How do trade, poverty and climate policies affect biodiversity?

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Abstract

Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. However, the changes that have been made to ecosystems have contributed to substantial gains in human well-being and economic development. For the coming 50 years, the degradation of ecosystem services could grow significantly worse. In this paper, we selected a number of policy options initiated. The options considered in this paper are: (1) Liberalization of agricultural markets, (2) Alleviation of extreme poverty in Sub-Saharan Africa and (3) Limiting climate change by stabilizing greenhouse gas concentration levels that coincide with the target of 2°C stabilization compared to pre-industrial levels. The impacts of these policy interventions on biodiversity and economic performance are assessed.

The quantitative analysis shows that most options are too little or too late to significantly decline the further loss of biodiversity. For limiting climate change (bio-energy) and poverty alleviation (increasing GDP) initial losses in the medium term (2010 -2030) of biodiversity seem to be inevitable but improvements are foreseen in the much longer term. In the long run can demographic transitions and poverty reduction be expected to ease this pressure. Implementation of full trade liberalization leads to an additional biodiversity loss until due to a global increase of land used for agriculture.

All options have an economic impact or 'costs'. In most cases there is a trade-off between biodiversity and economic growth. In the case of trade liberalization and poverty reduction higher economic growth comes at the expense of global biodiversity. However, on the regional, national and local scales there may be biodiversity *and* economic gains due to safeguarding a variety of functions from which –eventually- humanity entirely depends (see also the Millennium Ecosystem Assessment). Economic costs and biodiversity gains may be spread over time. Climate change policy will decrease economic growth, while beneficial effects on biodiversity and the economy (or avoided cost) can only be expected in the long run.

1. Introduction

Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history. However, the changes that have been made to ecosystems have contributed to substantial gains in human well-being and economic development. The main concern of many ecologists is that loss of biodiversity can entail any or all of the following: reduction in the extent or productivity of ecosystems; declines in the abundance or distribution of populations of particular species; and loss of genetic diversity within populations (CBD, 2003). Therefore, it was concluded in the Millennium Ecosystem Assessment that biodiversity plays a key role in the functioning of ecosystems and the provision of ecosystem services, and its loss therefore impacts on human well-being (MA, 2005).

For the coming 50 years, the degradation of ecosystem services could grow significantly worse, depending on different policies undertaken. The main anthropogenic interferences with ecosystems that are expected to become dominant are land use change, nitrogen deposition and climate change (MA, 2006). Several studies have investigated the impacts of climate change. They conclude that climate change is already affecting species distributions all over the world (Parmesan and Yohe 2003), and will have considerable further impacts in the 21st century (Thomas et al., 2004; Leemans and Eickhout, 2004). However, these studies only looked at consequences of climate change without considering other environmental impacts. Within the Millennium Ecosystem Assessment an effort was undertaken to combine different environmental conditions and assess these in four future scenarios (MA, 2006). It was concluded that, for terrestrial ecosystems, land use change is expected to be the dominant driver of biodiversity loss over the next century (MA, 2006; Sala et al. 2000). Land use change is mainly driven by agricultural expansion. Agricultural expansion is, in turn, driven by population growth and the shift to higher protein diets (Sage, 1994). Consequently, a growing fraction of the expanding agricultural area is used for the production of food and fodder crops for feeding animals (Bouwman et al., 2004).

Most of these environmental studies do not address the economic development that coincides with these environmental stresses and therefore fail to discuss to a full extent the domains of sustainable development. Moreover, in most scenarios studies where policy options are suggested the economic and environmental consequences are not discussed in a comparative way. For example, many economic studies discuss the economic consequences of trade liberalization, but hardly mention the environmental side of the story (Anderson, 1999). Here, we apply an innovative approach of combining economic and biophysical tools and analyze the specific consequences of different policy options. For this analysis we use a combined modeling framework on the basis of GTAP and the Integrated Model to Assess the Global Environment (IMAGE: Alcamo et al., 1998). This modeling framework is introduced in Eickhout et al. (2004) and further elaborated in Van Meijl et al. (2006). The latest improvements of the GTAP-IMAGE modeling framework are discussed in Tabeau et al. (2006).

In this paper, we selected a number of policy options initiated, proposed and discussed in international forums, which can be expected to have a large impact on biodiversity. The selected policy options influence several of the major pressures on biodiversity loss: habitat loss, (over-)exploitation of natural resources, agriculture and eutrophication, climate change, fragmentation and infrastructural development. The impacts of these policy interventions are assessed for economic and environmental consequences. This loss of biodiversity is of central concern in our environmental analysis. Parties to the Convention of Biological Diversity (CBD) agreed upon a significant reduction in the current rate of loss of biological biodiversity at the global and regional levels by 2010. We developed an indicator to address this policy goal and we used this indicator as a proxy for environmental consequences, since in biodiversity most of the environmental stresses come together. Therefore, in our analysis of the different policy options we compare the consequences for both GDP and this biodiversity indicator.

In Section 2 the methodology of this analysis is described. We explain the framework that is used to assess the environmental and economic consequences of different policy options, the baseline and the three policy options. Results are reported in section 3. Section 4 is devoted to uncertainties and sensitivities. Section 5 concludes.

2. Methodology

The framework we use to assess the environmental and economic consequences of different policy options combine: i) macro-economic projections, with ii) an agricultural trade model (extended version of GTAP: Global Trade Analysis Project) and iii) a global integrated environmental assessment model (IMAGE: Integrated Model to Assess the Global Environment) and iv) a global biodiversity assessment model (GLOBIO3). The macro-economic and demographic projections form the input of the combined modelling framework. The results of GTAP-IMAGE are fed to the biodiversity model GLOBIO3.

2.1 The GTAP-IMAGE-GLOBIO model

To analyse the economic and environmental consequences of changes in global drivers and policies, we developed a global economic-biophysical framework by combining the extended GTAP model (Van Meijl *et al.*, 2006) with the IMAGE model (Alcamo *et al.*, 1998; IMAGE Team, 2001). This model framework has been applied in a study for the future of European rural areas (Eickhout et al., 2006). The extended version of the standard GTAP model was developed to improve the treatment of agricultural production and land-use (Van Meijl *et al.*, 2006). Since it is assumed that the various types of land-use are imperfectly substitutable, the land-use allocation structure was extended by taking into account the degree of substitutability between agricultural types (Huang *et al.*, 2004). For this reason, OECD's more detailed Policy Evaluation Model (OECD, 2003) structure was used. Moreover, in this extended version of the GTAP model the total agricultural land supply was modelled using a land-supply curve, specifying the relation between land supply and a rental rate (Tabeau et al., 2006). Through this land-supply curve, an increase in demand for agricultural products will lead to land conversion to agricultural land and a modest increase in rental rates when enough land is available. If almost all agricultural land is in use, increase in demand will lead to increase in rental rates.

Macro-economic drivers like population and economic growth are used as input in both the GTAP and IMAGE models. In the extended GTAP model yield depends on an exogenous (autonomous) trend factor (technology, science, knowledge transfer) and also on land prices. This implies that there are substitution possibilities among production factors. If land gets more expensive, the producer uses less land and more of other production factors such as capital. The impact of a higher land price is that land productivity or yields will increase. The exogenous trend of the yield was taken from the FAO study "Agriculture towards 2030" (Bruinsma, 2003) where macro-economic prospects were combined with local expert knowledge.

The economic consequences for the agricultural system are calculated by GTAP. The outputs of GTAP include sectoral production growth rates, land-use, and an adjusted management factor describing the degree of land intensification. This information is used as input for the IMAGE simulations, together with the same global drivers as used by GTAP. Since the IMAGE model performs its calculations on a grid scale (of 0.5 by 0.5 degrees) the heterogeneity of the land is taken into consideration on a grid level (Leemans *et al.*, 2002). Protected areas cannot be used for agricultural use in the IMAGE land-use model. Therefore, a fixed map of protected areas (taken from UNEP-WCMC) is also used as input of the IMAGE model. IMAGE simulations deliver an amount of land needed per world region and the coinciding changes in yields resulting from changes in the extent of used land and climate change.

Next, these additional changes in crop productivity are given back to GTAP, therefore correcting the exogenous (technology, science, knowledge transfer) trend component of the crop yield. A general feature is that yields decline if large land expansion occurs, since marginal lands are taken into production. In the near term, these factors are more important than the effects of climate change. Through this iteration, GTAP simulates crop yields and production levels on the basis of economic drivers and changes in environmental conditions. This combined result is once more used as input in IMAGE to consistently calculate the environmental consequences in terms of land use. The linkage of the extended version of GTAP and IMAGE is visualized in Figure 1. Outputs of this modelling framework thar are used by the biodiversity model, are nitrogen deposition, climate change and land-use change.

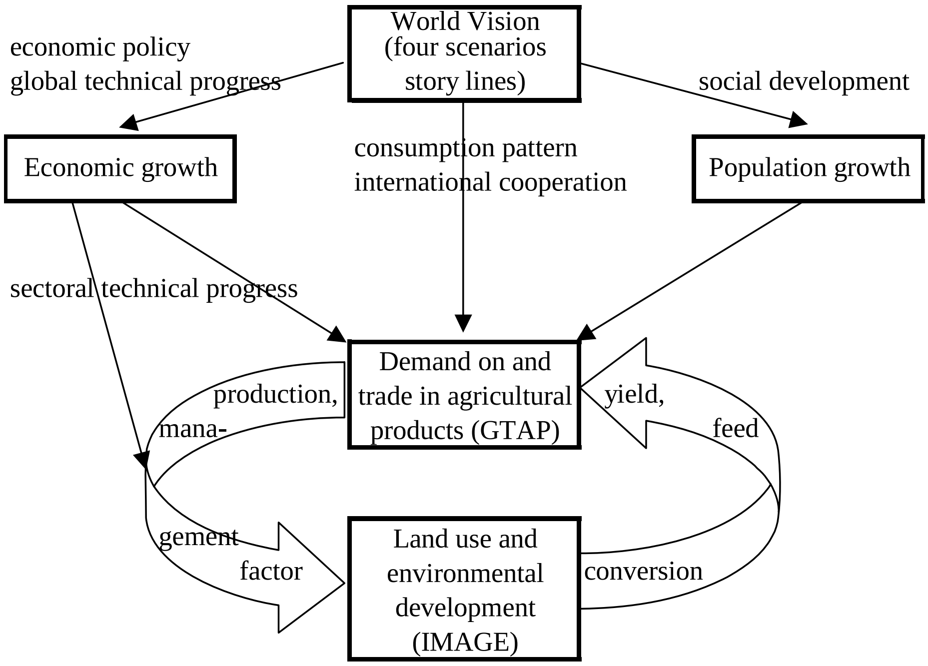

Figure 1: The GTAP-IMAGE modeling framework (Eickhout et al., 2004)

The biodiversity model GLOBIO3 (Alkemade *et al.*, in prep) is conceived as a model measuring habitat integrity through remaining species-level diversity, i.e. in terms of the mean abundance of the original species. At the heart of GLOBIO3 is a set of regression equations relating degree of pressure to degree of impact (dose-response relationships). The dose-response relationships are derived from the database of biodiversity response to change. Where possible, relationships for each pressure are derived by biome and region – depending on the amount of available data. A meta-analysis is currently underway to examine which areas of the database are most urgently in need of expansion. To estimate the impact on biodiversity of pressures under a given scenario at, for example, 2020, a map of each of the pressures in 2020 is required, which also includes the impact of any policy option reducing (or increasing) the pressure (for example, farming type or protected area designation). The driving forces (pressures) incorporated within the model are: i) land-cover change such as agriculture, forestry and built up area (taken from IMAGE), ii) land-use intensity (partly taken from IMAGE), iii) nitrogen deposition (taken from IMAGE), iv) infrastructure development (exogenously assumed), v) fragmentation and vi) climate change (both taken from IMAGE). The mean species abundance (MSA) is calculated in steps. First the MSA is calculated on the bases of the land-use intensity classes. Subsequently different pressures on these “starting” values are superimposed, resulting in decreasing MSA values. Pressures considered are: i) climate change, ii) nitrogen deposition, iii) infrastructure and iv) fragmentation.

There is little quantitative information about the interaction between pressures. The model can therefore make a range of assumptions, from “all interact completely” (only the maximum response is delivered) or “no interaction” (the responses to each pressure being cumulative). For this analysis we used results assuming no interaction, which means that the individual MSA values are multiplied for each square km grid cell. The resulting figure is an estimate for the mean species abundance as a result of all pressures.

Finally, we also dealt with costs of the different measures as a means of broadening the scope of our analysis and acknowledging that economic development is needed for alleviation of poverty, which is assumed to be a prerequisite for maintaining biodiversity (MA, 2005). To assess the economic consequences or “costs” of selected policy options, we used GDP as a crude measure, showing the cumulative effect of a policy on GDP relative to the baseline: e.g. an effect of 1% means that GDP is 1% above the baseline level. The estimates are based on the GTAP-IMAGE modeling framework. It should be noted that this approach does have some serious drawbacks. Using a macroeconomic measure like GDP ignores distributional effects. The results refer too to structural effects; adjustment costs are not taken into account. Hence, estimates are provisional but do provide what we believe are the correct orders of magnitude.

2.2 Baseline

A “baseline scenario” is used to explore policy options on their effects on biodiversity and economic growth. The baseline scenario is defined here as an autonomous process of socio-economic developments on which policy makers have no influence.

The scenario includes autonomous developments in demography, economics and technology, and current policies agreed upon in international treaties. The scenario is based on moderate assumptions on population growth and economic development. The global population grows from 6.1 billion in 2000 to 9 billion in 2050, but at a declining growth rate. Over the same period, the global average income increases from $5,300 to $ 16,000 per capita. The compounded effect of population and economic growth represents more than a fourfold increase in global GDP in the next half century. Due to structural shifts of economies to less energy-intensive sectors and technological improvements leading to energy savings, total primary energy consumption increases by just over a factor of 2: from 400 to 900 EJ in 2050. In the baseline, energy supply continues to rely on fossil resources (coal, oil and gas) and thus emissions of greenhouse gases from combustion also keep rising. Together with emissions from land-use and other sources, this leads to an ongoing rise in global temperature to 1.8 K over pre-industrial levels in 2050. This means that the rise in the next half century will exceed the observed increase in the last 130 years. After implementation of the Kyoto Protocol for 2008-2012, no further climate mitigation measures are taken in this baseline.

Table 1 Baseline developments, population, GDP and biodiversity in 2000 and 2050

	2000	2050	change
Population (billion)	6.1	9.0	
GDP per capita ($)	5,300	16,000	
Primary energy consumption (EJ)	400	900	
Temperature change (°C)			1.8
Biodiversity (NCI %)	70	63	

Consumption of agricultural products lags behind overall economic growth, but the combined effect of more people eating more calories, especially in currently undernourished regions, and the shift towards more animal products in the diet at higher income levels implies a sharp increase in agricultural output. If we follow and extend the assumptions on agricultural productivity according to the FAO projection towards 2030 (Bruinsma, 2003), the total area required for food-crops, grass and fodder remains fairly stable over the entire period. This illustrates that productivity assumptions here are relatively optimistic compared to other recent studies. For example, in the scenarios of the Millennium Ecosystem Assessment (MA, 2006) the total crop area increases by 8% to 23% over the same period.

Up to 2050 a further decline in biodiversity from about 70% to 63% is projected. It should be noted that the purpose of the baseline was to serve as a reference for evaluating policy options, not as a precise prediction of the future. Intensification of agriculture and forestry, infrastructure, human settlement, pollution and fragmentation have contributed to this decline. The most affected biomes are drylands, followed by tropical forests and tundra. Infrastructure plus related settlement and climate change are the dominant causes of further loss in the baseline development. The share of agriculture remains constant, provided that agricultural productivity shows a considerable rise. The linearity of the biodiversity loss in the 2000-2050 period is remarkable, while both population growth and economic development are exponential processes. This can be seen in the decreasing rates of the population growth. Simultaneously, the economic growth rates are increasing. Together, this results in a roughly linear effect. The results for biodiversity are given in Table 2, with the importance of the different contributors to this change in biodiversity. From this Table 2, it can be concluded that the CBD-target for 2010 is unachievable and that the target of a significant reduction of biodiversity at all levels is even in 2050 not achievable if no additional policy options are undertaken.

In Table 2, the biodiversity results on a regional level are given. From this regional results it can be observed that climate change predominantly affects Northern regions like former USSR, while increase in infrastructure affects all regions, especially South & East Asia. Sub-Saharan Africa is the only region where agricultural development plays a significant role in further biodiversity loss. The doubling of the population in this region and the absence of substantial improvements in agricultural productivity drive the agricultural expansion. Conversion of mainly tropical grasslands and savannah takes place to accommodate the agricultural expansion. Further, tropical forest is converted (deforestation). Other factors adding to further biodiversity decline are climate change, infrastructural development and forestry.

Table 2 Baseline, biodiversity in 2000 and 2050 and impact of different drivers by region

	Biodiversity		Contribution of drivers to loss (in %)					
	2000	2050	Agri-culture	Forestry	Infra-structure	Fragme n-tation	Clima te chang e	Nitrogen deposition
World	70	63	17	11	33	-3	38	4
Sub-Saharan Africa	73	61	34	10	55	-1	28	4
South & East Asia	55	46	8	22	41	-9	27	10
North Africa	87	84	-53	-1	44	4	105	0
West Asia	76	72	5	-2	34	2	61	0
Latin America & Caribbean	66	59	-3	4	51	-2	48	2
North America	75	66	46	12	13	-4	34	-1
Europe	45	34	28	19	36	-4	22	0
former USSR	76	71	-7	-7	2	-1	56	5
Oceania and Japan	78	74	-44	3	56	-1	87	0

2.3 Policy options

Policy options that aim at realizing the 2010 target of a significant reduction of the loss of biodiversity can be numerous. Effective measures preferably aim at the reduction of pressure factors that affect biodiversity. The main pressure factors are land-use change and intensification of land-use; land degradation; climate change; economic and population growth and corresponding infrastructural development; pollution. However, many of these pressures will also change because of other implemented policies not aiming specifically at biodiversity. In this analysis we have not analyzed options that can be introduced specifically for biodiversity concerns (like introduction of protected areas or sustainable timber plantations). Here, we analyzed policy options that will be implemented in other policy arenas, but will have an influence on the feasibility to achieve the CBD target through the different drivers as described above. Through this approach, we show the interrelations of different policy options with biodiversity goals that are being discussed separately in CBD.

We selected a number of policy options initiated, proposed and discussed in international fora, and aim at reducing biodiversity loss (at least partly) or drivers that can be expected to have a large impact on biodiversity. The selected policy options influence several of the major pressures on biodiversity loss: habitat loss, (over-)exploitation of natural resources, agriculture and eutrophication, climate change, fragmentation and infrastructural development.

1. **Full trade liberalisation in agriculture from 2015**, driven by free-trade considerations and development arguments following the current WTO Doha Round. Liberalization of the agricultural

market has an effect on economic drivers and influence changes of food production, land-use, agricultural intensification, habitat loss, and nitrogen deposition, and is accompanied by high rates of technology transfer.

2. **Alleviation of extreme poverty and hunger in Sub-Saharan Africa**, direct investments from developed countries into Sub-Saharan Africa are combined with trade liberalization of agriculture in line with the proposals by the Millennium Project (UN Millennium Project, 2005). Assuming effective implementation of these additional direct investments, including higher productivity of 10%, this options leads to a 25% GDP increase in Sub Saharan Africa on top of the baseline in 2030. Additional economic and technology support to the poor and hungry in Sub-Saharan Africa will change the lifestyle, technology, demographics and finally land-use in the poorest regions. This option is calculated in combination with liberalization of the agricultural market.

3. Implementation of an ambitious **climate change mitigation policy** option, stabilizing CO_2-equivalent concentrations at a level of 450 ppmv in line with the EU target of keeping the global temperature increase below 2 ^{o}C Limiting climate change includes more stringent application of measures aiming to comply with the ultimate UNFCCC goal, including an increase in bio-fuels in order to mitigate climate change.

The options were selected on the basis of: i) the possibilities of the GTAP/IMAGE/GLOBIO model, ii) the potential of policies on biodiversity iii) the options' coverage of the major causes of biodiversity loss according to the CBD, iv) current political discussions or targets in the international fora, v) the option's link to real political means to intervene and vi) the availability of an operational indicator.

3. Results

Table 3 presents the effects on biodiversity and GDP of the three options by region.

The quantitative analysis shows that most options have a negative effect on getting closer to the CBD 2010-target: a significant reduction in the current rate of loss of biological biodiversity at the global and regional levels by 2010. For limiting climate change and poverty alleviation (increasing GDP) initial losses in the medium term (2010 -2030) of biodiversity seem to be inevitable through biofuels and increased food demands respectively. However, these short-term losses can be seen as investments to improve the state of ecosystems in the long-term through less climatic impacts and less anthropogenic interference with ecosystems (MA, 2005). Eventually, these long term benefits might offset the medium term losses, although this is not found within the time frame until 2050 in our analysis.

Implementation of full trade liberalization leads to an additional biodiversity loss until 2050 due to a global increase of land used for agriculture, concentrated in Latin America and Southern Africa. The production shift and expansion in these regions is driven by cost-efficiency reasons, since labor and land costs are particularly low in these regions. This shift of production is at the expense of production in the US, Europe and Japan, resulting in higher land requirements at the global level since current crop yields are much higher in these developed regions.

All options have an economic impact or 'costs'. In most cases there is a trade-off between biodiversity and economic growth. In the case of trade liberalization and poverty reduction higher economic growth comes at the expense of global biodiversity. However, on the regional, national and local scales there will be biodiversity *and* economic gains due to safeguarding a variety of functions from which –eventually- humanity entirely depends (see also the Millennium Ecosystem Assessment). Economic costs and biodiversity gains may be spread over time. Climate change policy will slightly decrease economic growth, while beneficial effects on biodiversity and the economy (or avoided cost) can only be expected in the long run.

Table 3: Impacts of three analyzed policy options on biodiversity and GDP

	Liberalization agricultural trade		Poverty Reduction (including liberalization)		Limiting climate change[2]	
	biodiversity	GDP[1]	biodiversity	GDP[1]	biodiversity	GDP[2]

World		1,0		1,0		-1,0
Sub-Saharan Africa	-3.7	5,0	-5.7	25,3	-1.7	1,2
North Africa	-0.2	17,0		17,0	0.6	-1,2
South & East Asia	-0.3	2,0	0.3	2,0	0.8	-0,2
West Asia	-0.7	0,2		0,2	0.2	-1,9
Latin America & Caribbean	-5.4	2,0		2,0	-1.6	-1,1
North America	1.4	0,0		-0,2	-1.5	-2,1
Europe	4.2	0,2		0,0	-0.2	-1,2
former USSR	-0.1	0,4		0,4	-2.0	-0,3
Oceania	-0.1	0,6		0,6	-0.6	-1,5

[1] Cumulative percentage changes from the baseline in 2030.

[2] Direct abatement costs as percentage of GDP.

Liberalization

Trade liberalization is beneficial for economic growth. Especially developing regions reap the benefits from free trade in agriculture. According to our evaluation, the world economy will experience a growth of 1% in 2030. GDP in developing countries is higher.

Liberalization of the agricultural market has by far the strongest effect in Latin America, reducing the biodiversity by -5.4%. Liberalization induces a boost in “south-south-trade” in agricultural products, driven by low production costs and an ample supply of productive land. In Latin America, there is a strongly expansion of agriculture, and the area for food crops, grass and fodder grows by 40% in 2050 compared to the baseline. The main habitats affected by land conversion are tropical dry and rain forest (inducing deforestation), and grassland and savannah areas.

In Sub-Saharan Africa liberalization leads to a significant further reduction of the remaining biodiversity (-3.7%). Not surprisingly, tropical forest, grassland and savannah bear the burden. The negative biodiversity effect of liberalization is smaller than in Latin-America. In absolute terms, shifts in global agricultural production are small, given the modest role Africa plays in world trade. In relative terms the region highly benefits from trade liberalization. GDP increases by 5% above baseline values in 2030.

The largest positive effect on biodiversity in Europe (+4.2%). Lifting trade regulations implies that other players on the international market can improve their position at the expense of Europe and North America. Hence, the upward trend in agricultural land use of the baseline is reversed as agricultural production declines by 24%. The abandoned land is slowly returning to a more natural state, with a higher biodiversity value; however this process is still not completed by 2050. Mediterranean forests, woodland, and shrub and temperate forest areas, show the biggest improvement.

Liberalization has a distinct positive effect on biodiversity in North America (+1.4%). The increase in agricultural land use of the baseline is now reversed, as the opening up of global markets induces a shift of agricultural production to other regions like Latin America and Sub-Saharan Africa. Lifting trade regulations allows these regions to capture a larger share of the world market, capitalizing on lower production cost structures and availability of productive land.

Poverty reduction

Addressing extreme poverty and hunger in Sub-Saharan Africa, not only involves trade liberalization, but also an increase in aid from industrialized countries. This increase in official development assistance will slightly mitigate the positive effects of liberalisation in industrialised countries. However, this shift in investment will boost economic growth in Sub-Saharan Africa. GDP per capita is projected to be 25% above baseline levels in 2030. In this region (both liberalization) and poverty reduction lead to a significant further reduction of the remaining biodiversity (-3.7% and -5.7%, respectively). Increased agricultural production is the main driving force for both, leading to more conversion. Not surprisingly, tropical forest, grassland and savannah bear the burden, especially in case of poverty reduction. In absolute terms, shifts in global agricultural production are small, given the modest role Africa plays in world trade. In relative terms the region highly benefits from trade liberalization. GDP increases by 5% above baseline values in 2030. To meet the Millennium Development Goals, poverty is removed in all its dimensions in the poverty reduction option, while economic growth is assumed to experience strong growth. In 2030, GDP per capita in Sub-Saharan Africa is projected to be 25% above baseline level. The higher demand for agricultural production and the improved infrastructure will exert a downward pressure on biodiversity. The negative impact of higher economic growth is partly offset by higher productivity in agriculture with a net effect on biodiversity of -5.7%.

Limiting Climate change

Climate change policy will require dramatic changes in the energy system. This is a costly option, However, costs can be limited by involving all regions (a global coalition) and using efficient and flexible mechanisms (e.g. emissions trading). Abatement costs for the world as a whole are in the order of global GDP percentages. The distribution of costs across regions will depend crucially on the allocation of emission permits (burden-sharing). In a multi-stage approach (Den Elzen *et al.*, 2005) developing countries might benefit from the surplus of emission rights and gain from the export of emission permits.

In the climate mitigation option, China becomes an area for bio-fuel production, taking advantage of available agricultural land (through productivity increases). This partly counteracts the biodiversity gain from climate change mitigation (total effect +0.4%).

Limiting the effects of climate change leads to biodiversity decreases (-1.7%). The Sub-Saharan region becomes an important area for bio-fuel production at the expense of tropical grasslands and savannah. In a climate regime with a global system of emissions trading, a fair burden-sharing rule might allocate a surplus of emission rights to Sub-Saharan Africa. This system is economically beneficial for the region. Revenues from the export of emission permits to industrialized regions might improve income levels in the order of 1%.

The climate option has the largest effect on Russia and North Asia. The region becomes an important area for bio-fuel production. Developments in the baseline have led to large areas of abandoned agricultural land that can be exploited. The increased land use more than counteracts the positive effect of climate measures. Suitable land is scarce and the net loss of habitat remains limited in size, affecting primarily temperate forest area. At the same time, the negative effect of climate change is removed and the net effect on biodiversity is almost neutral. As climate change affects mostly boreal and temperate forests, and Mediterranean biomes, biodiversity gains in these biomes can be expected.

4. Uncertainties and sensitivities

There are numerous sources of uncertainty that influence the outcome of this analysis, ranging from problem framing, indicator selection, data imprecision, model uncertainties (model parameters and structure, and dose-response relationships), to scenario and option assumptions (ignorance on future developments). These cannot be dealt with completely here. Only the most important uncertainties and assumptions affecting the baseline and option results are addressed in this section, and qualitative expert judgments on their biodiversity effects are given.

Baseline

The key finding for the decline of global biodiversity (7% decrease between 2000 and 2050) is probably an underestimation of the future decline, as the explored scenario is optimistic on agricultural productivity increases. Taking more scenarios into account can shed light on this subject. Most of the options show exaggerated effects, either to the positive or negative side. Not yet known is what the combined effect of options will be. Such an elaborate task demands many different assumptions on combined policy effects.

The baseline scenario contains several assumptions on world and regional development that have an important influence on land-use (mainly agriculture). The development of the total required crop area in the baseline is relatively low in comparison with other often used IPCC scenarios (up to 20%), and up to 28% lower than the MA scenarios (see figure below). This is caused by the fact that implemented productivity increases are optimistically in the baseline. This is a very influential variable for agricultural land-use and biodiversity. Thus, the baseline contains important technological improvements that will reduce the biodiversity loss rates in the future. It is important to keep this in mind when judging the potential effects of options.

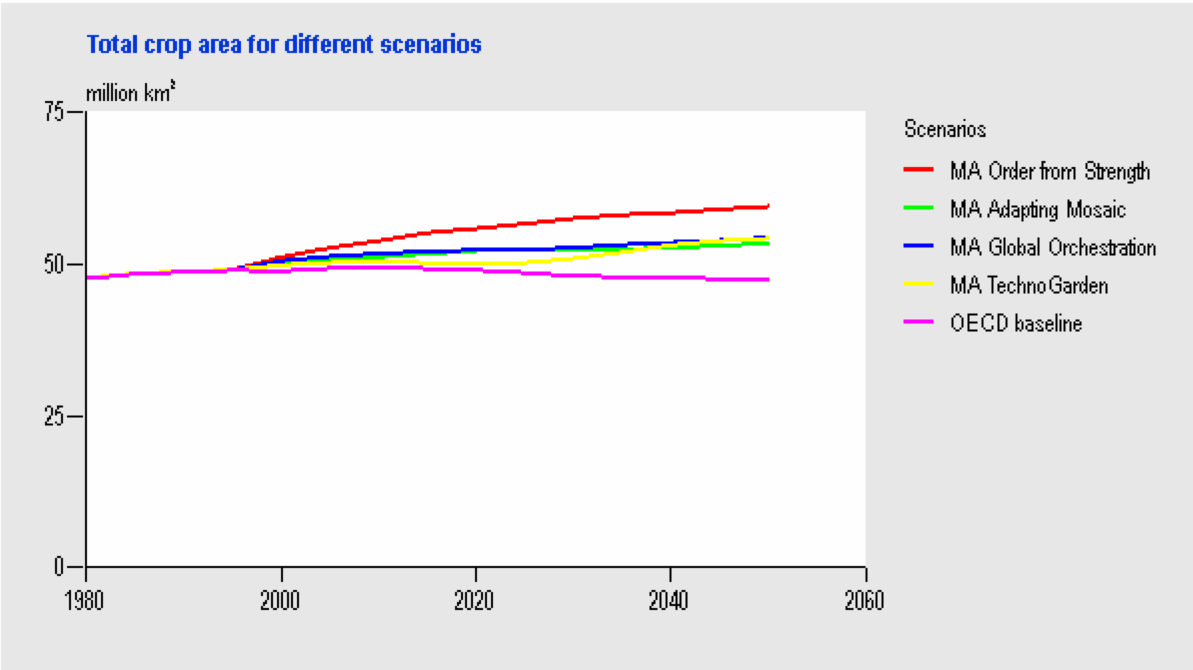

Figure 2: ***Total world crop area for the different MA scenarios, compared with the OPECD baseline used in the present analysis. The OECD baseline uses less area for food production than the MA scenarios (up to 20%).***

Indicators

The used biodiversity proxy indicator combines biome areas with biome quality (in terms of mean species abundance), which make it possible to assess land-use dynamics and impacts of pressures. Other biodiversity indicators will show similar general patterns of overall biodiversity decline, with the same main drivers for this decline, but the exact number will vary between indicators.

Regional declines in biodiversity and land-cover shifts will show considerable variation, depending on the assumed effects of changing agricultural and trade policies (with trade-offs between regions when production moves to other areas). Changes in land-cover are the result of land allocation rules, and implementing different rules (for instance, making more use of marginal grounds) will result in different shifts.

The main missing element in the present analysis is the aquatic habitat, and thus the impacts of overexploitation of fish resources, destruction of sea-fringing habitats, and pollution of inland waters as well as effects of options such as large-scale aquaculture. Preliminary analyses on this subject indicate an even stronger decline in biodiversity values for the year 2000 (40%, opposed to 30% for terrestrial).

Models

The main ecosystem models used are IMAGE and GLOBIO3. In these models, sensitivities and uncertainty are related mainly to the underlying dose-response relationships on climate sensitivity and biodiversity response to environmental pressures and land-use dynamics. The relationships are based on the best current available and extensive literature reviews. Using the terminology from the Millennium Ecosystem Assessment (MA, 2005), the knowledge base can be characterized as “established incomplete knowledge” for IMAGE, and as “established” to “speculative knowledge “ for GLOBIO3, depending on the type of pressure.

The GTAP model captures economic and demographic developments that determine land-use. The most important uncertainties in the GTAP model are related to macro-economic and demographic growth. Sensitivity analysis shows that model outcomes are mostly determined by variation in economic growth. This is caused by the relatively low demographic growth, relative to economic growth. Sensitivities are generally low, but are considerable for Africa, as developments in this region are determined by the more sensitive part of the land-supply curve. Land-use is dependent on the position and elasticity of the land-supply curve, and trade flows are very dependent on the values of the Armington elasticities, which are difficult to estimate.

Policy options

The liberalization option is rather extreme in assuming that all barriers of agricultural products to free trade are abolished simultaneously. In reality, such agreements are introduced with delays, exemptions and special conditions leading to more gradual and partial shifts. Differences in wages and land rents that drive the observed shift from North to South tend to decrease as time elapses. Thus the effects will never materialize to the full extent reported here. Moreover, the WTO rules allow for interventions in unfettered trade under certain conditions, including environmental impacts and regulations. Altogether, this means that the negative effects of liberalization are probably smaller as the process will take place along more smoothened trajectories. This will result in a less dramatic effect on additional land-use, production shifts and biodiversity decline.

The poverty reduction strategy is implemented in a fairly straightforward way. Trade liberalization is combined with extra income growth as a result of increased investments. Agricultural productivity and labor productivity are adjusted upwards. A more specific targeting of investments might help the poor *and* reduce the pressure on biodiversity. These strategies could focus on increased off-farm income and exit from agriculture (Dixon *et al.* 2001). On the other hand, MDG-focused investments assume a relatively strong emphasis on infrastructure, given the extensive road system in Sub-Saharan Africa (SSA). This might increase the pressure on biodiversity. In the long run, the negative impact of improved human development in SSA on biodiversity might be mitigated by a demographic transition. Improvements in health, education and income will have a downward pressure on fertility rates. Ultimately, population growth, one of the major drivers of biodiversity loss, will decline. Given the long lag times, the positive effect on biodiversity is, within the scenario horizon, assumed to be negligible. Altogether, the impact of implementing a more sophisticated poverty strategy remains ambiguous within the scenario period.

The impact of climate change is probably underestimated. If this were to result in a higher deployment of bio-fuels to compensate climate impacts, it would lead –in turn– to higher biodiversity impacts due to habitat loss. The negative impact on biodiversity of bio-fuel crops due to habitat loss might be overestimated. The model assumes entire restoration of the original biodiversity after an area has been abandoned. However, in practice not all abandoned land will be restored naturally. If bio-fuel crops are established on these degraded lands this might reduce the impact or even slightly improve biodiversity. In the climate mitigation option bio-fuel crops (20%) were allocated as much as possible in abandoned land. An analysis of option combinations would be a valuable addition to the present study.

5. Conclusions

In this study we used a novel framework to explore the impacts of a number of stylized policy options. This framework, linking economic and biophysical models, allows us to evaluate 'biodiversity costs' *and* 'economic costs', simultaneously.

Effective implementation of full trade liberalization in agriculture from 2015, driven by free-trade considerations and development arguments following the current WTO Doha Round. Implementation leads to an additional biodiversity loss of 1.3% until 2050 due to a 6.5% global increase of land used for agriculture, concentrated in Latin America and Southern Africa. The production shift and expansion in these regions is driven by cost-efficiency reasons, since labour and land costs are particularly low. This shift of production is at the expense of production in the US, Europe and Japan, resulting in disproportionately higher land requirements at the global level since current crop yields are much higher in these developed regions. The increase of agricultural land is at the expense of forest and grassland areas. About 1.3 Million km^2 or 20% of the baseline agricultural area will no longer be required for intensive agricultural production in the US, Canada, OECD Europe and Japan. This area potentially enables restoration of biodiversity, but only in the long term as initially the land previously used for agriculture will have low biodiversity

In order to alleviate extreme poverty as targeted in the Millennium Development Goals, direct investments from developed countries into Sub-Saharan Africa are combined with trade liberalisation of agriculture in line with the proposals by the Millennium Project (UN Millennium Project, 2005). Assuming effective implementation of these additional direct investments, including higher productivity of 10%, this options leads to a 25% GDP increase in Sub Saharan Africa on top of the baseline in 2030. This increase in GDP has a direct effect on food consumption in Africa, mainly produced in their own region, leading to a 10% increase of agricultural land (globally 3% extra) and an additional biodiversity loss of about 5.7%. Not all possible effects are taken into account. A hunger and poverty strategy requires heavy investments in infrastructure leading to further biodiversity losses. On the other hand, reducing extreme hunger and poverty can promote the demographical transition, break the poverty trap and decrease unintentional deterioration of natural capital (according to the Millennium Ecosystem Assessment)

Implementation of an climate change mitigation policy option, stabilizing CO_2-equivalent concentrations at a level of 450 ppmv in line with the option of keeping the global temperature increase below 2 ^oC requires substantial changes in the world energy system. One of the more promising options for reducing emissions (in particular in transport and electric power) is the use of bio-energy. A scenario has been explored in which bio-energy plays an important role in reducing emissions[1]. In this scenario major energy consumption savings are achieved and 23% of the remaining global energy supply is produced from bio-fuels in 2050. This leads to an additional biodiversity loss of around 1% by 2050 as a result of the habitat loss for producing bio-fuels (about 10% of the global agricultural area). In the short term, the biodiversity gain (+1%) from less climate change and reduced nitrogen deposition due to less fossil fuel burning. does not compensate for the natural habitat loss (-2%). Preliminary estimates show that after 2100 the initial biodiversity loss due to bio-fuel production may be exceeded by the biodiversity gains from avoided future climate change. Smart combinations of bio-fuel production with other land use options have not been explored

All options have an economic impact or 'cost'. In most cases there is a trade-off between biodiversity and economic growth. In the case of trade liberalisation and poverty reduction higher economic growth comes at the expense of global biodiversity. However, on the regional, national and local scales there will be biodiversity *and* economic gains because of safeguarding a variety of functions on which –eventually- humanity entirely depends (see the Millennium Ecosystem Assessment). Economic costs and biodiversity gains may be spread over time. Climate change policy will decrease economic growth, while beneficial effects on biodiversity and the economy (or avoided cost) can only be expected in the long term.

From the above it is evident that the options considered are too little or too late to meet the CBD 2010-target. Some options, like climate change mitigation, show beneficial effects, but only after several decades. In the short

[1] But note that other combinations of measures to reduce greenhouse gas emissions are also conceivable.

term, these options exert increasing pressure on biodiversity. It is evident that economic growth takes place at the expense of further decline in biodiversity. The challenge remains to find realistic policy options that conserve biodiversity *and* help the extreme poor.

Promising future options to explore are:

- Search for ways to keep the long-term benefits of some options for safeguarding biodiversity, whilst reducing their short term pressures. For example, the climate change mitigation option considered in this study relies strongly on substitution of renewable bio-fuels for fossil fuels. Other mitigation options that may have less negative impact, or actually provide benefits for biodiversity conservation could be explored. With the assumptions made here, this might undermine reaching the climate target or at least lead to higher cost.

- Limit the trade-off between economic growth and biodiversity. More attention for agricultural productivity and stimulating efficient land-use. Further enhancement of agricultural productivity ("closing the yield gap") is the key factor in reducing the need for land and consequently the rate of biodiversity loss. Technology transfer and capacity building are a pre-condition to that. The feasibility of this option is one of the key focuses of the International Assessment of Agricultural Science and Technology for Development (IAASTD or Ag-assessment), currently under way. This enhancement should be implemented carefully, in order not to cause new undesired negative effects, like emissions of nutrients and pesticides and risks of land degradation.

- Trade liberalisation contributes to poverty alleviation, although unbalanced and direct liberalisation may hinder poverty alleviation in those regions where sufficient institutions and government control are not available. In order to achieve complete poverty alleviation and to avoid unnecessary and persistent loss of biodiversity by land conversion in low-cost areas, trade liberalisation needs to be combined with controlled policy interventions.

- Targeting the distribution of economic growth and investments on poor people. In the long term economic growth and poverty reduction may help biodiversity, as it is assumed to accelerate the demographic transition and adoption of more productive and sustainable land management practices.

- Solve the value problem. Conserving biodiversity depends crucially on what societies are willing to pay for conservation. More emphasis could go into demonstrating value and designing markets to capture the value of these commons.

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