10 GLOBIO 3: Framework for the assessment of global terrestrial biodiversity

- The GLOBIO 3 framework was developed to assess past, present and future biodiversity. It consists of clear and transparent relationships between pressure factors and biodiversity, based on state-of-the-art knowledge.
- The pressure factors or driving forces of biodiversity loss considered are land-cover change, land-use intensity, fragmentation, climate change, atmospheric N deposition and infrastructure development. The model is linked to the IMAGE 2.4 framework through changes in land use, shifts in vegetation zones, and climate change.
- Issues that can be addressed with GLOBIO 3 on a regional, continental and global scale include: (i) impacts of human pressures on biodiversity and ecosystems, and their relative importance; (ii) expected trends in mean species abundance (under various future scenarios) and (iii) likely effects of various policy options.

10.1 Introduction

During the sixth meeting of the Conference of Parties on the Convention on Biological Diversity (CBD), the parties committed themselves to achieving a significant reduction of the current rate of biodiversity loss at the global, regional and national level by 2010 (UNEP, 2002a). The governments adopted a plan of implementation at the 2002 World Summit on Sustainable Development (WSSD) in Johannesburg which recognizes the same target; this plan endorsed the CBD as the key instrument in realizing the conservation and sustainable use of biological diversity.

Among the several studies on global biodiversity loss carried out the last few years are those describing the contemporaneous situation (Hannah et al., 1994; Sanderson et al., 2002; Wackernagel et al., 2002; McKee et al., 2003; Cardillo et al., 2004) or expert opinions used for estimating impacts (Sala et al., 2000). In the Global Environmental Outlook 3 (UNEP, 2002b) the consequences of four socio-economic scenarios on biodiversity were assessed using both the Natural Capital Index (NCI) approach of IMAGE and the GLOBIO 2 approach (UNEP/RIVM, 2004). In the IMAGE-NCI approach, energy use, land-use change, forestry and climate change were considered as pressure factors and biodiversity loss defined as a deviation from the undisturbed pristine situation due to these pressure factors. In GLOBIO 2 (UNEP, 2001) the human influence on biodiversity is based on relationships between species diversity and the distance to roads.

To meet the challenge of evaluating the targets set by CBD and WSSD, an international consortium of UNEP-World Conservation and Monitoring Centre (WCMC), UNEP-GRID-Arendal and Netherlands Environmental Assessment Agency (MNP) has combined the GLOBIO 2 and the IMAGE-NCI approach into a new Global Biodiversity Model framework (GLOBIO 3). The outcomes of this model framework are in line with the indicators decided on by the Conference of Parties of the CBD in Kuala Lumpur (UNEP, 2004), particularly with regard to the extent of ecosystems and habitats, and the abundance and distribution of species. The GLOBIO 3 framework, designed to support policy makers in a supra-national setting (e.g. CBD, United Nations Environmental Programme, Organization for Economic Co-operation and Development and European Union), can be used to evaluate the consequences of possible socio-economic scenarios and policy options for biodiversity at global and regional level. It may also help to formulate strategies for biodiversity conservation and sustainable development.

The GLOBIO 3 framework is based on transparent relationships between pressure factors and biodiversity, derived from state-of-the-art knowledge from available literature and data. The model can be used to assess (i) biodiversity in the past, present and future in relation to the impacts of human pressures on species diversity and abundance; (ii) the relative importance of these pressures and (iii) likely effects of various policy options. The model is designed to make a quantitative comparison of biodiversity patterns and changes in these on the world-region scale.

In this chapter we will briefly describe the modelling approach and the relationships between the pressure factors and species diversity that are included in the GLOBIO 3 model framework. Subsequently, we will present results of the model applied to the current situation and for different scenarios for the year 2030.

10.2 Modelling approach

General

The GLOBIO 3 model framework describes biodiversity by means of estimating remaining mean species abundance of original species, relative to their abundance in primary vegetation. This measure of mean species abundance (MSA) is similar to the Biodiversity Integrity Index (Majer and Beeston, 1996) and the Biodiversity Intactness Index (Scholes and Biggs, 2005) and can be considered as a proxy for CBD indicators (UNEP, 2004).

The core of GLOBIO 3 is a set of regression equations describing the impact on biodiversity of the degree of pressure using dose–response relationships. These dose–response relationships are derived from a database of observations of species response to change. The database includes separate measures of MSA, each in relation to different degrees of pressure exerted by various pressure factors or driving forces. The entries in the database are all derived from studies in peer-reviewed literature, reporting either on change through time in a single plot, or on response in parallel plots undergoing different pressures.

The current version of the database includes data from about 500 reports: about 140 reports on the relationship between species abundance and land cover or land use, 50 on atmospheric N deposition (Bobbink, 2004), over 300 on impacts of infrastructure (UNEP, 2001) and several literature reports on minimal area requirements of species. Dose–response relationships for climate change are based on model studies (Bakkenes et al., 2002; Leemans and Eickhout, 2004).

Many studies address the effects of human pressure on global biodiversity and distinguish various indirect and direct drivers or pressure factors (Table 10.1). A direct driver unequivocally influences ecosystem processes and can therefore be identified and measured with varying degrees of accuracy. Main categories of direct drivers are changes in land cover and land use, species introduction and removal, and external inputs such as fertilizer use, pest control or irrigation water (Millennium Assessment, 2003). An indirect driver operates more diffusely, often by altering one or more direct drivers. Major indirect drivers include demographic, economic and socio-political circumstances; science and technology and cultural factors.

The driving forces (pressures) considered by GLOBIO 3 include land-cover change (taken from IMAGE), land-use intensity (partly taken from IMAGE), atmospheric nitrogen (N) deposition (see chapter 8), infrastructure development (as applied in GLOBIO 2), fragmentation and climate change (both taken from IMAGE).

Indirect drivers, such as human population density and energy use, are not used explicitly in the GLOBIO 3 framework, but have an impact on biodiversity through their influence on other –direct – drivers. For example, changes in the direct drivers (land use, climate, atmospheric N deposition and forestry) due to changing demography and socio-economic developments are calculated with IMAGE. Changes in infrastructure are calculated with the GLOBIO 2 model (UNEP, 2001).

Drivers of biodiversity loss

Land use and land-use intensity. We found about 140 published data sets comparing the species diversity and abundance between different land-cover/land-use types. Some of these studies include pristine, undisturbed ecosystems (e.g. primary forest). The different land-use types from these studies were grouped in ten globally consistent categories: primary vegetation, including naturally non-vegetated areas like deserts and ice cover; slightly disturbed or managed primary forests; secondary forests; forest plantations; agroforestry; livestock grazing; man-made pastures; low input agriculture; intensive agriculture and built-up areas (Table 10.2). Most studies describe plant or animal species in the tropical forest biome, but the small number of available studies in other biomes confirms the general picture.

We calculated the value of MSA as the mean of all studies covering each land-cover/land-use category (Table 10.2). The MSA estimates obtained are thus in line with the results of Scholes and Biggs (2005), who estimated fractions of original species populations to be found in a range of land-use types based on expert knowledge.

The data for land cover/land use and changes in these, in which the resolution is 0.5 by 0.5 degrees, originate in the IMAGE model. This model has no fractional land use: i.e. a grid cell is covered either by agricultural land or natural vegetation, and each grid cell is assigned one natural land-cover type. To increase the spatial detail, we combined this data with the Global Land Cover 2000 (GLC 2000) map (Bartholome et al., 2004). GLC 2000, derived from the VEGA2000 data set with a daily global image from the Vegetation sensor on board the SPOT4 satellite representing the year 2000, has a resolution of ~0.5 by 0.5 minutes. GLC 2000 has also been used in combination with other data to develop a land-cover base map for IMAGE (chapter 6).

We calculated the proportion of each land-cover/land-use type within each IMAGE grid cell from GLC 2000. The GLC 2000 map has 10 forest classes, 5 classes of low vegetation (grasslands and scrubland), 3 cultivated land classes, ice and snow, bare areas and artificial surfaces (Bartholome et al., 2004). This classification is based on the Land Cover Classification System developed by FAO and United Nations Environment Programme (UNEP) (Di Gregorio and Jansen, 2000).

To calculate the impact of agricultural production intensity we assigned the categories 'intensive agriculture' and 'low input agriculture' to the GLC class of 'cultivated and managed areas', using estimates of the distribution of intensive and low-input agriculture in different regions of the world from Dixon et al. (2001) (Table 10.3). For all other regions we assumed 100% intensive agriculture. The change in agricultural land calculated by IMAGE for each world region for the future is distributed proportionally to current land use over all grid cells. Hence, expansion of agriculture, as determined by GLC 2000, leads to a loss of area in all (natural) land-cover types within the grid cell.

The GLC 2000 class containing a mosaic of cropland and forest has been assigned to the land-use category ‘agroforestry’ (Table 10.2), with grazing areas estimated by IMAGE for current and future years and distributed proportionally to all GLC 2000 classes containing low vegetation. We assign this mosaic to the category of ‘livestock grazing’. The GLC 2000 class of ‘herbaceous cover’ is found within areas where forest is a potential vegetation type according to the potential vegetation map generated by IMAGE based on the BIOME model (Prentice et al., 1992) is classified as artificial pastures.

To calculate the impact of forestry we need to assign the land-use categories ‘slightly disturbed or managed forest’, ‘secondary forest’ and ‘forest plantations’ to the GLC 2000 classes. We use data on forest use from FAO (2001) to derive fractions of primary and secondary forest, and forest plantations, of the total forest area for different world regions (Table 10.4). These fractions are applied to all grid cells that contain one or more GLC 2000 forest classes. For future calculations we use calculated timber demands to derive the fractional area needed to produce the timber and distributed the new fraction to each grid cell.

Furthermore, water bodies are excluded from the analysis, while all artificial surfaces are considered to be built-up areas. Bare areas are assigned to primary vegetation if the potential vegetation type is ice and snow, tundra or desert (where bare rocks or sand are abundant). Shrub classes are assumed to be secondary vegetation if the potential vegetation is forest (except for boreal forests).

Atmospheric N deposition. We reviewed some 50 studies on experimental addition of N in natural systems and the effects on species richness and species diversity. Based on this review, dose–response relationships were established between the annual rate of atmospheric N deposition exceeding the empirical critical load level and relative MSA. We assumed that the addition of N in these studies is equivalent to N deposition occurring in the field. The N-deposition pressure factor applies only to natural land and not to cropland, because the addition of N in agricultural systems is assumed to be much higher than the additional N deposition. Table 10.5 presents the regression equations for the biomes developed by Bobbink (2004).

Global atmospheric N deposition fields were calculated by using emission inventories for N gases for the corresponding years as input for the TM5 chemistry-transport model. Deposition rates for historical and future years were obtained by scaling the current deposition fields for the mid-1990s using emission inventories for N gases for the corresponding years (see chapter 8).

Effects of N deposition are based on the critical load values for major ecosystems, as described by Bouwman et al. (2002), who used the soil map of the world and sensitivity of ecosystems to N inputs to produce a critical load map. The exceedance of N deposition in excess of critical load is calculated from global N deposition fields (see chapter 8) and the critical load map, while the N exceedance and the dose–response relationships for the different biomes are used to assess the effects of N deposition on the species abundance.

Infrastructural development. The impact of infrastructural development is based on the GLOBIO 2 model. GLOBIO 2 includes relationships between the distance to roads and MSA for various biomes based on over 300 peer-reviewed articles comprising information on more than 200 different species (UNEP, 2001). The impact of infrastructural development includes direct effects of disturbance on wildlife, fragmentation due to barrier effects, increased hunting activities and small-scale encroachment along roads.

The dose–response relationships were used to construct impact zones along linear infrastructure (roads, railways, power lines, pipelines) based on data from the Digital Chart of the World (DCW) (DMA, 1992). Buffers of different width were calculated and assigned to impact zones which were aggregated to 0.5 by 0.5 degree grid cells. MSA values were assigned to each impact zone (Table 10.6).

Fragmentation. If the unfragmented area of a land-cover type is large, all original species may find sufficient area suitable for supporting at least a minimal viable population, whereas a small unfragmented area may only support a minimal viable population of a few species (Verboom et al., 2006). The minimal area requirement of 156 mammal and 76 bird species, i.e. the minimal area that species need to support a minimal viable population, is used to construct a general relationship between the percentage of species with sufficient area and patch size. Data are taken from Allen et al. (2001), Bouwman et al. (2002) and Woodroffe and Ginsberg (1998). For plant species we assume a much smaller area requirement (1 km^2) than for animals. Table 10.7 shows the fractions of original species having sufficient area to maintain a minimal viable population. These figures are assumed to represent the relative MSA.

Climate change. The treatment of climate change is different to that of the other pressure factors, as the available empirical evidence is limited to areas that are already experiencing significant impacts of change (such as the Arctic and montane forests). The current implementation in the model is based on estimates from EUROMOVE (Bakkenes et al., 2002; 2006), in which the proportion of species lost per biome in response to climate change is a function of temperature. These model results are compared with the predicted biome shifts in the IMAGE model (Leemans and Eickhout, 2005). Table 10.8 shows the slopes of the linear regression equations describing the global relationships between increase of temperature and stable area for each biome (IMAGE), or group of plant species occurring within a biome (EUROMOVE), which is considered to be an estimate of MSA. We used the regression lines that predict the smallest effects yielding conservative estimates (Table 10.8).

Calculation of biodiversity loss and relative contributions of each driver
The GLOBIO 3 model calculates the overall MSA value by multiplying the MSA values for each driver for each IMAGE 0.5 by 0.5 degree grid cell according to:

$$MSA_{\mathrm{i}} = MSA_{\mathrm{LU_i}} MSA_{\mathrm{N_i}} MSA_{\mathrm{I_i}} MSA_{\mathrm{F_i}} MSA_{\mathrm{CC_i}} \quad (1)$$

where i is the, index for the grid-cell, MSA_{Xi} relative mean species abundance corresponding to the drivers LU (land cover/use), N (atmospheric N deposition), I (infrastructural development), F (fragmentation) and CC (climate change). MSA_{LUi} is the area-weighted mean over all land-use categories within a grid cell. Figure 10.1 shows the overall MSA for the world for the year 2000.

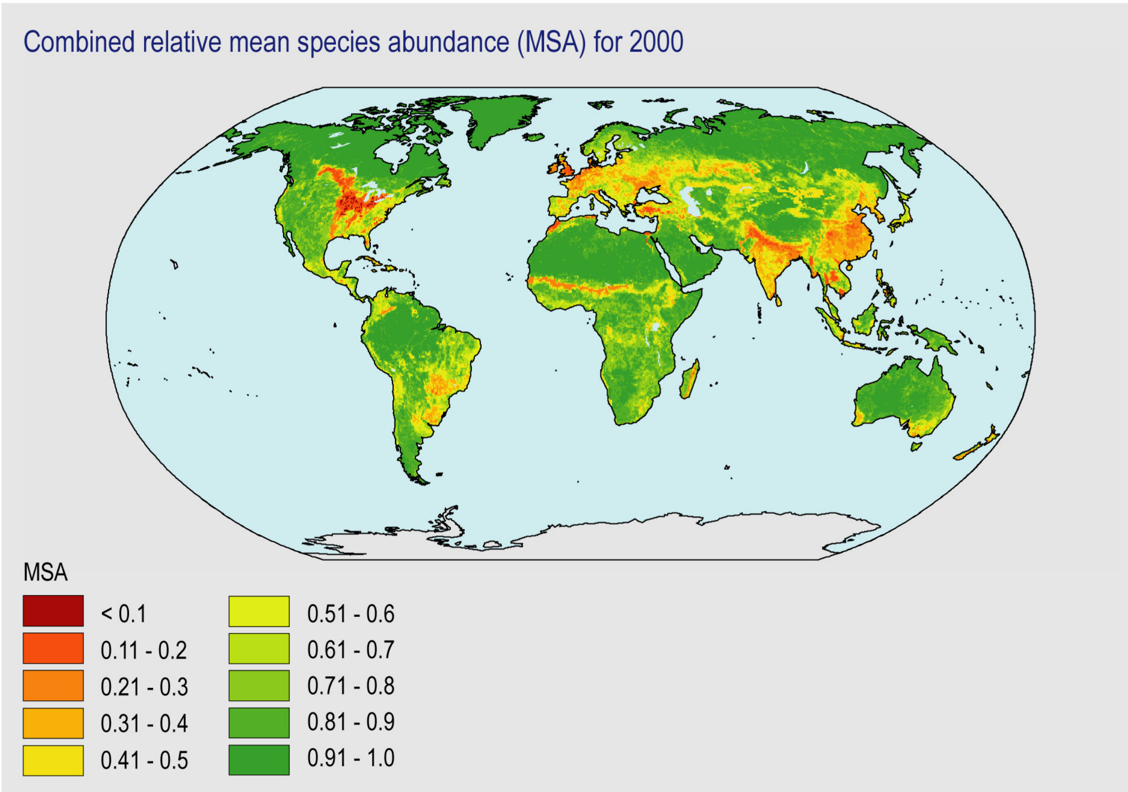

Figure 10.1 Combined relative mean species abundance (MSA_i) for the year 2000 using all pressure factors in this study. Land-use effects are dominant in this map. The spreading effect of infrastructure is also visible, especially in Northern Asia and Africa. Climate and nitrogen deposition are minor factors. 055k_imb06

The regional MSA_r is calculated as the area-weighted mean of MSA_i values of all grid cells located within a region:

$$MSA_r = \frac{\sum_i MSA_i \ A_i}{\sum_i A_i} \qquad (2)$$

where A_i is the land area occupied by grid-cell i.

The relative contribution of each driver to the loss of MSA was calculated from equations (1) and (2), as shown for the world in Figure 10.2. Agriculture is the most important factor worldwide in reducing MSA and thus biodiversity. This is because agricultural production systems cover vast areas and most agricultural practices imply a drastic change in the original land cover (clearing, cultivation, use of agro-chemicals, fertilizers, etc.). On the global scale, the second most impact factor is infrastructure, followed by fragmentation. Atmospheric N deposition, climate change and forestry are minor factors on global scale, but do play more prominent roles in some regions. In scenarios too, their role may become increasingly important. The relatively small contribution of forestry is partly explained by the assignment of the effects of deforestation to agriculture, since cleared forests are generally converted to crop or pasture land.

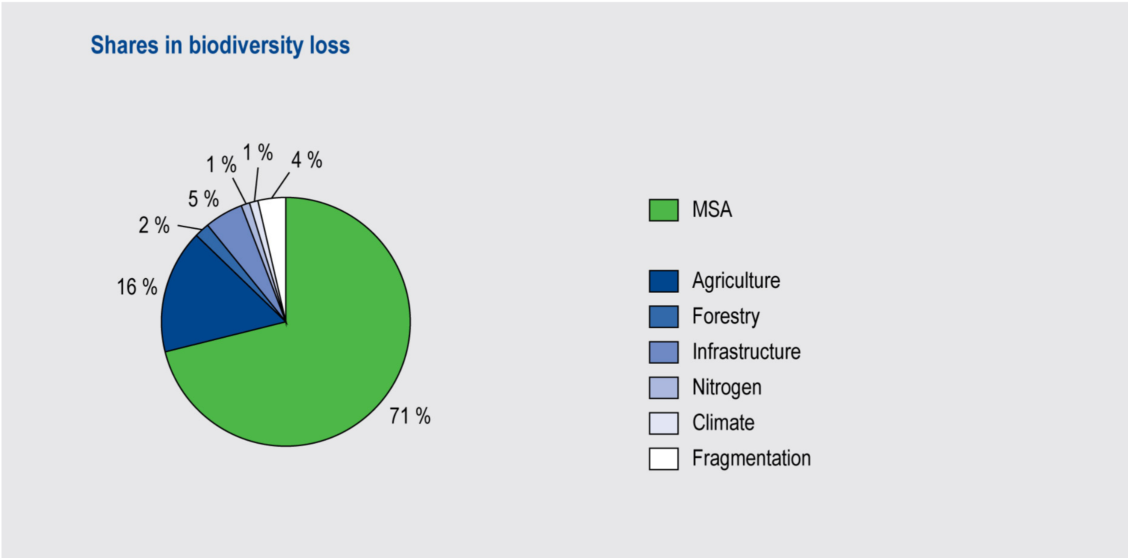

Figure 10.2 Relative global contribution of the different pressure factors to reduced MSA for the year 2000. 056g_imb06

Figure 10.2 also shows that the global MSA is about 70%, indicating that large parts of the world are still in a more or less pristine state. Regionally, however, there are striking differences (Figure 10.3). The regions that include large areas of desert (e.g. Northern Africa and Australia), ice cover (e.g. Greenland) or boreal forest and tundra (e.g. Canada and former USSR), which are not suitable for agriculture, show the highest MSA values.

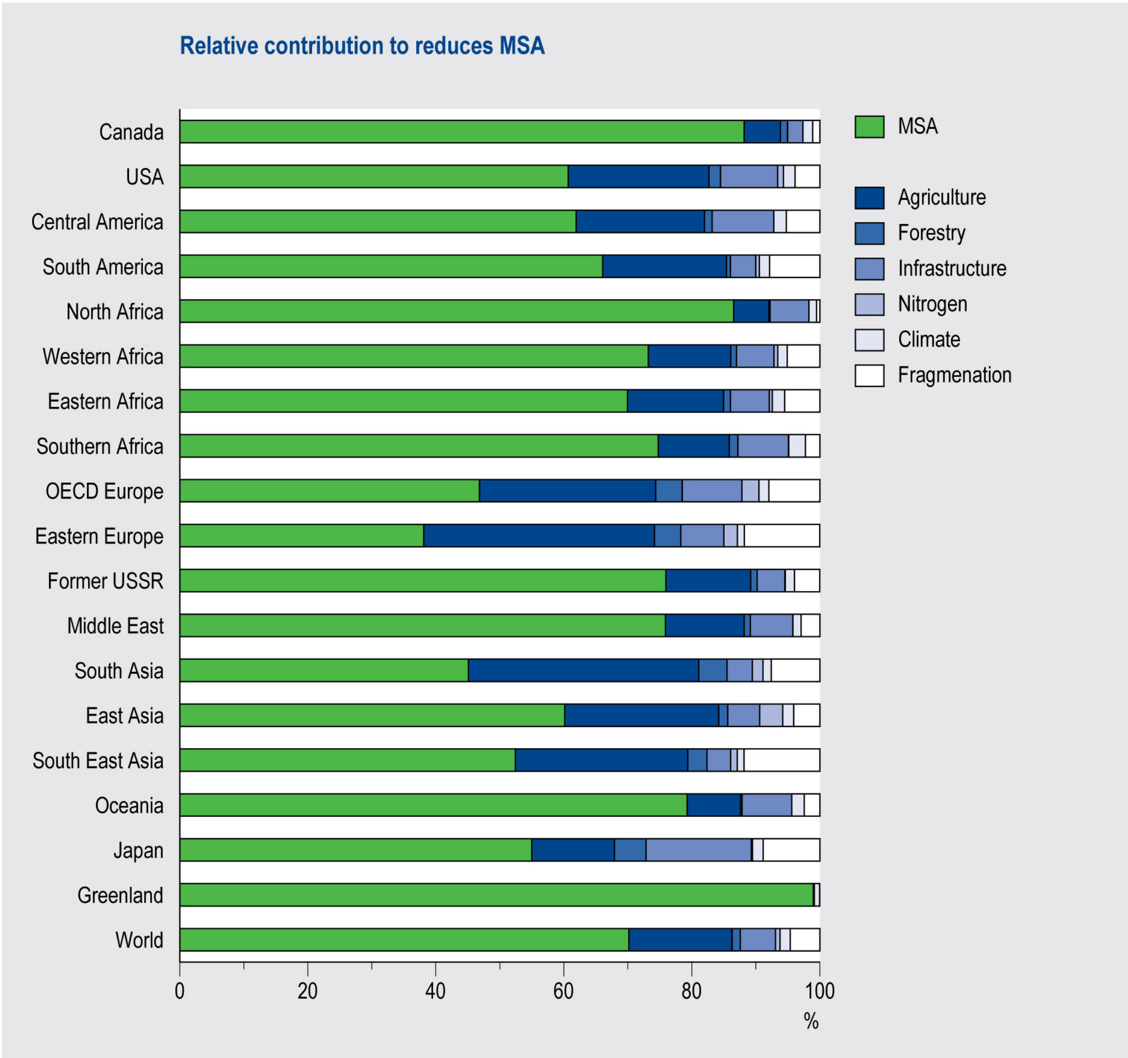

Figure 10.3 Regional differences of the relative contribution to reduced MSA of different pressure factors for the year 2000. **057g_imb06**

10.3 Implementation of the SRES scenarios

We assessed the development of biodiversity for four different scenarios for the period up to 2030,. These are A1b, A2, B1 and B2 from the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000), which were implemented with the IMAGE 2.2 model on global scale (IMAGE-team, 2001). The infrastructural development was derived from the GLOBIO 2 model (UNEP, 2001). Here we summarize some of the main elements of the SRES scenarios relevant to global biodiversity. For further details please refer to Nakicenovic et al. (2000). The storylines of the SRES scenarios describe developments in many different social, economic, technological, and environmental and policy dimensions. None of the scenarios include new explicit climate or biodiversity policies.

The A1 scenario describes a future world of very rapid economic growth, low population growth, and the rapid introduction and transfer of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income.

The A2 scenario describes a heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge slowly, which results in high population growth. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

The B1 scenario assumes continuing globalization and economic growth, and a focus on the environmental and social (immaterial) aspects of life. The scenario can be interpreted as the continuation of a balanced modernization process. Governance at all levels and regulated forms of market capitalism are seen as the way forward. It includes the strengthening of non-governmental organizations concerned about issues of sustainability and equity. The B1 scenario represents a modest and decent world, bureaucratic and regulated, but also in search of fairness and sustainability.

The B2 scenario portrays a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with moderate population growth, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Since the future infrastructural development is not an explicit part of the SRES scenarios, we assumed a large increase in infrastructure in the A1 and A2 scenarios, whereas infrastructural development is less rapid in B1 and B2. These assumptions are based on the Global Environmental Outlook 3 (UNEP, 2002b). Changes in land use, especially the increase of agricultural land, change in atmospheric N deposition and expected climate change were calculated with the IMAGE model.

There are clear differences between the four scenarios in the future development of the main driving forces of global biodiversity (Table 10.9). The future MSA values and the relative contribution of the pressure factors calculated using the procedures described above lead to decreases of the MSA in all scenarios (Table 10.10). Most biodiversity loss is seen in the A1 scenario (remaining MSA of 61%), while in the B1 scenario the decrease of MSA is much less (remaining MSA is 68%).

Expansion of agricultural land is the most prominent factor causing MSA decrease in all scenarios (Table 10.10). Results of Sala et al. (2000) are not entirely comparable, as they use a different set of pressure factors; however, they also state that land-use change will be the most important threat to biodiversity in coming decades. The most severe changes are expected in A1, with more rapid economic growth than in other scenarios. In this scenario land-use changes in combination with infrastructural development will cause biodiversity depletion. The effect of climate change is expected to increase in 30 years but still remains relatively small. Climate change is expected to have major impact on biodiversity in the longer term.

10.4 Concluding remarks

The GLOBIO 3 model framework is static rather than dynamic, and deterministic rather than stochastic. It is an operational tool to assess the combined effects of the most important pressure factors on biodiversity. The link with the integrated model IMAGE allows for analysis of scenarios, evaluation of policy measures at the international level and analysis of different potential policy options.

The advantage of the GLOBIO 3 approach is the use of quantitative dose–response relationships for different factors, which allows for estimating (i) biodiversity expressed as a proxy for the mean species abundance; and (ii) the quantification of the relative contribution of different pressure factors to the loss of biodiversity. Since GLOBIO 3 also calculates changes of the areas of different ecosystems, it can provide information on changes in distribution and abundance of selected species, and changes in the extent of selected ecosystems and habitats.

There are a number of limitations and uncertainties related to the dose–response relationships, the driving forces considered, and the underlying data used in GLOBIO 3 that we wish to address in the coming years. The dose–response relationships are now based on a limited set of studies that were published and interpreted in a uniform framework. The set of studies does not cover all biomes nor does it represent all important species groups. It is rather a compilation of existing knowledge biased in the direction of specific biomes. Reducing the uncertainty of the estimated effects will require more studies covering a wider range of environmental conditions and vegetation types.

Quantitative information on the interaction between pressure factors is scarce. To assess possible interactions, assumptions can be made that range from ‘all interact completely’ (only the maximum response is delivered) to ‘no interaction’ (the responses to each pressure factor are cumulative). Such interactions will be explored in the coming years.

Important factors that may affect biodiversity are not included. Sala et al. (2000) considered the impact of (both intended and unintended) biotic exchange of species and invasion of exotic species, as well as increased atmospheric CO_2 concentration, as major factors. Dose–response relationships were not established in GLOBIO 3 for these factors due to lack of data. Other factors like fire incidence, extreme events and pollution (except atmospheric N deposition) are not addressed either.

Another way to improve the methodology is the use of species distribution and abundance data. Long-term time series of species occurrence and abundance may help to partially validate the GLOBIO 3 results (De Heer et al., 2005). Models for distribution of species can be developed using different statistical techniques combining the drivers behind species distributions, as suggested by Guisan and Zimmermann (2000).

Apart from the dose–response relationships, the GLOBIO 3 model results depend largely on the quality of the input data, particularly the spatial distribution for the different land-use classes. We recognize that the areas of agricultural land use differ significantly between the FAO statistics (FAO, 2005) and satellite imagery (Klein Goldewijk et al., 2006), while the combination of IMAGE-simulated land cover with satellite data also causes inconsistencies. In addition, the GLC 2000 map may not be correct for use in combination with scenarios, because of land-use changes and climate change affecting the distribution of ecosystems.

In spite of all these problems and uncertainties, the results of GLOBIO 3 are in line with the results of other global studies. Patterns of human disturbance reflected by population density, degrees of human domination of ecosystems (McKee et al., 2003; Cardillo et al., 2004; Hannah et al., 1994), patterns of the ‘human footprint’ (Sanderson et al., 2002) and patterns of human appropriation of net primary production (Imhoff et al., 2004) are in agreement with the MSA estimates of GLOBIO 3. The similarity of the different analyses is not surprising, because all methods are dominated by factors related to land use and land conversion.

In addition to improvements of the approach described in this chapter, we are also working on a similar approach (based on driving forces) to assess changes in biodiversity in freshwater systems and coastal marine ecosystems.

Table 10.1. Major driving forces used in large-scale studies of human impacts on natural systems.

Driving force	Type[a]	Reference
Land-use change (including forestry)	D	Hannah et al. (1994); Sala et al. (2000); Sanderson et al. (2002); Wackernagel et al. (2002); Petit et al. (2001); UNEP/RIVM (2004); UNEP (2001)
Climate change	D	Sala et al. (2000); Petit et al. (2001); UNEP/RIVM (2004)
Atmospheric N deposition	D	Sala et al. (2000); Petit et al. (2001)
Biotic exchange	D	Sala et al. (2000)
Atmospheric CO_2 concentration	D	Sala et al. (2000)
Fragmentation	D	Wackernagel et al. (2002); Sanderson et al. (2002)
Infrastructure	D	Wackernagel et al. (2002); Sanderson et al. (2002); UNEP (2001)
Harvesting (including fisheries)	D	Wackernagel et al. (2002)
Human population density	I	McKee et al. (2003); Cardillo et al. (2004); UNEP/RIVM (2004)
Energy use	I	UNEP/RIVM (2004)

[a] Direct (D) and indirect (I) according to the definition of the conceptual framework of the Millennium Ecosystem Assessment (Millennium Assessment, 2003).

Table 10.2. Relationship between GLC 2000 classes and land-use categories used in GLOBIO 3, including corresponding relative mean species abundance (MSA).

Main GLC 2000 class (GLC 2000 class[a])	Sub-category	Description	MSA_{LU}
Snow and ice (20)	Primary vegetation	Areas permanently covered with snow or ice considered as undisturbed areas	1.0
Bare areas (19)	Primary vegetation	Areas permanently without vegetation (e.g. deserts, high alpine areas)	1.0
Forest (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)	Primary vegetation (forest)	Minimal disturbance, where flora and fauna species abundance are near pristine	1.0
	Slightly disturbed or managed forest	Forests with extractive use and associated disturbance like hunting and selective logging, where timber extraction is followed by a long period of regrowth with naturally occurring tree species	0.7
	Secondary forest	Areas originally covered with forest or woodlands where vegetation has been removed, forest regrowing or areas with a different cover and no longer in use	0.5
	Forest plantation	Planted forest, often with exotic species	0.2
Shrubs and grassland (11, 12, 13, 14, 15)	Primary vegetation (grass or shrubland)	Grassland or shrub-dominated vegetation (e.g. steppe, tundra or savanna)	1.0
	Livestock grazing	Grasslands where wildlife is replaced by grazing livestock	0.7
	Man-made pasture	Forests and woodlands that have been converted to grasslands for livestock grazing	0.1
Mosaic: cropland /forest (17)	Agroforestry	Agricultural production intercropped with (native) trees; trees kept for shade or as wind shelter	0.5
Cultivated and managed areas (16, 18)	Low input agriculture	Subsistence and traditional farming; extensive farming and low external-input agriculture	0.3
	Intensive agriculture	High external-input agriculture, conventional agriculture, mostly with a degree of regional specialization, irrigation-based and drainage-based agriculture.	0.1
Artificial surfaces (21)	Built-up areas	Areas more than 80% built-up	0.05

[a] 1, Broadleaved evergreen forest; 2, Closed broadleaved deciduous forest; 3, Open broadleaved deciduous forest; 4, Evergreen needle-leaf forest; 5, Deciduous needle-leaf forest; 6, Mixed forest; 7, Swamp forest; 8, Mangrove and other saline swamps; 9, Mosaic: forest/other natural vegetation; 10, Burnt forest; 11, Evergreen shrub; 12, Deciduous shrub; 13, Grassland; 14, Sparse shrub and grassland; 15, Flooded grassland and shrub; 16, Cultivated and managed areas; 17, Mosaic: cropland/forest; 18, Mosaic: cropland/other natural vegetation; 19, Bare areas; 20, Snow and ice; 21, Artificial surfaces.

Table 10.3. Percentage of low-input and intensively used agricultural land for selected world regions based on farming system descriptions (Dixon et al., 2001) and GLC 2000.

Region	Intensive agriculture (%)	Extensive agriculture (%)	Total (1000 km^2)
Middle East and North Africa	64	36	852
Sub-Saharan Africa	24	76	1632
Eastern Europe and Central Asia	42	58	2738
South and Central America	73	27	1576
South Asia	57	43	2141
East Asia and Pacific	93	7	2356

Table 10.4. Percentage of forest-use classes derived from FAO (2001) and GLC2000 for various world regions. The proportion of lightly used forest, which could not be estimated, is included in the primary forest category.

World region	Primary forest	Secondary forest (%)	Forest plantation	Total ($1000\ km^2$)
Canada	55	45	0	4830
USA	56	39	5	3462
Central America	85	14	1	1154
South America	84	15	1	8278
North Africa	31	31	38	45
Western Africa	92	7	1	4070
Eastern Africa	92	4	4	559
Southern Africa	97	2	1	2435
OECD Europe	60	35	5	1454
Eastern Europe	56	40	4	370
Former USSR	91	7	2	9260
Middle East	31	36	33	145
South Asia	53	7	40	857
East Asia	65	15	20	2230
Southeast Asia	75	15	10	2039
Oceania	91	7	2	1505
Japan	20	34	46	232
Greenland	0	0	0	0
Total	78	17	5	42925

Table 10.5. Regression equations for the relationship between atmospheric N deposition exceedance (NE)[a] and MSA_N for three ecosystems.

Ecosystem	Equation	Applied to GLC 2000 classes (see Table 10.2)
Arctic-Alpine ecosystem	$MSA_N = 0.9 - 0.05\ NE$	Snow and ice (20)
Boreal coniferous forest	$MSA_N = 0.8 – 0.14\ \ln (NE)$	Forests (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Grassland	$MSA_N = 0.8 – 0.08\ \ln (NE)$	Grassland and shrub (11, 12, 13, 14, 15)

[a] NE is calculated as N deposition minus critical load.

Table 10.6. Zones (in km) along linear infrastructural objects and their impact on relative mean species abundance (MSA_I) based on UNEP/RIVM (2004).

Vegetation cover	High impact (MSA_I=0.50)	Medium impact (MSA_I=0.75)	Low impact (MSA_I=0.9)	No-impact (MSA_I=1.0)
Cropland	0.0-0.5	0.5-1.5	1.5-5.0	>5.0
Grassland	0.0-0.5	0.5-1.5	1.5-5.0	>5.0
Boreal forest	0.0-0.3	0.3-0.9	0.9-3.0	>3.0
Temperate deciduous forest	0.0-0.3	0.3-0.9	0.9-3.0	>3.0
Tropical forest	0.0-1.0	1.0-3.0	3.0-10.0	>10.0
Desert and semi-desert	0.0-0.5	0.5-1.5	1.5-5.0	>5.0
Wetland	0.0-0.5	0.5-1.5	1.5-5.0	>5.0
Arctic tundra	0.0-1.0	1.0-3.0	3.0-10.0	>10.0
Ice and snow	0.0-0.5	0.5-1.5	1.5-5.0	>5.0

Table 10.7. The relationship between area and corresponding fraction of species (MSA_F) assumed to meet the minimal area requirement.

Area (km^2)	MSA_F
1	0.55
10	0.75
100	0.85
1000	0.95
>10000	1

Table 10.8. Slopes of the regression equations relating mean stable area relative to original area and temperature change (relative to pre-industrial) for calculating the MSA_{CC} for different biomes.

Biome	Slope ($^oC^{-1}$)	
	Image	EuroMove
Ice	0.023*	0.05
Tundra	0.154	0.07*
Wooded tundra	0.284	0.051*
Boreal forest	0.043*	0.079
Cool conifer forest	0.168	0.080*
Temperate mixed forest	0.045*	0.101
Temperate deciduous forest	0.100*	0.109
Warm mixed forest	0.052*	0.139
Grassland and steppe	0.098*	0.193
Hot desert	0.036*	-
Scrubland	0.129*	0.174
Savanna	0.093*	-
Tropical woodland	0.039*	-
Tropical forest	0.034*	-

[a] Slopes marked with '*' are used in the GLOBIO 3 model to calculate the correction factor for calculating the MSA_{CC}, starting from the values presented in Table 10.2 according to: $MSA_{CC} = 1 - Slope * \Delta Temperature$.

Table 10.9. Comparison of the late 1990s situation with the SRES scenarios for world population, global arable land area, temperature change, infrastructure development and forestry.

Characteristic	Late 1990s	SRES scenario			
		A1	A2	B1	B2
Human population (x billion)	6.1	8.2	9.3	8.2	8.4
Area agricultural land (Mkm^2)	17	20	21	19	20
Global temperature change[a]	0.61	1.25	1.33	1.31	1.33
Infrastructural development		high	high	moderate	moderate
Forestry		no change	no change	no change	no change

[a] Relative to pre-industrial

Table 10.10. Global MSA values for projected land use and climate in 2030 according to the four SRES scenarios as implemented in the IMAGE model (version 2.2).

	A1	A2	B1	B2
MSA	64.2%	66.0%	66.9%	66.9%
Agriculture	15.4%	16.1%	15.2%	16.1%
Forestry	3.0%	3.1%	3.2%	3.1%
Infrastructure	9.4%	7.1%	7.1%	6.1%
Nitrogen	1.5%	1.4%	1.0%	1.2%
Climate	2.9%	2.8%	3.0%	3.0%
fragmentation	3.6%	3.6%	3.6%	3.6%
Total	100.0%	100.0%	100.0%	100.0%