Environmental Science 3:258-267.

Duellman WE (1999) Global distribution of amphibians: patterns, conservation, and future challenges. In: Duellman WE (ed.). Patterns of Distribution of Amphibians: a Global Perspective. John Hopkins University Press, Baltimore. p 1–30.

Dyck A and Sumaila U (2009) Contribution of ocean fish populations to the world economy. Fisheries Centre Working Paper no. 2009-08. The University of British Columbia, Vancouver, Canada.

Edenhofer O, Knopf B, Barker T, Baumstark L, Bellevrat E, Chateau B, Criqui P, Isaac M, Kitous A, Kypreos S, Leimbach M, Lessmann K, Magne B, Scrieciu S, Turton H, and van Vuuren D (2010) The Economics of Low Stabilization: Model Comparison of Mitigation Strategies and Costs. The Energy Journal 31:11-48.

Eickhout BJ, Van Meijl H, and Tabeau A (2006) Modelling agricultural trade and food production under different trade policies. In: Bouwman AF, Kram T, Klein Goldewijk K (eds.) Integrated modelling of global environmental change. An overview of IMAGE 2.4. Report no. 500110002, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Engström R and Carlsson-Kanyama A (2004) Food losses in food service institutions Examples from Sweden. Food Policy 29:203-213.

European Communities (2008) The Economics of Ecosystems and Biodiversity, an interim report.

FAO (2001) Global forest resources assessment 2000. Main report. FAO Forestry Paper 140, Rome.

FAO (2006) Global forest resources assessment 2005. Progress towards sustainable forest management. FAO Forestry Paper 147, Rome.

FAO (2006b) FAOSTAT database collections. Food and Agriculture Organization of the United Nations, Rome.

FAO (2009) The state of world fisheries and aquaculture 2008. FAO, Rome.

FAO (2010) Global forest resources assessment 2010. Key findings. Rome.

FAO and WorldBank (2009) Awakening Africa's sleeping giant. Prospects for commercial agriculture in the Guinea savannah zone and beyond. The World Bank, Washington DC and FAO, Rome.

Fargione J, Hill J, Tilman D, Polasky S, and Hawthorne P (2008) Land Clearing and the Biofuel Carbon Debt. Science 319:1235-1238.

Ferrier S, Powell GVN, Richardson KS, Manion G, Overton JM, Allnut TF, Cameron SE, Mantle K, Burgess ND, Fith DP, Lamoreux JF, Kier G, Hijmans RJ, Funk VA, Cassis GA, Fisher BL, Flemons P, Lees D, Lovett JC, and van Rompaey RSAR (2004) Mapping More of Terrestrial Biodiversity for Global Conservation Assessment. Bioscience 54:1101-1109.

Huang H and Labys WC (2001) Environment and Trade: Theories and Methods. Research Paper 2001-1, Regional Research Institute, West Virginia University.

Fisher B, Nakicenovic N, Alfsen K, Corfee Morlot J, de la Chesnaye F, Hourcade J-C, Jiang K, Kainuma M, La Rovere E, Matysek A, Rana A, Riahi K, Richels R, Rose S, Van Vuuren D, Warren R, Ambrosi P, Birol F, Bouille D, Clapp C, Eickhout B, Hanaoka T, Mastrandrea MD, Matsuoko Y, O'Neill B, Pitcher H, Rao S, and Toth F (2007) Issues related to mitigation in the long-term context. In: Metz B, Davidson O, Bosch P, Dave R, Meyer L (eds.). Climate change 2007. Mitigation of climate change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, pp. 169-250.

Geist HJ and Lambin EF (2009) Proximate Causes and Underlying Driving Forces of Tropical Deforestation. BioScience 52:143-150.

Giller KE, Witter E, Corbeels M, and Tittonell P (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Research 114:23-34.

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, and Toulmin C (2010) Food Security: The Challenge of Feeding 9 Billion People. Science 327:812-818.

Groot RS de, Alkemade R, Braat L, Hein L, and Willemen L (2010) Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7:260-272.

Gregory RD, van Strien A, Vorisek P, Gmelig Meyling AW, Noble DG, Foppen RPB, and Gibbons DW (2005) Developing indicators for European birds. Philosophical Transactions of the Royal Society B: Biological Sciences 360:269-288.

Gurib-Fakim A, and Smith L (2009) Chapter 6 - Options to enhance the impact of AKST on development and sustainability goals. In: Agriculture at a Crossroads - The Global Report. International Assessment of Agricultural Knowledge, Science, and Technology. Island Press, Washington DC. p 377-440.

Hof AF, de Bruin KC, Dellink RB, den Elzen MGJ, and van Vuuren DP (2009) The effect of different mitigation strategies on international financing of adaptation. Environmental Science & Policy 12:832-843.

Hoogwijk M, Faaij A, Eickhout B, de Vries B, and Turkenburg W (2005) Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. Biomass and Bioenergy 29:225-257.

Houghton R (2008) Carbon Flux to the Atmosphere from Land-Use Changes: 1850-2005. In: TRENDS: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Hussain S, Brander L, McVittie A, Verburg P, Wagtendonk A, de Groot RS, van der Ploeg S, Vardakoulias O, and Tinch R (2010) The Economics of Ecosystems and Biodiversity [TEEB]: The Quantitative Assessment. UNEP.

IAASTD (2008) Synthesis Report of the International Assessment of Agricultural Science and Technology for Development. Island Press, Washington DC.

IAASTD (2009) Agriculture at a crossroads - the global report. International Assessment of Agricultural Knowledge, Science, and Technology. Island Press, Washington DC.

IAC (2004) Realizing the promise and potential of African agriculture - Science and technology strategies for improving agricultural productivity and food security in Africa InterAcademy Council, Amsterdam.

IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment. Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK

IUCN and UNEP (2006) The World Database on Protected Areas (WDPA). UNEP-WCMC, Cambridge, UK.

Izac AM, Egelyng H, and Ferreira G (2009) Options for Enabling Policies and Regulatory Environments. Chapter 7 in: McIntyre BD, Herren HR, Wakhungu J, and Watson RT (eds.). Agriculture at a Crossroads - The Global Report. International Assessment of Agricultural Knowledge, Science, and Technology. Island Press, Washington DC; pp 377-440.

James A, Gaston KJ, and Balmford A (2001) Can We Afford to Conserve Biodiversity? BioScience 51:43-52.

Janssen PHM, Petersen AC, van der Sluijs JP, Risbey JS, and Ravetz JR (2003) RIVM/MNP Guidance for uncertainty assessment and communication. Quickscan hints & actions list. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Jetz W, Wilcove DS, and Dobson AP (2007) Projected Impacts of Climate and Land-Use Change on the Global Diversity of Birds. PLoS Biology 5:e157.

Kader AA (2005) Increasing food availability by reducing postharvest losses of fresh produce. In: Mencarelli F, Tonutti P (eds.). Proceedings of the 5th International Postharvest Symposium: ACTA Horticulturae 682, ISHS 2005.

Kallio AMI, Moiseyev A, and Solberg B (2004) The Global Forest Sector Model EFI-GTM - The Model structure. European Forest Institute, Joensuu, Finland.

Kantor LS, Lipton K, Manchester A, and Oliveira V (1997) Estimating and addressing America's food losses. FoodReview:1-12.

Karousakis K. (2009) Promoting biodiversity co-benefits in REDD. In: OECD Environment Working Papers, No. 11: OECD Publishing, Paris, France

Keating B, Carberry P, Bindraban P, Asseng S, Meinke H, and Dixon J (2010) Eco-efficient agriculture: Concepts, challenges, and opportunities. Crop Science 50:S-1 – S-11

Kier G, Mutke J, Dinerstein E, Ricketts TH, Kuper W, Kreft H, and Barthlott W (2005) Global patterns of plant diversity and floristic knowledge. Journal of Biogeography 32:1107-1116.

Kindermann G, Obersteiner M, Sohngen B, Sathaye J, Andrasko K, Rametsteiner E, Schlamadinger B, Wunder S, and Beach R (2008) Global cost estimates of reducing carbon emissions through avoided deforestation. Proceedings of the National Academy of Sciences 105:10302-10307.

Kok MTJ, Tyler S, Prins A, Pintér L, Baumüller H, Bernstein J, Tsioumani E, Venema H, and Grosshans R (2010) Prospects for mainstreaming ecosystem goods and services in international policies. PBL publication no. 550050001, Netherlands Environmental Assessment Agency (PBL), The Hague/ Bilthoven, The Netherlands.

Kok MTJ, Bakkes JA, Eickhout B, Manders AJG, van Oorschot MMP, van Vuuren DP, van Wees M, and Westhoek HJ (2008) Lessons from global environmental assessments. PBL publication no. 500135002, Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Koning NBJ, van Ittersum MK, Becx GA, van Boekel MAJS, Brandenburg WA, van den Broek JA, Goudriaan J, van Hofwegen G, Jongeneel RA, Schiere JB, and Smies M (2008) Long-term global availability of food: continued abundance or new scarcity? NJAS - Wageningen Journal of Life Sciences 55:229-292.

Kuijk M van, Putz FE, and Zagt R (2009) Effects of Forest Certification on Biodiversity. Tropenbos International, Wageningen, The Netherlands.

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skanes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, and Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change 11:261-269.

Laurance WF (2006) Have we overstated the tropical biodiversity crisis? Trends in Ecology & Evolution, 22:65-70.

Laurance WF (2008) Can Carbon Trading Save Vanishing Forests. BioScience 58:286-287.

Leadley P, Pereira H, Alkemade R, Fernandez-Manjarrés J, Proenca V, Scharlemann J, and Walpole M (2010) Biodiversity scenarios: Projections of 21st century change in biodiversity and associated ecosystem services. Technical Series no. 50, Secretariat of the Convention on Biological Diversity, Montreal.

Leemans R and Eickhout B (2004) Another reason for concern: regional and global impacts on ecosystems for different levels of climate change. Global Environmental Change 14:219-228.

Lobell DB, Cassman KG, and Field CB (2009) Crop Yield Gaps: Their Importance, Magnitudes, and Causes. Annual Review of Environment and Resources 34:179-204.

Lockwood JL and McKinney ML (2001) Biotic Homogenization. Kluwer, New York. 289p.

Loh J, Green RE, Ricketts T, Lamoreux J, Jenkins M, Kapos V, and Randers J (2005) The Living Plant Index: using species population time series to track trends in biodiversity. Philosophical Transactions of the Royal Society B 360: 289-295.

Lundqvist J (2009) Losses and waste in the global crisis. Reviews in Environmental Science and Biotechnology 8:121-123.

Majer JD and Beeston G (1996) The Biodiversity Integrity Index: An Illustration Using Ants in Western Australia. Conservation Biology 10:65-73.

Margules CR, and Pressey RL (2000) Systemic conservation planning. Nature 405:243-253.

MEA (2005) Ecosystems and Human well-being: Synthesis of the Millennium Ecosystem Assessment. Island Press, Washington DC.

Meinshausen M (2006) What does a 2°C target mean for greenhouse gas concentrations? - A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates. In: Schellnhuber JS, Cramer W, Nakicenovic N, Wigley TML, and Yohe G (eds.). Avoiding Dangerous Climate Change. Cambridge University Press.

Miles L and Kapos V (2008) Reducing Greenhouse Gas Emissions from Deforestation and Forest Degradation: Global Land-Use Implications. Science 320:1454-1455.

Minnen J van (2008) PhD thesis - The terrestrial carbon cycle on the regional and global scale. Modelling, uncertainties and policy relevance. Wageningen UR, The Netherlands.

Minnen J van, Klein Goldewijk K, Stehfest E, Eickhout B, van Drecht G, and Leemans R (2009) The importance of three centuries of land-use change for the global and regional terrestrial carbon cycle. Climatic Change 97:123-144.

Mittermeier R, Mittermeier C, Gil P, Pilgrim J, Fonseca G, Brooks T, and Konstant W (2002) Wilderness - earth's last wild places. CEMEX, Mexico City.

MNP (2006) Natuurbalans 2006. Publication no. 500402001. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Mora C, Myers RA, Coll M, Libralato S, Pitcher TJ, Sumaila RU, Zeller D, Watson R, Gaston KJ, and Worm B (2009) Management Effectiveness of the World's Marine Fisheries. PLoS Biology 7:e1000131.

Moreira P and Padrao P (2004) Educational and economic determinants of food intake in Portuguese adults: a cross-sectional survey. BMC Public Health 4:58.

Mulongoy KJ and Chape S. (2004) Protected areas and biodiversity. An overview of key issues. UNEP/WCMC, Cambridge. p 56

Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, and Kent J (2000) Biodiversity hotspots for conservation priorities. Nature 403:853-858.

Nelleman C, MacDevette M, Manders T, Eickhout B, Svihus B, Prins AG, and Kaltenborn BPE (2009) The environmental food crisis – The environment's role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal.

Nepstad DC, Stickler CM, Filho BS, and Merry F (2008) Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point. Philosophical Transactions of the Royal Society B: Biological Sciences 363:1737-1746.

Nepstad D, Soares-Filho BS, Merry F, Lima A, Moutinho P, Carter J, Bowman M, Cattaneo A, Rodrigues H, Schwartzman S, McGrath DG, Stickler CM, Lubowski R, Piris-Cabezas P, Rivero S, Alencar A, Almeida O, and Stella O (2009) The End of Deforestation in the Brazilian Amazon. Science 326:1350-1351.

Neumann K, Verburg PH, Stehfest E, and Müller C (2010) The yield gap of global grain production: A spatial analysis. Agricultural Systems 103:316-326.

Nobre CA and Borma LDS (2009) 'Tipping points' for the Amazon forest. Current Opinion in Environmental Sustainability 1:28-36.

OECD (2008) OECD Environmental Outlook to 2030. OECD, Paris.

OECD and IEA (2006) World Energy Outlook. International Energy Agency (IEA), Paris, France.

Oldeman L, Hakkeling R, and Sombroek W (1991) World Map of the status of human induced soil degradation: an explanatory note. ISRIC/UNEP, Wageningen.

Olson DW, Dinerstein E, Wikramanayake ED, Burgess ND, Powell GVN, Underwood EC, D'Amico JA, Itoua I, Strand HE, Morrison JC, Loucks CJ, Allnutt TF, Ricketts TH, Kura Y, Lamoreux JF, Wettengel WW, Hedao P, and Kassem KR (2001) Terrestrial ecoregions of the world: a new map of life on earth. Bioscience 51:933-938.

Olson DM and Dinerstein E (2002) The Global 200: priority ecoregions for global conservation Annals of the Missouri Botanical Garden 89:199-224.

Oorschot M van, Ros J, and Notenboom J (2010) Evaluation of the indirect effects of biofuels on biodiversity: assessing acros spatial and temporal scales. Publication no. 500143007, Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Overbeek C, Bouwman A, Beusen A, and Pawlowski M (in press) Past and future nitrogen and phosphorus balances and feed use in global aquaculture: II finfish. Reviews in Fisheries Science.

PBL (2009) Beyond 2015: Long-term development and the Millennium Development Goals. Hilderink HBM, Lucas PL and Kok MTJ (eds.). Report no. 550025004, Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Pauly D, Alder J, Bennett E, Christensen V, Tyedmers P, and Watson R (2003) The future of fisheries. Science 302:1359-1361.

Pauly D, Watson R, and Alder J (2005) Global trends in world fisheries: impacts on marine ecosystems and food security. Philosophical Transactions of the Royal Society B: Biological Sciences 360:5-12.

Pawlowski M, Bouwman A, Beusen A, and Overbeek C (in press) Past and future nitrogen and phosphorus balances and feed use in global aquaculture: I shellfish and aquatic plants. Reviews in Fisheries Science.

Phelps J, Guerrero MC, Dalabajan DA, Young B, and Webb EL (2010) What makes a 'REDD' country? Global Environmental Change 20:322-332.

Ploeg JD van der (2010) The Food Crisis, Industrialized Farming and the Imperial Regime. Journal of Agrarian Change 10:98-106.

Potere D and Schneider A (2007) A critical look at representations of urban areas in global maps. GeoJournal 69:55-80.

Pretty JN, Morison JIL, and Hine RE (2003) Reducing food poverty by increasing agricultural sustainability in developing countries. Agriculture, Ecosystems and Environment 95:217-234.

Putz FE, Sist P, Fredericksen T, and Dykstra D (2008a) Reduced-impact logging: Challenges and opportunities. Forest Ecology and Management 256:1427-1433.

Putz FE, Zuidema PA, Pinard MA, Boot RGA, Sayer JA, Sheil D, Sist P, Elias, and Vanclay JK (2008b) Improved Tropical Forest Management for Carbon Retention. PLoS Biology 6:e166.

Rao S, Riahi K, Stehfest E, van Vuuren D, Cheolhung C, den Elzen M, Isaac M, and van Vliet J (2008) IMAGE and MESSAGE Scenarios Limiting GHG Concentration to Low Levels. IIASA, Laxenbourg.

Rockstrom J, Steffen W, Noone K, Persson A, Chapin FS, Lambin EF, Lenton TM, Scheffer M, Folke C, Schellnhuber HJ, Nykvist B, de Wit CA, Hughes T, van der Leeuw S, Rodhe H, Sorlin S, Snyder PK, Costanza R, Svedin U, Falkenmark M, Karlberg L, Corell RW, Fabry VJ, Hansen J, Walker B, Liverman D, Richardson K, Crutzen P, and Foley JA (2009) A safe operating space for humanity. Nature 461:472-475.

Rodrigues ASL, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Cowling RM, Fishpool LDC, da Fonseca GAB, Gaston KJ, Hoffmann M, Long JS, Marquet PA, Pilgrim JD, Pressey RL, Schipper J, Sechrest W, Stuart SN, Underhill LG, Waller RW, Watts MEJ, and Yan X (2004) Effectiveness of the global protected area network in representing species diversity. Nature 428:640-643.

Rodrigues ASL, Ewers RM, Parry L, Souza C, Jr., Verissimo A, and Balmford A (2009) Boom-and-Bust Development Patterns Across the Amazon Deforestation Frontier. Science 324:1435-1437.

Rood G, Nagelhout D, Ros J, and Wilting H (2006) Duurzame viskweek voor behoud van de visvoorraad; Evaluatie van transities op basis van systeemopties. MNP report no. 500083006, Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

Ros J, Overmars K, Stehfest E, Prins A, Notenboom J, and van Oorschot M (2010) Identifying the indirect effects of bio-energy production. PBL report no. 500143003, Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Rosegrant MW, Fernandez M, and Sinha A (2009) Chapter 5 - Looking into the future for agriculture and AKST. In: Agriculture at a Crossroads - The Global Report. International Assessment of Agricultural Knowledge, Science, and Technology. Island Press, Washington DC. p 307-376.

Sala O, Chapin III F, Armesto J, Berlow E, Bloomfield J, Irzo R, Huber-Samwald E, Huenneke K, Jackson R, Kinzig A, Leemans R, Lodge D, Mooney H, Oesterheld M, Poff N, Sykes M, Walker B, Walker M, and Wall D (2000) Global biodiversity scenarios for the year 2100. Science 287:1770-1774.

Sala OE, Sax D, and Leslie H (2009) Biodiversity consequences of increased biofuel production. In: Howarth R, and Bringezu S (eds.). Biofuels: environmental consequences and interactions with changing land use. Proceedings of the scientific committee on problems of the environment (SCOPE). International biofuels project rapid assessment, 22 – 25 September 2008, Gummersbach Germany, Cornell University, Ithaca NY, USA, pp. 127-137.

Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, and Woolmer G (2002) The Human footprint and the last of the wild. BioScience 52:891-904.

sCBD (2006) Global Biodiversity Outlook 2. Global Biodiversity Outlook 2. Secretariat of the Convention on Biological Diversity, Montreal Montreal.

sCBD (2009) Connecting biodiversity and climate change mitigation and adaptation: report of the second ad hoc technical expert group on biodiversity and climate change. CBD Technical series No. 41, Secretariat of the Convention on Biological Diversity, Montreal, 126 pages.

sCBD (2010) Global Biodiversity Outlook 3. Secretariat of the Convention on Biological Diversity, Montreal.

sCBD, PBL (2007) Cross-roads of life on earth. Exploring means to meet the 2010 Biodiversity Target. Solution-oriented scenarios for Global Biodiversity Outlook 2. Secretariat of the Convention on Biological Diversity (sCBD), Montreal and Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Scherr SJ and Yadav S (2001) Land degradation in the developing world. In: Pinstrup-Andersen P, and Pandya-Lorch R (eds.). The Unfinished Agenda. International Food Policy Research Institute, Washington DC, USA. p 133-138.

Schnepf RD, Dohlman E, and Bolling C. (2001) Agriculture in Brazil and Argentina: developments and prospects for major field crops. In: Agriculture and Trade Report No. (WRS013): Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture. p 85 pp.

Scholes RJ and Biggs R (2005) A biodiversity intactness index. Nature 434:45-49.

Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, and Yu T-H (2008) Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change. Science 319:1238-1240.

Smil V (2002) Eating Meat: Evolution, Patterns, and Consequences. Population and Development Review 28:599-639.

Smith P, Gregory PJ, van Vuuren D, Obersteiner M, Havlík P, Rounsevell M, Woods J, Stehfest E, and Bellarby J (2010) Competition for land. Philosophical Transactions of the Royal Society B: Biological Sciences 365:2941-2957.

Spangenberg JH (2007) Biodiversity pressure and the driving forces behind. Ecological Economics 61:146-158.

Stattersfield AJ, Crosby MJ, Long AJ, and Wege DC (1998) Endemic bird areas of the world: priorities for biodiversity conservation. In: Birdlife International. Cambridge, UK.

Stehfest E, Bouwman L, van Vuuren D, den Elzen M, Eickhout B, and Kabat P (2009) Climate benefits of changing diet. Climatic Change 95:83-102.

Stehfest E, Woltjer G, Tabeau A, Prins AG, Banse M, Eickhout B, and van Meijl H (forthcoming) Land use and greenhouse gas effects of European and global biofuel mandates.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, and Haan C (2006) Livestock's long shadow. Environmental issues and options. FAO, Rome.

Stokstad E (2010) Despite Progress, Biodiversity Declines. Science 329:1272-1273.

Sumaila U, Khan A, Dyck A, Watson R, Munro G, Tydemers P, and Pauly D (2010) A bottom-up re-estimation of global fisheries subsidies. Journal of Bioeconomics:1-25.

Thomas CD, Cameron A, Green RE, Bakkenes M, Beaumont LJ, Collingham YC, Erasmus BFN, de Siqueira MF, Grainger A, Hannah L, Hughes L, Huntley B, van Jaarsveld AS, Midgley GF, Miles L, Ortega-Huerta MA, Townsend Peterson A, Phillips OL, and Williams SE (2004) Extinction risk from climate change. Nature 427:145-148.

UN (1993) Convention on biological diversity (with annexes). Concluded at Rio de Janeiro on 5 June 1992. No 30619. United Nations Treaty Series, New York. p 143-382.

UNEP (2002) Global Environment Outlook 3. United Nations Environment Programme, Earthscan, London.

UNEP (2007) Global Environment Outlook 4. Environment for Development. United Nations Environment Programme, Nairobi.

UNEP (2008) Synthesis of global environmental assessment: Environment for development – policy lessons from global environmental assessments. United Nations Environment Programme, Nairobi. p 24.

UNESCO (2009) Water in a changing world. World Water Development Report 3.

UN Millennium Project (2005) Halving hunger: it can be done. Task Force on Hunger.

UNEP (1997) Global Environment Outlook. United Nations Environment Programme, Nairobi, Kenya.

Venter O, Laurance WF, Iwamura T, Wilson KA, Fuller RA, and Possingham HP (2009) Harnessing Carbon Payments to Protect Biodiversity. Science 326:1368-.

Verburg R, Stehfest E, Woltjer G, and Eickhout B (2009) The effect of agricultural trade liberalisation on land-use related greenhouse gas emissions. Global Environmental Change 19:434-446.

Vliet J van, den Elzen M, and van Vuuren D (2009) Meeting radiative forcing targets under delayed participation. Energy Economics 31:S152-S162.

Vuuren DP van, Den Elzen M, Lucas P, Eickhout B, Strengers B, Van Ruijven B, Wonink S, Van den Houdt R, Berk M, and Oostenrijk R (2007a) Stabilising greenhouse gas concentrations. Assessment of different strategies and costs using an integrated assessment framework. Climatic Change 81:119 - 159.

Vuuren DP van, den Elzen M, Lucas P, Eickhout B, Strengers B, van Ruijven B, Wonink S, and van Houdt R (2007b) Stabilizing greenhouse gas concentrations at low levels: an assessment of reduction strategies and costs. Climatic Change 81:119-159.

Vuuren DP van, Bellevrat E, Kitous A, and Isaac M (2010) Bio-Energy Use and Low Stabilization Scenarios. The Energy Journal:192-222.

Vuuren DP van, Berk M, Farla J, and de Vos R. (2006) From climate objectives to emission reduction. Insights into the opportunities for mitigating climate change. Report no. 500114003, The Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands. p 60.

Vuuren DP van, Sala OE, and Pereira HM (2006) The Future of Vascular Plant Diversity Under Four Global Scenarios. Ecology and Society 11:25.

Vuuren DP van and Faber A (2009) Growing within Limits. A Report to the Global Assembly 2009 of the Club of Rome. PBL publication number 500201001, Netherlands Environmental Assessment Agency (PBL), Bilthoven, The Netherlands.

Vuuren DP van, Meinshausen M, Plattner G-K, Joos F, Strassmann KM, Smith SJ, Wigley TML, Raper SCB, Riahi K, de la Chesnaye F, den Elzen MGJ, Fujino J, Jiang K, Nakicenovic N, Paltsev S, and Reilly JM (2008) Temperature increase of 21st century mitigation scenarios. Proceedings of the National Academy of Sciences 105:15258-15262.

WHO (2009) Global health risks: Mortality and burden of disease attributable to selected major risks. World Health Organization, Geneva, Switzerland.

Willett WC (2001) Eat, drink, and be healthy: the Harvard Medical School guide to healthy eating. Simon & Schuster, New York.

Wise M, Calvin K, Thomson A, Clarke L, Bond-Lamberty B, Sands R, Smith SJ, Janetos A, and Edmonds J (2009) Implications of Limiting CO2 Concentrations for Land Use and Energy. Science 324:1183-1186.

WWF (2006) WildFinder: Online database of species distribution, version 01.06. Accessed 19 January 2006.

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Final editing
Ben ten Brink
Stefan van der Esch
Tom Kram
Mark van Oorschot

Main-authors
Rob Alkemade, Robert Ahrens (Fisheries Centre UBC), Michel Bakkenes, Jan Bakkes, Maurits van den Berg, Ben ten Brink, Villy Christensen (Fisheries Centre UBC), Stefan van der Esch, Jan Janse, Michel Jeuken, Tom Kram, Paul Lucas, Ton Manders, Hans van Meijl (LEI), Mark van Oorschot, Elke Stehfest, Andrzej Tabeau (LEI), Detlef van Vuuren, Harry Wilting.

Contributors
Eric Arets (Alterra, Wageningen UR), Lex Bouwman, Gerard van Drecht, Henk Hilderink, Jelle van Minnen, Trudy Rood, Richard Verweij, Edward Vixseboxse, Jasper van Vliet.

External reviewers
Thomas Brooks (NatureServe), Tim Christophersen (sCBD), Fred Langeweg (former Deputy Director PBL), Rik Leemans (Wageningen UR), Markus Lehmann (sCBD), Anil Markandya (Basque Centre for Climate Change), GertJan Nabuurs (European Forest Institute), Aude Neuville (European Commission), Robert Nasi (CIFOR), Alfred Oteng (University of Ghana; former Chair of CBD-SBSTTA), Henrique Pereira (University of Lisbon), Walter Reid (former Director of the MA), Carmen Revenga (The Nature Conservancy), Bob Watson (UK-DEFRA)

General support
Henriët Schaafsma

English editing
Helen West, Annemieke Righart

Graphics and photos
Marian Abels, Filip de Blois, Allard Warrink, Jacqueline Wondergem

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Studio RIVM / Jan de Bie

Project leader and corresponding author
Ben ten Brink, ben.tenbrink@pbl.nl

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Reducing global biodiversity loss by combining solutions for agriculture, forestry, energy, and climate change

The 2010 target of the Convention on Biological Diversity to significantly reduce biodiversity loss, worldwide, has not been met. Conservation and protection will remain important measures to safeguard biodiversity. However, this will not be enough to counter the growing pressure on natural ecosystems – reducing species' prospects for survival as well as the supply of essential goods and services.

Reducing biodiversity loss requires a rethinking on the strategic orientation, from traditional conservation towards structural changes in production and consumption. An ambitious cross-sector strategy was explored within an integrated model framework. This strategy could halve the rate of biodiversity decline, by 2050, compared to the projected loss without new policies. We explored a combination of measures, which include an expanded protected area network, more efficient agriculture and forestry, improved forest management, less meat-intensive diets, and climate change mitigation. These measures also contribute to other objectives, such as improving food security.

This study was conducted at the request of the United Nations Environment Programme (UNEP), in preparation of the Conference of Parties (COP10) of the Convention on Biological Diversity in 2010.

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