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Economic Loss of Ecosystem Services from 1900 to 2050

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Abstract

This paper presents a partial valuation of the losses of ecosystem services between 1900 and 2000 and the expected losses between 2000 and 2050. We find significant gross losses in ecosystem services between both dates. The gross loss of natural capital between 1900 and 2000 is estimated at between US$20 trillion and US$45 trillion. In terms of regions, the greatest losses occurred in the OECD region, followed by Central and South America and South Asia. In terms of biomes the most important sources of losses were the tropical forests, followed by temperate forests. Grassland losses contributed a small share of the total.

In terms of flows, the total loss between 1900 and 2000 is estimated at between US$603 billion and US$1.3 trillion, which is around 1.7 and 3.8 percent of the GDP of 2000. However, against this loss we also have to account for the gain made by the conversion of forest and grassland to agriculture. This gain more or less cancels out the loss in the case of the lower bound figure. Only if the upper bound figure of gross losses is valid is there a net loss, which is about US$730 billion, or 2 percent of the 2000 GDP. It is also important to note that there are major differences in the net loss by region. In particular, Sub-Saharan Africa suffers net loss of 13 to 33 percent of its 2000 GDP. The other regions all show a gain if we take the lower bound figure for their losses of ecosystem services and in two regions (South Asia and China) the net figure is a gain even in the case of the upper bound of the losses.

Looking at the comparison between 2000 and 2050 we find similar overall results but with some notable differences. In terms of the natural capital the losses range from US$11 trillion to US$39 trillion, with the greatest losses expected in Sub-Saharan Africa, OECD and South Asia. In terms of biomes, the most affected are tropical forests followed by boreal forests. In terms of flows, after allowing for agricultural gains, we estimate a gain for between US$94 billion and US$930 billion. The only regions to show a net loss are Central and South America and Sub-Saharan Africa, but only with the upper bound of the gross loss figure.

1. Introduction

Much has been written and said on the loss of biodiversity that we have been experiencing in recent decades. Species are estimated to be going extinct at rates 100 to 1000 times faster than in geological times (Pimm *et al.* 1995). Moreover there is reason to believe that these extinctions are associated with economic and social losses. For example, between 1981 and 2006, 47 percent of cancer drugs and 34 percent of all `small molecule new chemical entities´ (NCE) for all disease categories were natural products or derived directly from them (Newman and Cragg, 2007). In some countries in Asia and Africa 80 percent of the population relies on traditional medicine (including herbal medicine) for primary health care (World Health Organization website[2]). As extinctions continue the availability of some of these medicines may be reduced and new drug developments may well be curtailed. Yet, while we have a number of pieces of anecdotal evidence of this nature, and there are several studies that look at the value of biodiversity in specific contexts, no one has estimated the global value of the loss of biodiversity as such[3]. This is because the links between biodiversity and biological systems and the economic and social values that they support are extremely complex. Even the measurement of biodiversity is problematic, with a multi-dimensional metric being regarded as appropriate (Purvis and Hector, 2000; Mace et al., 2003) but with further work being considered necessary to define the appropriate combination.

For this reason the focus, initiated by the Millennium Ecosystem Assessment (MEA, 2005), has been on measuring ecosystem services, which are derived from the complex biophysical systems. The MEA defines ecosystem services under four headings: provisioning, regulating, cultural and supporting and under each there are a number of sub-categories. Table 1 summarizes the main ecosystem services that the MEA has listed.

Table 1. Ecosystem Services

TYPE OF ECOSYSTEM SERVICE	
Provisioning Services • Food and fibre • Fuel • Biochemicals, natural medicines, and pharmaceuticals • Ornamental resources • Fresh water **Cultural services** • Cultural diversity, spiritual and religious values, educational values, inspiration, aesthetic values, social relations, sense of place and identity • Cultural heritage values • Recreation and ecotourism **Supporting services** • Primary production • Nutrient cycling • Soil formation	**Regulating services** • Air quality maintenance • Climate regulation (eg temperature and precipitation, carbon storage) • Water regulation (eg flood prevention, timing and magnitude of runoff, aquifer recharge) • Erosion control • Water purification and waste management • Regulation of human diseases • Biological control (e.g. loss of natural predator of pests) • Pollination • Storm protection (damage by hurricanes or large waves) • Fire resistance (change of vegetation cover lead increased fire susceptibility) • Avalanche protection • Other (loss of indicator species)

Source: MEA, 2005

[2] Traditional Medicine." World Health Organization web site. http://www.who.int/mediacentre/factsheets/fs134/en/index.html, accessed July 27th 2011.

[3] For a brief review see ten Brink (ed.) 2011, Chapter 5.4

The first thing to note is that services from ecosystems have also been facing major losses. During the last century the planet has lost 50 percent of its wetlands, 40 percent of its forests and 35 percent of its mangroves. Around 60 percent of global ecosystem services have been degraded in just 50 years (ten Brink, 2011).

While working at the ecosystem level makes things somewhat easier it is of critical importance to understand the causes of the loss of these services and the links between losses of biodiversity and the loss of ecosystem services. Indeed this is a major field of research for ecologists in which one thesis that has been developed over a long period is that more diverse ecosystems are more stable and less subject to malfunction (Haines-Young and Potschin, 2010; McCann, 2000, Tilman and Downing, 1994). Evidence in support of this has been provided from a range of natural and synthesized ecosystems, but the evidence also point to more complex relationships, in particular to the fact that the functions of ecosystems are determined more by the functional characteristics of the component organisms rather than the number of species (Grime, 1997). Overall, however, many ecologists would agree with the statement that "diversity can be expected, on average, to give rise to ecosystem stability", McCann, 2000, p.232.

To sum up, the current state of knowledge on the links between biodiversity and ecosystem services is still a topic of research and while some clear lines are emerging, they are not strong enough to allow a formal modelling to be carried out at a level that would produce credible estimates of the global value of biodiversity. The latter therefore remains a topic for research[4].

Since the objective of this study is to obtain estimates of changes in the economic values of services from natural systems at the global level we have, of necessity gone for ecosystem function valuation, recognizing that there is a complex link between changes in such values and the changes in the measures of biodiversity (defined appropriately). However, our ecosystem methodology does take into account the quality of an ecosystem and the services it produces, based on the species abundance within it. This is derived from the Mean Species Abundance (MSA) approach, which is explained more fully in the next section. To some extent therefore, the study does build on the linkages between the biodiversity of a biome and its ecosystem functions.

Specifically this paper examines the changes of key ecosystem services between 1900 and 2000, the estimated changes between 2000 and 2050 under some projected scenarios, and attempts to value these changes in monetary terms. Note that not all the services listed in Table 1 will be valued. Limitations of data restrict us to a few of the key ones and to that extent the exercise is incomplete and probably an underestimate of the changes in services.

The approach taken in the study is as follows. First an estimate is made of the range of ecosystem services that are being derived from the different biomes in the different regions of the world in 2000. These calculations are based on recent research that has been addressing exactly that question – i.e. the links between the level of services and the quantity and quality of the biomes. Second an estimate is made of what the quantity and quality of these biomes were in 1900, 2000 and what they will be in 2050, assuming current economic and environmental trends continue. Third the values of ecosystem services are estimated for the years 2000 and 2050, given the quality and quantity of the biomes. The estimates of the quality and quantity of the biomes are based on the work of GLOBIO team, which has estimated the combination of quantity and quality in terms of "Mean Species Abundance (MSA) Area". This concept is elaborated further in the next section. The

[4] Theoretical models of the economic values attached to biodiversity have been developed. See for example, Brock and Xepapadeas, 2003. Such models draw simple links between harvesting rates, system biodiversity and overall system value. As yet, however, they are not supported by empirical estimates that be used to apply the methods to derive these system values.

data show significant losses between 1900 and 2000, and a mixture of expected losses and gains between 2000 and 2050.

The analysis is therefore carried out for the two time frames: 1900-2000 and 2000-2050. Given the difficulties in knowing the prices and economic conditions in 1900 in adequate detail, the estimates are based on the following mental experiment. First we estimate what would have been the value of the services in 2000 with the 1900 MSA areas had they been available in 2000, and second we estimate what would have been the value of the ecosystem services in 2050 if the 2000 MSA Areas had been available in 2050. The difference between the 1900 and 2000 values is then the gain we would have had in 2000, if the 1900 levels of services had been available. Likewise the difference between the 2000 and the 2050 levels tells us what we have lost (or gained) by 2050 as a result of the change in services between 2000 and 2050. Both calculations make the simplifying assumption that the changes are marginal and that the unit value of areas does not change as a result. Given the limited data it is difficult to do anything else.

The next step in the overall assessment is to value the gains that have been made by the conversion of the biomes with significant ecosystem benefits to agricultural use. The net benefits of agriculture from the land that has been converted to that use from forest clearance or grassland modification are then subtracted from the losses due to biodiversity as a result of the loss of MSA areas. The resulting figures show the net losses or gains in 2000 and in 2050 under the thought experiment of what would have been the situation had we not suffered any change of biomes during the 20th century and the first half of the 21st century. We conclude with some reflections on the results, what messages can be drawn from them and where we should not extend ourselves beyond what the data can reveal.

2. Change in MSA area

2.1 The model

The Global Biodiversity Model GLOBIO3 is used to assess the impacts of human activities on biodiversity in different biomes and world regions (Alkemade *et al*., 2009). The model links environmental drivers and biodiversity impacts using cause-effect relationships derived from the literature. The impacts are driven by climate change, fragmentation, land-use change, infrastructures, carbon and nitrogen cycles. GLOBIO3 Model is linked to the IMAGE 2.4 Model as changes in drivers are assessed using the latter, which is an Integrated Model to Assess the Global Environment (Bouwman *et al*., 2006) quantifying the impacts of human activities on natural environment and reflecting social, economic and technological features in the society.

In this model biodiversity is analyzed as "the remaining mean species abundance (MSA) of original species, relative to their abundance in pristine or primary vegetation, which are assumed to be not disturbed by human activities for a prolonged period" (Alkemade et al., 2009: 375). The peculiarity of MSA is related to the fact that it is not built on actual observations in the study area, but on the relations between pressures or drivers and impacts on species abundance. For each pressure under analysis a meta-analysis is first carried out to put in relation the MSA values with a number of drivers. The MSA values used in the meta-analysis are constructed from indicators taken from the literature, and specifically the abundance of different species (number of individuals per species, density or cover) registered in primary vegetation areas (natural or relatively untouched) and the abundance of species in disturbed environments. The MSA indicator as dependent variable in the meta-analysis is constructed by dividing the latter number by the former.

MSA values are calculated for each of the above mentioned drivers taking into account the cause-effect relationships for each driver as estimated in the meta-analysis. As the IMAGE Model uses the area of land as an input, the MSA value of a geographical region is calculated as the area-weighted mean of MSA values for each region. The GLOBIO3 Model is then used to assess the expected impacts of the selected drivers on MSA in a number of world regions and future scenarios, as well as the impacts of specific pre-defined policy measures. For the purpose of this study we used the first set of the results provided by GLOBIO3 Model related to the estimated changes in MSA areas over the period 1900-2050 for a number of biomes and world regions. Biomes refer to ecosystems with similar climatic conditions and are characterized by specific features related to plants and leaves. A biome can be defined as a major habitat type. The classification used for this study refers to seven different biomes, namely: ice and tundra, grassland and steppe, scrubland and savanna, desert, and boreal, temperate and tropical forests. Projections of MSA areas are shown for all the seven biomes, while the economic valuation is presented only for grassland/steppe and the forest biomes. This choice is related to the limited availability of valuation studies and monetary estimates in many biomes. Seven world regions are analysed as listed in Table 2 below.

Table 2. World regions

World regions	Description
OECD	Western and Eastern Europe, Western Offshoots (Australia, Canada, New Zealand, US)
CSAM	Central and Latin America
MEA-NAFR	Middle East and North Africa
SAFR	Sub-Saharan Africa
RUS_CASIA	Russia and Central Asia
SASIA	South Asia
CHN	China

For the purpose of this study we decided to use the MSA area indicator for the physical impacts as it is built on the product of the area of the residual ecosystem and its quality in terms of species abundance. The measure therefore takes into account a quality dimension of the ecosystem which is related to its capacity to provide ecosystem services. In one of our previous studies (Chiabai *et al.*, 2011), we used directly the change in hectares over time, as we wanted to estimate the impacts of changes in forest areas in different biomes, so that we multiplied the projected variation in area by the monetary values, calculated on a per hectare basis, for a set of ecosystem services provided by those biomes. In this study, we decided to use the variation in MSA area indicator instead of the area directly, for two main reasons. First, this indicator is expressed in terms of area and secondly it incorporates the impact on biodiversity. The economic impact is assessed through the impact on ecosystem services (ES), which are expected to decrease as a consequence of the pressure on the natural environment, as discussed in the introduction. A common unit of measurement has to be used for this assessment and monetary values are usually provided in terms of values per hectare, which allows for comparisons across different ES. This is the reason why we need an indicator based on the area on the physical side as well. Secondly, the use of MSA area instead of the simple area, allows us to integrate in the assessment the fact that biodiversity loss is causing a degradation of the ecosystem which in turns reflects a decrease in the provision of ecosystem services[5].

Two main underlying assumptions are made in this regards. The first is that the provision of ES is linearly related to the area of the ecosystem and to the magnitude of the biodiversity indicator, the MSA area. The second assumption is that the estimated monetary values per hectare refer to ES provided in undisturbed environmental conditions.

According to this approach, the following formulation is used to calculate the expected economic impacts associated with a degradation of the ecosystems and related loss of ES:

$$I = V_h * \Delta h * Q \tag{1}$$

Where I is the estimated economic impact, V_h is the value per hectare of the ES and Q is the quality of the ecosystem measured as species abundance. The variation in the MSA area indicator, assessed through GLOBIO3 Model, is the combination between the area of the remaining ecosystem and its quality.

2.2 Limitations and uncertainties

GLOBIO3 Model presents a number of limitations related to the construction of the MSA indicator, the drivers estimated through IMAGE 2.4 Model and in general to the set of data used.

MSA area indicator is a pressure-based indicator taking into account the relationship between pressures and species abundance. This relationship has been built on a literature review process in order to construct a meta-analysis, which however includes only a limited set of studies which are taken from a sample that excludes several biomes, species and geographical regions. Furthermore, the MSA indicator is constructed by giving equal weight to each hectare, while areas with higher species richness should be assigned a higher weight. In addition this indicator takes into account the change in the number of species but this is an imperfect measure as it does not represent entirely the biodiversity loss (see earlier discussion on the measurement of biodiversity).

However, the most important limitation of this indicator is probably related to the fact that it is not built on individual species, but it is based on the mean calculated over all the species. In this sense "it represents the average response of the total set of species belonging to the ecosystem" (Alkemade et al., 2009: 375). This is a major limitation as averages do not take into account the functional relationship between the different elements of an ecosystem and cannot therefore properly assess the health of an ecosystem. As stated in Villa and McLeod (2002: 341), "it would be inappropriate to use averages to evaluate the health of an organism on the basis of functionality indicators for its vital organs. Even if the exact dynamics of the interaction are not known, a conservative indicator should be drastically influenced by the fact that even just one is very dysfunctional or subjected to high risk".

Another limitation of the GLOBIO3 Model relates to the drivers of biodiversity loss included in the model. Some of them are not considered, such as the impact of augmented CO_2 concentration in the atmosphere, increased forest fires, extreme events and pollution. Lastly, uncertainty also arises from the quality of the data used in the model, related for example to the measurements and

[5] We acknowledge that the adjustment for changes in biodiversity is relatively simple in the GLOBIO assessment but given the generally clear link between some indicators of biodiversity and the quality and quantity of ecosystem services we felt justified in using the MSA measure as the one to which ecosystem service calculations should be applied.

forecasts for climate, and the availability of data and maps for agricultural land, forest areas and infrastructures.

On the other side, the model allows to us assess the impact on MSA on a worldwide basis, which is quite difficult (and controversial) at the current stage considering the lack of quantitative data on global species trends. The results of the GLOBIO3 Model have been used in many assessment reports (e.g. UNEP's Global Environment Outlooks, CBD’s Global Biodiversity Outlook 2 and the OECD Environmental Outlook). The Convention on Biological Diversity (CBD) accepted the MSA indicator to evaluate the achievement of the 2010 target about the reduction of biodiversity loss at global, regional and national levels.

2.3 Projections of MSA areas

Tables 3-8 present the main results in terms of MSA area in year 1900, 2000, 2050 and the projected change over those periods. Results are reported per world region and in terms of biomes.

In all the three time frames, the largest MSA area is recorded for desert, boreal forests, and scrubland and savanna. The world region with the largest MSA area is the OECD (Western and Eastern Europe, US, Canada, Australia and New Zealand). The relative contribution of each biome type within each world region differs in the three periods considered, depending on the shifts recorded over time between type of biome and land-use.

The distribution of MSA area by world region remains fairly constant over the two periods 1900-2000 and 2000-2050. In terms of overall losses in the period 1900-2000, it appears from Table 6 that the highest loss was recorded for South Asia SASIA (40% loss on 1900 levels), followed by Central and South America (CSAM), China (CHN) and the OECD region. In terms of biomes, temperate forests have recorded the highest loss (45% loss on 1900 levels, mainly registered in OECD region), followed by grassland/steppe (mainly in OECD region), scrubland and savanna (mainly in Sub-Saharan Africa SAFR), and tropical forests (mainly in Central and South America CSAM). These have been the most affected biomes in the period 1900-2000.

Table 7 shows the changes in MSA area over the period 2000-2050. South Asia (SASIA) is expected to lose another 30% of MSA area in 50 years, in addition to the 40% loss registered in the previous period over 100 years. Sub-Saharan Africa (SAFR) will also see a further considerable decrease in MSA area, registering a loss of 18%, comparable to that of the previous period but referring to 50 years only. In the other regions the decrease in MSA area is expected to be smaller but following the same trend registered in the previous period. If we look at the most affected biomes, the period 2000-2050 will see the highest loss in scrubland and savanna (22%, mainly in Sub-Saharan Africa SAFR), followed by temperate forests (18%, mainly in OECD region), grassland/steppe (16%, mainly in OECD region) and tropical forests (12%, mainly in Sub-Saharan Africa SAFR).

There is a shift registered in the type of biome affected over time, due to the combination of the different pressures in terms of land-use change, infrastructures, climate change, fragmentation, etc. While in the period 1900-2000 the most affected biome is temperate forest (OECD region having the highest loss), in the period 2000-2050 the most vulnerable biome turns out to be scrubland and savanna (with the highest decrease in Sub-Saharan Africa). Overall, the estimated loss of MSA area is significant (21% in 1900-2000 and 12% in 2000-2050, with a total loss of 31% over the whole period), and the most affected regions are South Asia and Sub-Saharan Africa (Table 8).

Table 3. MSA area by biome and world region, year 1900 (1000ha)

Biome	OECD	CSAM	MEA_ NAFR	SAFR	RUS_ CASIA	SASIA	CHN	Total	% on total
Ice and tundra	423,734	20,183	0	0	290,684	11,794	178,340	924,735	7.8%
Grassland and steppe	560,128	166,240	105,941	191,707	271,132	64,086	292,332	1,651,566	13.9%
Scrubland and savanna	363,089	454,955	30,511	1,044,123	0	276,279	286	2,169,243	18.3%
Boreal forests	725,526	22,944	0	0	1,160,247	10,150	119,542	2,038,410	17.2%
Temperate forests	620,356	145,706	0	32,704	133,330	63,087	185,196	1,180,380	10.0%
Tropical forests	32,809	909,390	0	354,737	0	338,356	3,770	1,639,062	13.8%
Desert	394,271	21,061	898,727	591,297	121,686	89,565	140,179	2,256,785	19.0%
Total	**3,119,914**	**1,740,480**	**1,035,179**	**2,214,567**	**1,977,079**	**853,318**	**919,645**	**11,860,181**	
% on total	26.3%	14.7%	8.7%	18.7%	16.7%	7.2%	7.8%		100.0%

Table 4. MSA area by biome and world region, year 2000 (1000ha)

Biome	OECD	CSAM	MEA_ NAFR	SAFR	RUS_ CASIA	SASIA	CHN	Total	% on total
Ice and tundra	405,576	16,983	0	0	279,055	10,167	158,638	870,420	9.3%
Grassland and steppe	385,470	131,285	72,466	145,425	212,944	37,588	215,643	1,200,822	12.9%
Scrubland and savanna	291,855	319,427	17,046	809,263	0	157,025	169	1,594,784	17.1%
Boreal forests	606,849	18,882	0	0	989,207	6,672	84,347	1,705,957	18.3%
Temperate forests	341,601	63,364	0	21,466	91,490	29,761	105,763	653,445	7.0%
Tropical forests	19,219	717,571	0	278,665	0	204,996	2,191	1,222,642	13.1%
Desert	351,629	17,156	848,938	546,730	118,892	66,693	130,857	2,080,896	22.3%
Total	**2,402,199**	**1,284,667**	**938,450**	**1,801,548**	**1,691,589**	**512,904**	**697,609**	**9,328,965**	
% on total	25.7%	13.8%	10.1%	19.3%	18.1%	5.5%	7.5%		100.0%

Table 5. MSA area by biome and world region, year 2050 (1000ha)

Biome	OECD	CSAM	MEA_ NAFR	SAFR	RUS_ CASIA	SASIA	CHN	Total	% on total
Ice and tundra	381,614	15,041	0	0	258,109	8,684	146,299	809,748	9.9%
Grassland and steppe	322,192	116,629	65,597	114,110	175,338	20,193	191,473	1,005,532	12.3%
Scrubland and savanna	245,209	276,781	14,773	611,574	0	92,045	130	1,240,512	15.2%
Boreal forests	549,979	16,580	0	0	911,206	4,593	72,567	1,554,924	19.0%
Temperate forests	289,280	53,888	0	11,839	74,035	17,671	85,989	532,702	6.5%
Tropical forests	17,321	669,493	0	219,830	0	169,682	1,755	1,078,081	13.2%
Desert	313,272	15,496	818,883	515,059	109,103	44,309	125,653	1,941,774	23.8%
Total	**2,118,867**	**1,163,909**	**899,253**	**1,472,412**	**1,527,791**	**357,177**	**623,864**	**8,163,273**	
% on total	26.0%	14.3%	11.0%	18.0%	18.7%	4.4%	7.6%		100.0%

Table 6. Changes in MSA area by biome and world region, period 1900-2000 (1000ha)

Biome	OECD	CSAM	MEA_ NAFR	SAFR	RUS_ CASIA	SASIA	CHN	Total	% on 1900 levels
Ice and tundra	-18,158	-3,200	0	0	-11,629	-1,627	-19,701	-54,316	-5.9%
Grassland and steppe	-174,658	-34,955	-33,475	-46,282	-58,187	-26,498	-76,689	-450,744	-27.3%
Scrubland and savanna	-71,234	-135,528	-13,465	-234,860	0	-119,254	-118	-574,459	-26.5%
Boreal forests	-118,677	-4,062	0	0	-171,040	-3,478	-35,195	-332,452	-16.3%
Temperate forests	-278,755	-82,342	0	-11,238	-41,840	-33,326	-79,433	-526,934	-44.6%
Tropical forests	-13,590	-191,819	0	-76,072	0	-133,360	-1,579	-416,421	-25.4%
Desert	-42,642	-3,905	-49,790	-44,567	-2,793	-22,872	-9,321	-175,890	-7.8%
Total	**-717,715**	**-455,812**	**-96,729**	**-413,019**	**-285,489**	**-340,414**	**-222,036**	**-2,531,216**	
% on 1900 levels	-23.0%	-26.2%	-9.3%	-18.7%	-14.4%	-39.9%	-24.1%		-21.3%

Table 7. Changes in MSA area by biome and world region, period 2000-2050 (1000ha)

Biome	OECD	CSAM	MEA_ NAFR	SAFR	RUS_ CASIA	SASIA	CHN	Total	% on 2000 levels
Ice and tundra	-23,962	-1,942	0	0	-20,946	-1,483	-12,339	-60,672	-7.0%
Grassland and steppe	-63,278	-14,656	-6,869	-31,315	-37,606	-17,395	-24,171	-195,289	-16.3%
Scrubland and savanna	-46,646	-42,645	-2,273	-197,689	0	-64,980	-39	-354,272	-22.2%
Boreal forests	-56,870	-2,302	0	0	-78,001	-2,079	-11,780	-151,033	-8.9%
Temperate forests	-52,321	-9,476	0	-9,627	-17,456	-12,091	-19,775	-120,744	-18.5%
Tropical forests	-1,897	-48,078	0	-58,835	0	-35,314	-436	-144,560	-11.8%
Desert	-38,357	-1,660	-30,055	-31,671	-9,790	-22,385	-5,205	-139,122	-6.7%
Total	**-283,332**	**-120,759**	**-39,197**	**-329,137**	**-163,798**	**-155,726**	**-73,745**	**-1,165,693**	
% on 2000 levels	-11.8%	-9.4%	-4.2%	-18.3%	-9.7%	-30.4%	-10.6%		-12.5%

Table 8. Changes in MSA area by biome and world region, period 1900-2050 (1000ha)

Biome	OECD	CSAM	MEA_ NAFR	SAFR	RUS_ CASIA	SASIA	CHN	Total	% on total
Ice and tundra	-42,120	-5,143	0	0	-32,575	-3,110	-32,041	-114,988	-12.4%
Grassland and steppe	-237,937	-49,611	-40,343	-77,596	-95,793	-43,893	-100,859	-646,033	-39.1%
Scrubland and savanna	-117,880	-178,173	-15,738	-432,549	0	-184,234	-157	-928,731	-42.8%
Boreal forests	-175,548	-6,364	0	0	-249,041	-5,557	-46,975	-483,485	-23.7%
Temperate forests	-331,076	-91,818	0	-20,865	-59,296	-45,416	-99,207	-647,678	-54.9%
Tropical forests	-15,487	-239,897	0	-134,907	0	-168,674	-2,015	-560,981	-34.2%
Desert	-80,999	-5,565	-79,845	-76,238	-12,583	-45,256	-14,526	-315,012	-14.0%
Total	**-1,001,047**	**-576,571**	**-135,926**	**-742,155**	**-449,287**	**-496,141**	**-295,781**	**-3,696,908**	
% on 1900 levels	-32.1%	-33.1%	-13.1%	-33.5%	-22.7%	-58.1%	-32.2%		-31.2%

3. The economic impact

The methodological approach adopted to estimate the economic loss associated with a loss of MSA area is largely based on the study of Chiabai *et al*. (2011). The economic impact is assessed through the loss of ecosystem services (ES) engendered by a degradation of the ecosystem, this latter being measured in terms of loss of MSA area.

ES have been valued in the literature using a broad set of methodologies, ranging from market to non-market techniques, depending on the type of benefits considered. In this study we use a combination of methods, following the framework developed in Chiabai *et al.* (2011) and adapting it to the specific context under analysis. Monetary values are available in different metrics, but for comparability purposes we refer to values per hectare. The economic impact is estimated over two periods of time, 1900-2000 and 2000-2050, for which MSA data were available in terms of point estimates in time. We use therefore MSA data for the years 1900, 2000 and 2050, and we combine them with monetary values of ES (present value), estimated on a per hectare basis. Basically, we estimate first the loss in terms of present values, and second we convert these latter into annual economic flows using the formula of perpetual revenue under the assumption of constant flows over time. It was not possible to estimate annual flows independently, due to the huge amount of data and information necessary for this purpose, both on the physical and economic side, in terms of MSA data, quantitative flows of ES and monetary values per year. Present values are however very important as they refer to the existing natural capital and changes in this latter show the actual depletion of natural resources. Natural capital includes natural resources (e.g. trees, fish, minerals), land and ecosystems, which provide flows of environmental goods and services to human being. An adequate natural capital has to be maintained over time to generate sufficient flows of ES in a condition of long-term sustainability. If this is not preserved, then its ability to generate perpetual flows is compromised.

The economic impact (loss or gain) is estimated in year 2000 and in year 2050 for the two time frames. Original economic values are taken from the literature and standardized to the year 2000 to build a baseline scenario. These values are projected in a second step in year 2050 following different assumptions and methods according to the type of ES analysed; and for the year 1900 based on the assumption that the 1900 levels of services are available in 2000. In this way we have point estimates in the time frame 1900-2050. It was not possible to present the analysis for year 1900 or for 1950 with the economic and social conditions that prevailed in that year, for two main reasons. First, original monetary estimates of ES are not available for those years. Second, the value-transfer back to 1900 or 1950 was infeasible for some ES, such as carbon and timber due to insufficient and inadequate economic statistics. An assessment back to 1900 would indeed require an extrapolation for constructing new estimates beyond the known trends with insufficient data, resulting in too much uncertainty.

The analysis of the economic impact is carried out for the following biomes, for which economic data were available: grasslands and steppe, boreal, temperate and tropical forests. The ecosystem services analysed in the forest biomes include wood and non-wood forests products, carbon and cultural services (recreational and passive use). As regards grassland and steppe, we estimated the impact on food provisioning, erosion prevention, conservation, recreation and amenity. The choice of these ES is mainly based on the availability of physical data and monetary estimates.

The specific methods used for each ES and biome, underlying assumptions and methodological limitations are discussed here below, together with the results presented in terms of values per hectare for the two years, 2000 and 2050. The economic impacts are estimated based on the three calculations for these two years.

3.1 Forests

3.1.1 Wood and non-wood forest products

Wood forests products (WFPs) are estimated taking into account seven economic sectors, including industrial roundwood, wood pulp, recovered paper, sawnwood, wood-based panels, paper and paper board, and wood fuel. Non-wood forest products (NWFPs) include goods and services of biological origin derived from the forest, as defined by FAO (1999) (Table 9).

The estimation process differs for WFP and NWFP. For the former we used an approximation of the stumpage price (the value of standing trees)[6], calculated by taking into account export/import values and quantities, and domestic production for year 2000 (ForesSTAT from FAO[7]), finally adjusted for net profit (Bolt et al., 2002). The assessment is made at the country level using the bottom-up approach followed in Chiabai *et al.* (2011). The calculation has been however adjusted to take into account also import values/quantities besides export values/quantities:

$$V_{i,j} = \left[VIE_{i,j} \times \frac{QP_{i,j}}{QIE_{i,j}} \right] \times p_i \qquad (2)$$

Where $V_{i,j}$ represents the annual value of WFPs by country i and product j, $VIE_{i,j}$ is the average of the annual import and export values, $QP_{i,j}$ is the annual domestic production quantity, $QIEq_{i,j}$ is the average of annual import and export quantities, p is the profit rate. We took as reference the year 2000 and we computed all the values in US$2000. These values are aggregated across countries and divided by the forest area designated to timber production in each country and forest biome in 2000, using a weighted mean. According to this approach, we are assuming a constant productivity factor for each forest hectare. This is a limitation of the estimates, as productivity is actually influenced by the type of forest. The lack of economic data (export and import values and quantities, profit rates) by forest type for each country compelled us to make this simplistic assumption.

Table 9. Non wood forest products

Plant products	Animal products
Food	Living animals
Fodder	Hides, skins and trophies
Raw material for medicine and aromatic products	Wild honey and beeswax
Raw material for colorants and dyes	Bush meat
Raw material for utensils, crafts & construction	Other edible animal products
Ornamental plants	
Exudates	
Other plant products	

Sources: FAOSTAT and FAO/FRA 2005. Adapted from Chiabai et al. (2011)

[6] Stumpage is the value paid by a contractor to the landowner for the standing trees in a designated harvest area. The contractor assumes the right to harvest the trees, under specific requirements concerning the timing of harvest or the conservation of the area.
[7] http://faostat.fao.org/site/626/default.aspx#ancor

As regards NWFPs, these can be plants or animals, the former including for example medicinal or aromatic plants, ornamental plants, raw material for utensils, colorants and dyes, and the second referring to hides, skins, trophies, wild honey, bush meat, etc. These are estimated using information from FAO, which provide export values of the total removals of these products by country. Export values are aggregated by region and divided by the total forest area to get an annual value per hectare. NWFPs play an important role for indigenous people in developing countries; however their contribution to the economy is very low, compared to timber and other WFPs.

For both WFPs and NWFPs, values estimated for year 2000 are assumed to be constant over time[8]. Considering that the natural capital is generating flows of ES year after year, and that these flows can be translated into monetary terms, we can convert these latter into a present value, using the following formulation:

$$PV_i = \sum_{t=1}^{T} \frac{(V_i)_t}{(1+d)^t} \qquad (3)$$

Where PV_i is the present value per hectare of WFPs and NWFPs for country i calculated for the baseline year 2000, V_i is the annual value per hectare and d is the discount rate. As V_i is constant over time the formulation is simplified by dividing this value by the discount rate. A 3% rate is used for this calculation. It is assumed that flows of WFP and NWFP will continue over time constantly (i.e. that the use of the resource is broadly sustainable). Tables 10 reports the present values per hectare generated by WFPs and NWFPs in the baseline year 2000. We do not differentiate between the two categories as NWFPs provide a very low contribution to the total present value, ranging from 0.02% to a maximum of 1.93%, as estimated in Chiabai *et al*. (2011). These values can be used also for the projections in year 2050, as no increase in real prices for timber is expected globally in the long run (as discussed in Chiabai *et al.*, 2011 and Clark, 2001).

Table 10. Present values for WFPs and NWFPs (2000 US$/ha)

	Forest biomes		
World regions	**Boreal**	**Temperate**	**Tropical**
OECD	83,738	29,980	5,711
CSAM	24,343	159	36,115
MEA_NAFR	-	-	-
SAFR	-	714	111,214
RUS_CASIA	9,258	4,733	-
SASIA	100,559	5,689	47,002
CHN	89,177	19,123	1,678

The highest values are registered for tropical forests in Sub-Saharan Africa (SAFR), and boreal forests in South Asia (SASIA) and China (CHN) regions. Temperate forests generate much lower values. According to these estimates, tropical and boreal forests generate much higher economic

[8] This assumption was corroborated by an analysis of the timber prices and associated rents in the World Bank database (Bolt *et al*., 2002). See Chiabai et al. (2011).

values than temperate forests. As discussed in detail in Chiabai *et al*. (2011), values per hectare for WFPs are overestimated as we presume that timber removal occurs only in plantations, while in reality it takes place also in primary forests. Illegal harvesting is not considered in our calculations due to lack of reliable data on its dimension.

3.1.2 Carbon

The estimation process is based on the quantitative assessment of the biomass carbon capacity by forest type and country, and consequently the calculation of a price of carbon stocked per hectare, following the approach suggested in Chiabai *et al*. (2011). The carbon capacity is taken from the literature, and basically from two studies, Myneni *et al.* (2001), and Gibbs (2007). These studies make use of the biome-average approach to calculate the average carbon capacity in different forest biomes. The approach is based on direct estimates of the existing forest biomass (Olson *et al.* 1983, Reichle, 1981), complemented by the analysis of forest inventories archived by the United Nations Food and Agricultural Organization (FAO) (Gibbs, 2007). The advantage of this method is related to the availability of these figures at a global scale, but the limitation is due to inadequate sampling at national level, causing that the data cover only specific locations while important portions of the forest are not taken into account.

In our estimates we used the data available at country level, and we assumed the same carbon capacity for the regions not covered by the two studies when located in the same geographical area and covered by the same type of forest. The countries included in the two studies are Canada, Northern America, China, Japan, Russia, Finland, Sweden, Eurasia, South Eastern Asia, Brazilian Amazon, Latin America, Sub-Saharan Africa and Tropical Asia. According to Myneni *et al*. (2001), forest carbon capacity ranges from an average of 25.77 tC/ha in China to an average of 59.4 tC/ha in some European countries such as Austria, Belgium, Croatia, Czech Republic, Denmark, France, Germany, Greece, Italy, Netherlands, Norway, Poland, Portugal, Slovenia, Spain, Switzerland, Turkey, and United Kingdom. Gibbs et al. (2007) provide estimates of carbon capacity for tropical forests in different countries making reference to a number of studies (Houghton, 1999; DeFries *et al*., 2002; Brown, 1997; Achard *et al*., 2004; Gibbs and Brown, 2007a, 2007b; IPCC, 2006), according to which carbon capacity ranges from 17 tC/ha in Sub-Saharan Africa tropical dry forests to 250 tC/ha in Asian tropical equatorial forests.

The second step consists of using estimated prices per ton of CO_2, convert them into prices per ton of carbon (1 ton carbon ≈ 3.66 tons CO2) and calculate the present value of carbon stocked in forests multiplying the price per tC by the carbon capacity. The price per ton of CO_2 is taken from Markandya *et al*. (2010), who provide values ranging from 4US$ to 53US$ per ton of CO_2 for year 2000, and 13US$-179US$ for year 2050. Tables 11 and 12 report present values for carbon stocks for the years 2000 and 2050, in US$2000.

Tropical forests register in general the highest values (specifically in Sub-Saharan Africa SAFR, Central and South America CSAM and South Asia SASIA), which depends on the high capacity of carbon capacity in this forest biome. A limitation of these estimates is that we have not considered different lands uses, which is a main factor of variation in carbon sequestration capacity, as well as altitude, slope and similar features related to the type of land and soil, due to the lack of data at a global scale.

Table 11. Present values for carbon stocks in year 2000 (2000 US$/ha)

	Forest biomes					
	Boreal		Temperate		Tropical	
World regions	LB	UB	LB	UB	LB	UB
OECD	593	7,858	828	10,974	1,547	20,502
CSAM	270	3,575	748	9,912	2,658	35,221
MEA_NAFR	-	-	-	-	-	-
SAFR	-	-	943	12,490	3,174	42,055
RUS_CASIA	598	7,922	773	10,238	-	-
SASIA	943	12,490	1,804	23,908	2,515	33,328
CHN	409	5,419	409	5,419	1,523	20,186

Note: LB = lower bound; UB = upper bound. LB=4US$ per ton of CO_2. ***UB=53US$ per ton of*** CO_2.

Table 12. Present values for carbon stocks in year 2050 (2000 US$/ha)

	Forest biomes					
	Boreal		Temperate		Tropical	
World regions	LB	UB	LB	UB	LB	UB
OECD	1,927	26,539	2,692	37,062	5,029	69,242
CSAM	877	12,073	2,431	33,477	8,639	118,954
MEA_NAFR	-	-	-	-	-	-
SAFR	-	-	3,064	42,184	10,315	142,034
RUS_CASIA	1,943	26,756	2,511	34,578	-	-
SASIA	3,064	42,184	5,864	80,747	8,175	112,562
CHN	1,329	18,301	1,329	18,301	4,951	68,176

Note: LB = lower bound; UB = upper bound. LB=13US$ per ton of CO_2. ***UB=179US$ per ton of*** CO_2.

3.1.3 Cultural services

Forest cultural services comprise recreational and passive-use values, which are estimated using meta-analysis, value-transfer and scaling-up techniques as performed in Chiabai *et al*. (2011). The meta-regression function used to estimates these values takes the following form:

$$V = f(S, I) \qquad (4)$$

V is the annual value (recreational or passive use, based on Willingness to Pay), *S* and *I* are explanatory variables, the first representing the forest-related features, such as forest area and forest type, and *I* includes socio-economic variables such as income per capita and population of the country. We used the *beta* coefficients (which give the sensitivity of the annual estimated values to changes in the explanatory variables) estimated in Chiabai *et al.* (2011) to carry out a value-transfer from the study sites to the policy sites, and scaling-up from national to regional level. The coefficients on income are in the range of 0.63 for recreational values and 0.75 for passive use, while the coefficients on forest size are -0.43 for recreation and -0.39 for passive use. For this latter population is also significant and positive, with a coefficient of 0.64.

The value-transfer and scaling-up model is performed using the following equation:

$$V_p = V_s^* \left(\frac{P_p}{P_s} \right)^{\delta} \left(\frac{S_p}{S_s} \right)^{\sigma} \left(\frac{I_p}{I_s} \right)^{\gamma} \quad (5)$$

Where V_s* is the average annual value for the world region having original or study site values (taken from the literature), V_p is the value we would like to estimate which refers to world regions for which no original value exists (policy sites), *P* is the population of the country, *I* the country GDP per capita (adjusted for the Purchasing Power Parity, World Bank *World Development Indicators*), and *S* is the forest size designed to recreation or conservation (FAO/FRA2005).

Most of the studies for recreation and passive use (based on stated and revealed preferences) are from Europe and North America. Mean and median WTP for these regions are therefore used as reference values to carry out the value-transfer. All the original values from Chiabai *et al* (2011) have been re-estimated using the world regions and forest biomes analysed in the current study. The original values represent annual flows in terms US$ per hectare per year. These have been transformed into present values using a 3% discount rate assuming perpetual constant flows generated by the forests (see equation 3). Values are finally projected from 2000 to 2050 using the coefficients estimated in the meta-regression mentioned above.

Tables 13-16 show the estimated present values in year 2000 and 2050, both presented in US$2000. The highest values for passive use are estimated for OECD region and China (CHN), while the highest recreational values are registered respectively in China (CHN) and South Asia (SASIA). Values are obviously increasing in 2050 but the rate of increase differs considerably between world regions, ranging from 1.9 to 4.2 increase for passive use values, and from 1.6 to 3 for recreational values. This can be explained mainly by the depletion and degradation of forests, consistently with the “diminishing marginal utility” theory according to which the first unit of a good provides the consumer with a higher utility than the successive units. Therefore, if the good becomes scarcer, then its value is boost up. In addition, the estimates in 2050 depend on the projected population and GDP increase, which are expected to raise differently country by country.

Table 13. Value-transfer results: present values for passive use in year 2000 (2000 US$/ha)

World regions	Mean	Median	Max	Min
OECD	53,203	44,712	148,296	16,678
CSAM	20,175	16,955	56,234	6,324
MEA_NAFR	-	-	-	-
SAFR	24,976	20,990	69,617	7,829
RUS_CASIA	8,307	6,981	23,155	2,604
SASIA	18,135	15,241	50,549	5,685
CHN	40,255	33,830	112,204	12,619

Table 14. Value-transfer results: present values for passive use in year 2050 (2000 US$/ha)

World regions	Mean	Median	Max	Min
OECD	104,531	87,848	291,365	32,768
CSAM	45,678	38,388	127,321	14,319
MEA_NAFR	-	-	-	-
SAFR	95,854	80,556	267,179	30,048
RUS_CASIA	27,096	22,771	75,525	8,494
SASIA	76,666	64,430	213,695	24,033
CHN	158,131	132,894	440,768	49,571

Table 15. Value-transfer results: present values for recreation in year 2000 (2000 US$/ha)

World regions	Mean	Median	Max	Min
OECD	39,837	9,396	212,509	203
CSAM	6,138	1,448	32,746	31
MEA_NAFR	-	-	-	-
SAFR	16,764	3,954	89,425	86
RUS_CASIA	2,568	606	13,700	13
SASIA	61,859	14,591	329,990	316
CHN	62,421	14,723	332,986	319

Table 16. Value-transfer results: present value for recreation in year 2050 (2000 US$/ha)

World regions	Mean	Median	Max	Min
OECD	65,461	15,440	349,204	334
CSAM	10,721	2,529	57,190	55
MEA_NAFR	-	-	-	-
SAFR	34,782	8,204	185,547	178
RUS_CASIA	7,532	1,777	40,179	38
SASIA	166,777	39,337	889,672	851
CHN	190,657	44,970	1,017,060	973

3.2 Grassland and steppe

The values of ES in grassland are estimated using the database values and the coefficients of the meta-regression function as calculated in Hussain *et al* (2011). The following ES categories are valued within this biome: food provisioning, recreation and amenity, erosion prevention and conservation. The countries considered in the assessment include Northern Europe, United States, Asia and Africa. The limitation of this approach is that we can estimate an overall value of ES provided by grassland while we cannot provide values for specific ES. The meta-regression function takes the following form:

$$V = f(S, R, A, I) \tag{6}$$

Where V is the annual value of ES provided by grasslands from the existing case studies[9], S is the grassland area within 50km radius of the study site, R is the length of roads within 50km radius of the study site, A is an accessibility index, I is the country GDP per capita (measured in Purchasing Power Parity).

The results of the meta-regression show that the estimated coefficients have the expected signs but only one variable is significant, namely the accessibility index, which indicates that grasslands with higher accessibility have a higher value. Income has a positive sign which means that grasslands located in richer countries have higher economic value. The grassland area is negative, which is due to a substitution effect influencing negatively its value. Finally, the existence of roads impacts negatively the value of the grassland ES, which is due to a fragmentation effect as discussed in Hussain et al. (2011).

Due to the limitation of data in this context, we used the coefficients on income only, being of the expected sign, to transfer the ES grassland values from the original case study sites to policy sites, using the following equation:

$$V_i = V_s^* \left(\frac{I_i}{I_s} \right)^{\gamma} \qquad (7)$$

V_i is the annual estimated value for grassland in the world region i, V_s* is the annual mean or median value observed in the original case studies described in McVittie *et al.* (2011), and I is the GDP per capita adjusted using Purchasing Power Parity (PPP). Original values estimated in Hussain et al. (2011) are annual values and have been converted into present values using a 3% discount rate. Values are finally projected to year 2050 using the following equation:

$$V_{i,T_1} = V_{i,T_0} \left(\frac{I_{i,T_1}}{I_{i,T_0}} \right)^{\gamma} \qquad (8)$$

Where $V_{i,T0}$ is the value for the world region i in year 2000, $V_{i,T1}$ is the value projected to year 2050, T_0 is the baseline 2000 year and T_1 is the projection year 2050. Results are presented in tables 17-18 below. The highest values are registered for OECD region, China (CHN), Russia and Central Asia (RUS_CASIA).

The rate of increase from year 2000 to year 2050 ranges from 1.9 (registered for China) to 3.6 (registered for Russia).

[9] Contingent valuation and choice experiments have been used for recreational values of grasslands and wildlife conservation, hedonic pricing has been used for the amenity value, and the net factor income and market prices have been used to estimate food provisioning (McVittie *et al.* (2011).

Table 17. Value-transfer results for grassland ES, stock values in year 2000 (2000 US$/ha).

World region	Mean	Median
OECD	5,930	1,027
CSAM	2,969	514
MEA_NAFR	2,139	370
SAFR	1,126	195
RUS_CASIA	3,231	559
SASIA	2,381	412
CHN	5,806	1,005

Table 18. Value-transfer results for grassland ES, stock values in year 2050 (2000 US$/ha)

World region	Mean	Median
OECD	17,015	2,945
CSAM	6,124	1,060
MEA_NAFR	6,646	1,151
SAFR	3,024	524
RUS_CASIA	11,914	2,062
SASIA	5,105	884
CHN	11,253	1,948

4. The economic impact related to a loss of MSA area

The economic impact associated with the MSA area decrease is calculated for two periods of time, 1900-2000 and 2000-2050, taking into account both changes in present values and in annual economic flows, by world region and biome. The variation in the present value is related to the change in the natural capital (represented in this study by the four biomes types) and is calculated by multiplying the estimated present values per hectare (for each ES in each biome and each world region) by the projected change in MSA areas for the two periods under analysis. For WFP and forest cultural services, we used the forest area designated respectively to plantations, recreation and conservation available from FAO data for year 2005. Due to data limitation, forest land uses are assumed to be constant from 1900 to 2050, which is a simplifying assumption.

4.1 Gross economic impact on natural capital

The changes in the present value or natural capital for the two periods are presented in Tables 19 and 20. Gross losses are reported in US$2000 separately for the two periods, 1900-2000 and 2000-2050. The highest losses in the period 1900-2000 are registered in OECD region, Central and South America (CSAM), and South Asia (SASIA), while in the period 2000-2050 the expected losses are greatest for Sub-Saharan Africa (SAFR), in addition to OECD region and South Asia. As regards the type of biome concerned, the greatest impact is expected for tropical forests in both periods. In general forests are most affected than grassland and steppe. Annex A reports the changes in present value for the four forest ES, carbon, WFP and NWFP, recreation and passive use, by forest type and world region.

Table 19. Change in present values due to MSA area loss 1900-2000 (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR		SAFR		RUS_CASIA		SASIA		CHN		Total	
	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Grassland/steppe	-179	-1,036	-18	-104	-12	-72	-9	-52	-33	-188	-11	-63	-77	-445	-339	-1,960
Boreal forests	-3,270	-4,433	-25	-43	0	0	0	0	-1,114	-2,446	-139	-183	-1,873	-2,076	-6,421	-9,181
Temperate forests	-4,043	-7,578	-304	-1,151	0	0	-57	-199	-179	-595	-264	-1,041	-1,000	-1,457	-5,847	-12,022
Tropical forests	-121	-413	-1,935	-8,395	0	0	-2,379	-5,424	0	0	-3,054	-7,326	-6	-36	-7,495	-21,595
Total	**-7,612**	**-13,460**	**-2,283**	**-9,693**	**-12**	**-72**	**-2,444**	**-5,676**	**-1,326**	**-3,229**	**-3,468**	**-8,614**	**-2,956**	**-4,015**	**-20,101**	**-44,757**
% on tot	***-38%***	***-30%***	***-11%***	***-22%***	***-0.1%***	***-0.2%***	***-12%***	***-13%***	***-7%***	***-7%***	***-17%***	***-19%***	***-15%***	***-9%***		

Note: *LB = lower bound; UB = upper bound. LB=4US$ per ton of CO_2, and median values for grasslands, forest recreation and passive use. UB=53US$ per ton of CO_2, and mean values for grasslands, forest recreation and passive use.*

Table 20. Change in present values due to MSA area loss 2000-2050 (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR		SAFR		RUS_CASIA		SASIA		CHN		Total	
	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Grassland/steppe	-186	-1,077	-16	-90	-8	-46	-16	-95	-78	-448	-15	-89	-47	-272	-366	-2,116
Boreal forests	-1,978	-3,636	-24	-55	0	0	0	0	-788	-2,833	-115	-205	-674	-902	-3,578	-7,631
Temperate forests	-1,165	-3,200	-85	-400	0	0	-174	-586	-144	-729	-304	-1,263	-327	-711	-2,200	-6,890
Tropical forests	-35	-165	-946	-6,356	0	0	-2,903	-10,869	0	0	-1,474	-5,317	-4	-33	-5,362	-22,740
Total	**-3,365**	**-8,078**	**-1,071**	**-6,901**	**-8**	**-46**	**-3,093**	**-11,549**	**-1,010**	**-4,010**	**-1,908**	**-6,875**	**-1,052**	**-1,918**	**-11,506**	**-39,377**
% on tot	***-29%***	***-21%***	***-9%***	***-18%***	***-0.1%***	***-0.1%***	***-27%***	***-29%***	***-9%***	***-10%***	***-17%***	***-17%***	***-9%***	***-5%***		

Note: *LB = lower bound; UB = upper bound. LB=13US$ per ton of* CO_2, *and median values for grasslands, forest recreation and passive use. UB=179US$ per ton of* CO_2, *and mean values for grasslands, forest recreation and passive use.*

Figures 1-4 show the percent share of the total loss by geographical region in the upper and lower bound scenarios. In the period 1900-2000 the highest share of loss is for the OECD, followed by Central/South America (CSAM) and South Asia (SASIA) for the upper bound scenario, while in the lower bound scenario OCED region is followed by South Asia (SASIA) and China (CHN) (the precise ranking depending on the value of carbon). In the period 2000-2050, Sub-Saharan Africa shows an increase in the expected economic loss and is ranked in the first place in the upper bound scenario. OECD region is still among the highest affected, but with a lower share of total losses, followed by Central/South America and South Asia (in the upper bound scenario).

Figure 1. Gross economic loss by region, 1900-2000 (lower bound scenario)

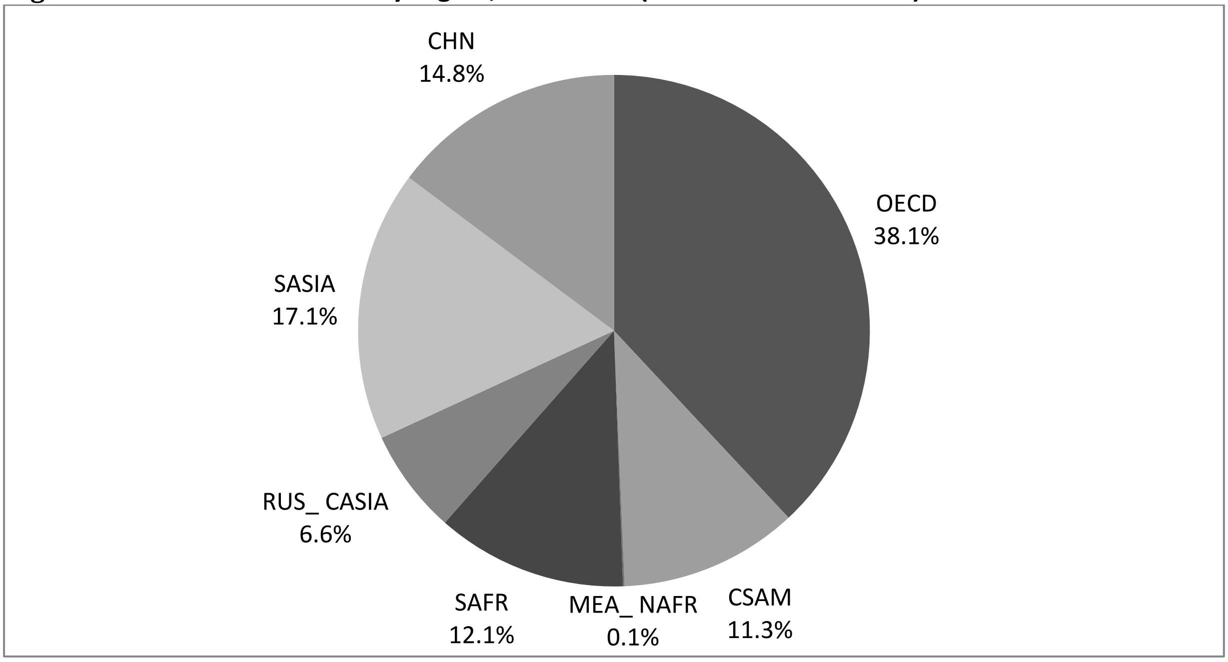


Figure 2. Gross economic loss by region, 1900-2000 (upper bound scenario)

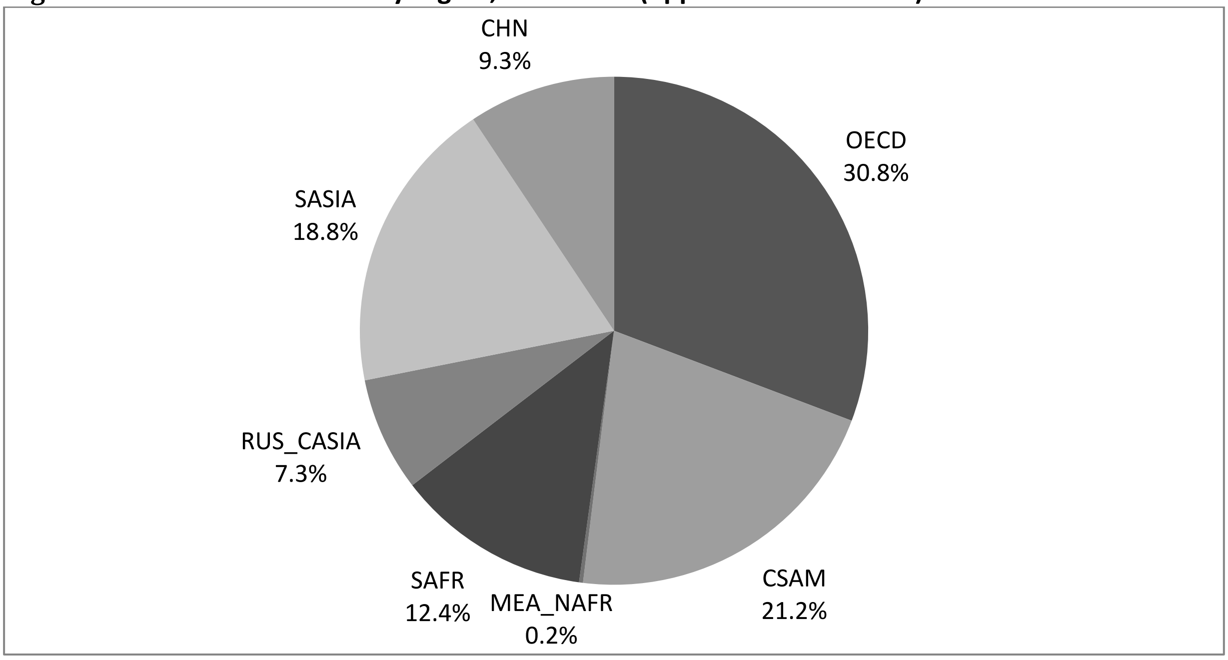


Figure 3. Gross economic loss by region, 2000-2050 (lower bound scenario)

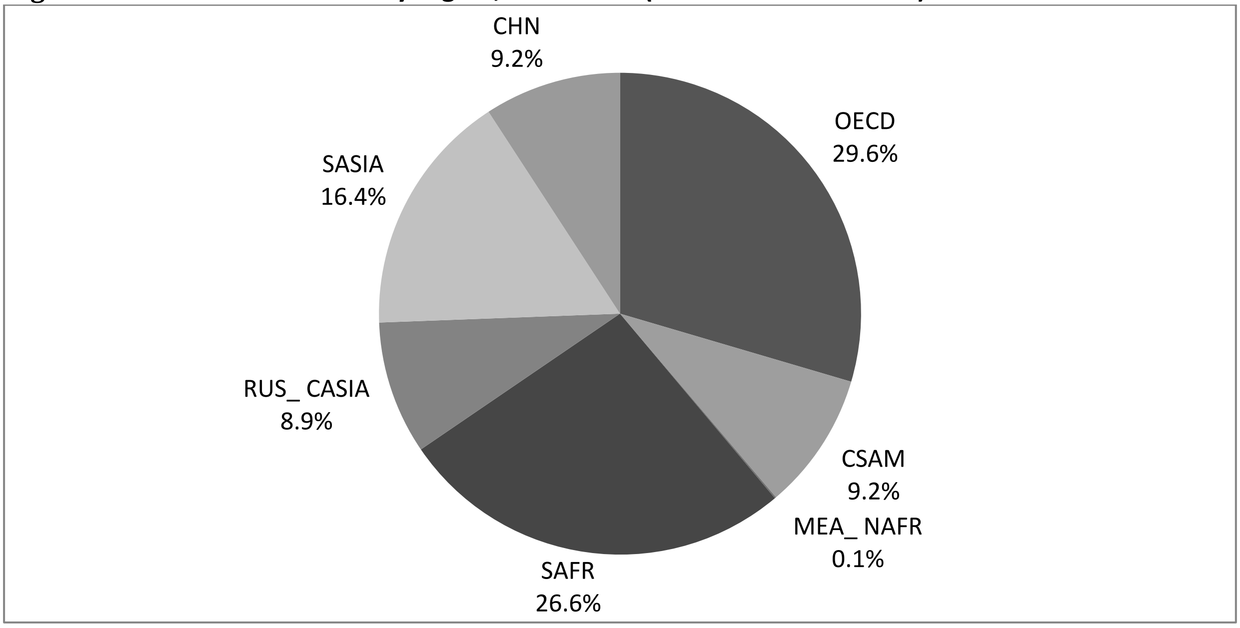
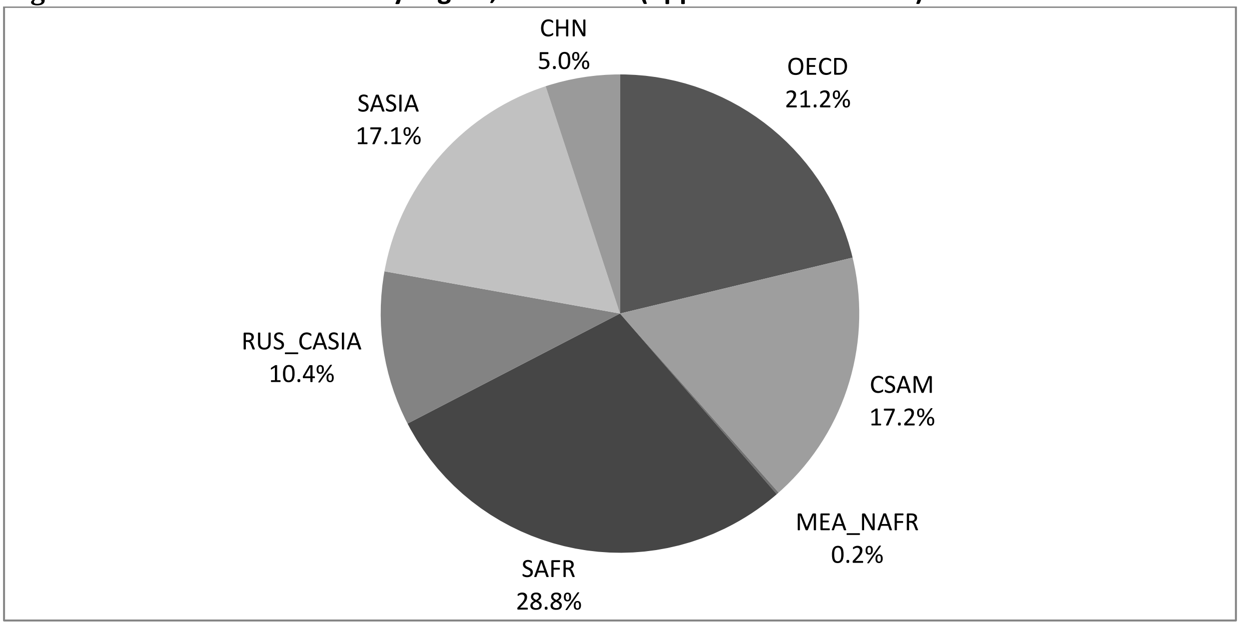


Figure 4. Gross economic loss by region, 2000-2050 (upper bound scenario)



4.2 Net economic impacts on annual flows provided by ES taking account of agricultural benefits

In this section the changes in values of natural capital as estimated above are converted into annual flows using the conventional 3% discount rate (see equation 3) and compared with the expected flows of benefits generated by agricultural production[10]. Basically, we assume that the hectares lost in grassland and forests are converted into agricultural land and the associated economic benefits are calculated as follows:

[10] The conversion of carbon stock values to flows is an artificial construct as in fact the carbon stock does not represent a present value of a sequence of flows. Rather the flow associated with a give carbon stock gives us an annuity that would result to someone who had securitized that capital value of the carbon.

$$AgB_i = GDPA_i \left(\frac{\Delta MSAarea_i}{Ag_i} \right) \tag{10}$$

Where AgB_i represents the expected benefits from agricultural production in world region *i*, $GDPA_i$ is the GDP in the agricultural sector, *ΔMSAarea* is the registered variation in the MSA area in forests and grassland, and AG_i is the area designated to agriculture in each world region. The formula is calculated for both year 2000 and 2050 (Bakkes and Bosch 2008).

Tables 21 and 22 present the final results related to changes in annual gross flows in the periods 1900-2000 and 2000-2050, expected benefits from the agricultural sector and net economic losses or gains in terms of 2000 and 2050 GDP.

Table 21. Change in annual values due to MSA area loss 1900-2000, d=3% (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR		SAFR		RUS_CASIA		SASIA		CHN		Total			% on 2000 GDP	
	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	mid range	UP	LB	UP
Grassland/steppe	-5.4	-31	-0.5	-3.1	-0.4	-2	-0.3	-1.6	-1.0	-5.6	-0.3	-1.9	-2.3	-13	-10	-34	-59	-0.05%	-0.27%
Boreal forests	-98	-133	-0.8	-1.3	0	0	0	0	-33	-73	-4.2	-5.5	-56	-62	-193	-234	-275	-0.5%	-0.8%
Temperate forests	-121	-227	-9.1	-35	0	0	-2	-6	-5.4	-17.8	-7.9	-31	-30	-44	-175	-268	-361	-0.5%	-1.0%
Tropical forests	-3.6	-12.4	-58	-252	0	0	-71	-163	0	0	-92	-220	-0.2	-1.1	-225	-436	-648	-0.6%	-1.8%
Total flow loss	**-228**	**-404**	**-68**	**-291**	**-0.4**	**-2.1**	**-73**	**-170**	**-40**	**-97**	**-104**	**-258**	**-89**	**-120**	**-603**	**-973**	**-1,343**	**-1.7%**	**-3.8%**
Benefit ag. prod.	**404**		**101**		**2.8**		**11.3**		**49**		**572**		**167**			**614**		1.7%	2.9%
Net loss or benefit	175.3	-0.2	32.6	-189.7	2.5	0.7	-62.0	-159.0	9.0	-48.1	468.5	314.1	78.6	46.8	10.9	-358.9	-728.8		
% on 2000 GDP	1.0%	-0.001%	1.1%	-6.2%	0.5%	0.1%	-12.6%	-32.4%	0.7%	-3.7%	11.5%	7.7%	1.6%	1.0%	0.03%	-1.0%	-2.0%		

Note: *LB = lower bound; UB = upper bound. LB=4US$ per ton of* CO_2*, and median values for grasslands, forest recreation and passive use. UB=53US$ per ton of* CO_2*, and mean values for grasslands, forest recreation and passive use.*

Table 22. Change in annual values due to MSA area loss 2000-2050, d=3% (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR		SAFR		RUS_CASIA		SASIA		CHN		Total			% on 2050 GDP	
	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	mid range	UP	LB	UP
Grassland/steppe	-5.6	-32	-0.5	-2.7	-0.2	-1	-0.5	-2.8	-2.3	-13.4	-0.5	-2.7	-1.4	-8	-11	-37	-63	-0.01%	-0.03%
Boreal forests	-59	-109	-0.7	-1.6	0	0	0	0	-24	-85	-3.4	-6.2	-20	-27	-107	-168	-229	-0.05%	-0.12%
Temperate forests	-35	-96	-2.6	-12	0	0	-5	-18	-4.3	-21.9	-9.1	-38	-10	-21	-66	-136	-207	-0.03%	-0.1%
Tropical forests	-1.0	-5.0	-28	-191	0	0	-87	-326	0	0	-44	-160	-0.1	-1.0	-161	-422	-682	-0.1%	-0.3%
Total flow loss	**-101**	**-242**	**-32**	**-207**	**-0.2**	**-1.4**	**-93**	**-346**	**-30**	**-120**	**-57**	**-206**	**-32**	**-58**	**-345**	**-763**	**-1,181**	**-0.2%**	**-0.6%**
Benefit ag. prod.	**399**		**62**		**2.9**		**182**		**129**		**945**		**272**			**1,276**		0.7%	0.5%
Net loss or benefit	298.0	156.6	29.7	-145.2	2.7	1.5	88.9	-164.8	99.2	9.1	887.4	738.4	240.9	214.9	930.5	512.4	94.4		
% on 2050 GDP	0.4%	0.2%	0.3%	-1.5%	0.04%	0.02%	0.6%	-1.2%	1.2%	0.1%	2.4%	2.0%	0.5%	0.5%	0.48%	0.26%	0.05%		

Note: *LB = lower bound; UB = upper bound. LB=13US$ per ton of* CO_2*, and median values for grasslands, forest recreation and passive use. UB=179US$ per ton of* CO_2*, and mean values for grasslands, forest recreation and passive use.*

The loss in MSA area always generates an annual economic loss due to a reduced provision of ES. However, when account is taken of the agricultural benefits these losses can be offset in some regions. Results in table 21 show an impact at worldwide level ranging from a net benefit of 0.01% to a net loss of -2.1% of 2000 GDP. The world region reporting the highest loss in the period 1900-2000 is Sub-Saharan Africa (SAFR), mainly in tropical forests. Central and South America (CSAM) follow, with a 6.2% net loss in the upper bound scenario. South Asia (SASIA) and China (CHN) report a net benefit, while the other regions show mixed results ranging from a benefit in the lower bound scenario to a loss in the upper bound scenario. As regards the specific biomes analysed, the highest economic loss is estimated in tropical forests, followed by temperate and boreal forests, while grasslands are much less impacted.

Tables 22 presents the results for the period 2000-2050, showing a net benefit at a global scale ranging from 0.05 to 0.48% of 2050 GDP. Sub-Saharan Africa (SAFR), and Central and South America (CSAM) are the most impact geographical region and report a loss in the upper bound scenario of respectively 1.2% and 1.5% of 2050 GDP, mainly registered in tropical forests.

We report here below a brief analysis of the changes in annual gross flows for the forest ES, which can explain some of these trends (i.e. without accounting for the agricultural benefits). Results by world regions sometimes differ from those obtained in Chiabai *et al.* (2011), which is related to the different geographical aggregation used in the two studies. The large impact in all ES expected in tropical forests, as discussed here below, can be explained by the combined effect of a decrease in MSA area (12% from 2000 to 2050, as shown in Table 7) and high economic values per hectare.

Carbon in forests

As regards carbon, Sub-Saharan Africa (SAFR) is the most impacted region with a damage ranging from 1.5 to 20% of the country 2000 GDP in the period 1900-2000, and from 0.1 to 2% of the 2050 GDP in the period 2000-2050. Central and South America (CSAM) follow with a lower percent of damage. The much lower percent of damage expected by 2050 is due to the fact that the loss is measured in 2050 GDP, which is expected to increase considerably in all countries. In absolute terms, however, economic losses related to carbon in SAFR in the next 50 years are twice as higher as in the previous 100 years, and are almost the same in the other world regions. In both regions the loss is mainly registered in tropical forests. Overall the highest loss is expected in tropical forests, due to their larger carbon capacity.

Table 23. Change in annual values for carbon in forests 1900-2000, d=3% (bn US$2000)

Biome	**OECD**		**CSAM**		**MEA_NAFR**	**SAFR**		**RUS_CASIA**		**SASIA**		**CHN**		**Total**		**% on 2000GDP**	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-2	-28	-0.03	-0.4	0	0	0	-3	-41	-0.1	-1.3	-0.4	-6	-6	-76	-0.02%	-0.2%
Temperate forests	-7	-92	-1.8	-24	0	-0.3	-4	-1.0	-12.9	-1.8	-24	-1	-13	-13	-170	-0.03%	-0.5%
Tropical forests	-0.6	-8.4	-15	-203	0	-7	-96	0	0	-10	-133	-0.1	-1.0	-33	-441	-0.1%	-1%
Total flow loss	**-10**	**-128**	**-17**	**-228**	**0**	**-8**	**-100**	**-4**	**-54**	**-12**	**-159**	**-1**	**-20**	**-52**	**-688**		
GDP 2000US$	17,713		3,067		515	491		1,288		4,079		4,851		36,688			
% on 2000 GDP	**-0.1%**	**-0.7%**	**-0.6%**	**-7%**	**0%**	**-1.5%**	**-20%**	**-0.3%**	**-4.2%**	**-0.3%**	**-3.9%**	**-0.03%**	**-0.4%**	**-0.1%**	**-1.9%**		

Note: *LB = lower bound; UB = upper bound. LB=4US$ per ton of* CO_2. *UB=53US$ per ton of* CO_2.

Table 24. Change in annual values for carbon in forests 2000-2050, d=3% (bn US$2000)

Biome	**OECD**		**CSAM**		**MEA_NAFR**	**SAFR**		**RUS_CASIA**		**SASIA**		**CHN**		**Total**		**% on 2050GDP**	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-3	-45	-0.1	-0.8	0	0	0	-5	-63	-0.2	-2.6	0	-6	-9	-118	-0.004%	-0.1%
Temperate forests	-4	-58	-0.7	-10	0	-1	-12	-1.3	-18.1	-2.1	-29	-1	-11	-10	-138	-0.01%	-0.1%
Tropical forests	-0.3	-3.9	-12	-172	0	-18	-251	0	0	-9	-119	-0.1	-0.9	-40	-546	-0.02%	-0.3%
Total flow loss	**-8**	**-107**	**-13**	**-182**	**0**	**-19**	**-263**	**-6**	**-81**	**-11**	**-151**	**-1**	**-18**	**-58**	**-802**		
GDP 2050US$	74,176		9,906		6,437	13,962		8,602		37,234		45,171		195,489			
% on 2050 GDP	**-0.01%**	**-0.1%**	**-0.1%**	**-1.8%**	**0%**	**-0.1%**	**-2%**	**-0.1%**	**-0.9%**	**-0.03%**	**-0.4%**	**-0.003%**	**-0.04%**	**-0.03%**	**-0.4%**		

Note: *LB = lower bound; UB = upper bound. LB=13US$ per ton of* CO_2. *UB=179US$ per ton of* CO_2.

WFP and NWFP

Sub-Saharan Africa (SAFR) shows the highest loss also for WFP and NWFP in both periods (11% of the 2000 GDP and 0.3% of 2050 GDP), mostly in tropical forests. This high loss might be due to the huge development of the forestry industry in these last decades, as extensively explained in Chiabai *et al*. (2011). From 1980 to 2000 in South Africa this sector has seen an increase in sales of up to 1460% (Chamshama and Nwonwu, 2004).

As regards the type of biome, boreal and tropical forests show the same loss in percent of the GDP. Boreal forests are in danger particularly in OCED region, China (CHN) and Russia (RUS_CASIA) in both periods.

Table 25. Change in annual values for WFP and NWFP 1900-2000, d=3% (bn US$2000)

Biome	OECD	CSAM	MEA_NAFR	SAFR	RUS_CASIA	SASIA	CHN	Total	% on 2000 GDP
Boreal forests	-74	-0.4	0	0	-25	-3.6	-55	-157	-0.4%
Temperate forests	-62	0.0	0	-0.1	-3.2	-2.0	-26	-94	-0.3%
Tropical forests	-0.4	-26	0	-55	0	-65	-0.05	-147	-0.4%
Total flow loss	**-136**	**-26**	**0**	**-55**	**-28**	**-71**	**-81**	**-398**	
GDP 2000US$	17,713	3,067	515	491	1,288	4,079	4,851	36,688	
% on 2000 GDP	**-0.8%**	**-0.9%**	**0%**	**-11%**	**-2.2%**	**-1.7%**	**-1.7%**	**-1.1%**	

Table 26. Change in annual values for WFP and NWFP 2000-2050, d=3% (bn US$2000)

Biome	OECD	CSAM	MEA_NAFR	SAFR	RUS_CASIA	SASIA	CHN	Total	% on 2050 GDP
Boreal forests	-35	-0.2	0	0	-11	-2.2	-18	-67	-0.03%
Temperate forests	-12	-0.01	0	-0.04	-1.3	-0.7	-7	-20	-0.01%
Tropical forests	-0.1	-6	0	-43	0	-17	0.0	-66	-0.03%
Total flow loss	**-47**	**-7**	**0**	**-43**	**-13**	**-20**	**-25**	**-154**	
GDP 2050US$	74,176	9,906	6,437	13,962	8,602	37,234	45,171	195,489	
% on 2050 GDP	**-0.1%**	**-0.1%**	**0%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.06%**	**-0.1%**	

Forest recreational activities

Forest recreation shows much lower losses, but Sub-Saharan Africa is still the region having the largest economic damage in the period 1900-2000, registered for tropical forests. Overall, however, temperate forest is the biome most affected, due to the extent of recreational activities registered in this forest type. As regards the period 2000-2050, Central and South America (CSAM) and Russia (RUS_CASIA) are expected to support the highest cost for decreased recreation, respectively in tropical and boreal forests. Overall, the highest loss is expected in boreal forests.

Table 27. Change in annual values for forest recreation 1900-2000, d=3% (bn US$2000)

Biome	OECD		CSAM		MEA_N AFR	SAFR		RUS_CASIA		SASIA		CHN		Total		% on 2000GDP	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-2	-7	-0.02	-0.1	0	0	0	-0.5	-2	-0.01	-0.1	-0.2	-1	-2	-10	-0.01%	-0.03%
Temperate forests	-4	-16	-0.5	-2	0	-0.05	-0.2	-0.1	-0.5	-0.1	-1	-0.4	-2	-5	-21	-0.01%	-0.1%
Tropical forests	-0.2	-0.8	-1	-4	0	-0.3	-1	0	0	-1	-2	-0.01	-0.04	-2	-9	-0.01%	-0.02%
Total flow loss	**-5**	**-23**	**-2**	**-6**	**0**	**-0.4**	**-1**	**-1**	**-2**	**-1**	**-3**	**-1**	**-3**	**-9**	**-39**		
GDP 2000US$	17,713		3,067		515	491		1,288		4,079		4,851		36,688			
% on 2000 GDP	**-0.03%**	**-0.1%**	**-0.05%**	**-0.2%**	**0%**	**-0.1%**	**-0.3%**	**-0.04%**	**-0.2%**	**-0.02%**	**-0.1%**	**-0.01%**	**-0.1%**	**-0.03%**	**-0.1%**		

Note: *LB = lower bound, media values; UB = upper bound, mean values.*

Table 28. Change in annual values for forest recreation 2000-2050, d=3% (bn US$2000)

Biome	OECD		CSAM		MEA_ NAFR	SAFR		RUS_CASIA		SASIA		CHN		Total		% on 2050GDP	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-1.2	-5.3	-0.02	-0.1	0	0	0	-0.6	-2.6	-0.02	-0.1	-0.2	-0.8	-2.1	-8.9	-0.001%	-0.005%
Temperate forests	-1.1	-4.8	-0.1	-0.4	0	-0.1	-0.3	-0.1	-0.6	-0.1	-0.6	-0.3	-1.4	-1.9	-8.1	-0.001%	-0.004%
Tropical forests	-0.04	-0.2	-0.5	-2	0	-0.5	-2.1	0	0	-0.4	-1.7	-0.01	-0.03	-1.4	-6.0	-0.001%	-0.003%
Total flow loss	**-2.4**	**-10.3**	**-0.6**	**-2.4**	**0**	**-0.6**	**-2.4**	**-0.7**	**-3.2**	**-0.6**	**-2.4**	**-0.5**	**-2.2**	**-5.4**	**-22.9**		
GDP 2050US$	74,176		9,906		6,437	13,962		8,602		37,234		45,171		195,489			
% on 2050 GDP	**-0.003%**	**-0.01%**	**-0.01%**	**-0.02%**	**0%**	**-0.004%**	**-0.02%**	**-0.01%**	**-0.04%**	**-0.002%**	**-0.01%**	**-0.001%**	**-0.005%**	**-0.003%**	**-0.01%**		

Note: *LB = lower bound, media values; UB = upper bound, mean values.*

Forest passive use

As regards forest passive use, Sub-Saharan Africa is again the most affected region in both periods, mainly in tropical forests having the highest passive use values. In terms of biomes, however, the greatest impact is recorded in temperate forests in the period 1900-2000 and in tropical forests in 2000-2050. It can be noticed that in the first period, the high impact in Sub-Saharan Africa is partially attributable to the very low GDP of the region. In the next period (2000-2050), the weight of SAFR decreases but still remains important, which is due to the high absolute loss expected in tropical forests in this region (US$26 to US$31 bn US$2000, the largest registered impact).

Table 29. Change in annual values for forest passive use 1900-2000, d=3% (bn US$2000)

Biome	OECD		CSAM		MEA_N AFR	SAFR		RUS_CASIA		SASIA		CHN		Total		% on 2000GDP	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-21	-25	-0.3	-0.4	0	0	0	-5	-6	-0.4	-0.5	-1	-1	-27	-32	-0.1%	-0.1%
Temperate forests	-49	-58	-6.8	-8	0	-1	-2	-1.1	-1.4	-4.0	-5	-2	-3	-64	-76	-0.2%	-0.2%
Tropical forests	-2.4	-2.8	-16	-19	0	-9	-10	0	0	-16	-19	-0.04	-0.1	-43	-51	-0.1%	-0.1%
Total flow loss	**-72**	**-85**	**-23**	**-27**	**0**	**-10**	**-12**	**-6**	**-7**	**-20**	**-24**	**-3**	**-4**	**-134**	**-160**		
GDP 2000US$	17,713		3,067		515	491		1,288		4,079		4,851		36,688			
% on 2000 GDP	**-0.4%**	**-0.5%**	**-0.7%**	**-0.9%**	**0%**	**-2%**	**-2.4%**	**-0.45%**	**-0.54%**	**-0.5%**	**-0.6%**	**-0.07%**	**-0.1%**	**-0.37%**	**-0.44%**		

Note: *LB = lower bound, media values; UB = upper bound, mean values.*

Table 30. Change in annual values for forest passive use 2000-2050, d=3% (bn US$2000)

Biome	OECD		CSAM		MEA_ NAFR	SAFR		RUS_CASIA		SASIA		CHN		Total		% on 2050GDP	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-20	-23	-0.4	-0.5	0	0	0	-7	-8	-1.1	-1.3	-1	-2	-29	-35	-0.01%	-0.02%
Temperate forests	-18	-21	-1.8	-2	0	-4	-5	-1.6	-1.9	-6.1	-7	-2	-3	-34	-40	-0.02%	-0.02%
Tropical forests	-0.7	-0.8	-9	-11	0	-26	-31	0	0	-18	-21	0.0	-0.1	-53	-63	-0.03%	-0.03%
Total flow loss	**-38**	**-45**	**-11**	**-13**	**0**	**-30**	**-36**	**-9**	**-10**	**-25**	**-30**	**-3**	**-4**	**-116**	**-138**		
GDP 2050US$	74,176		9,906		6,437	13,962		8,602		37,234		45,171		195,489			
% on 2050 GDP	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**0%**	**-0.2%**	**-0.3%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.1%**	**-0.01%**	**-0.01%**	**-0.06%**	**-0.07%**		

Note: *LB = lower bound, media values; UB = upper bound, mean values.*

4.3 Distribution of the impact by ES

Finally, we analyze how the damage is distributed between ES in both periods of time. It was not possible to disentangle the impacts on each ES provided by grassland, as the economic values used for this particular biome refer to the overall set of services provided. Figure 5 and 6 report the losses for the period 1900-2000, while Figure 7 and 8 refer to the next period 2000-2050. Losses are reported in terms of percent over the total gross damage, not taking into account the benefits registered in the agricultural sector. There is a big difference between the two scenarios, especially as regards the share between carbon and WFP/NWFP. This discrepancy is largely attributable to the range of carbon prices used, varying from 4 to 53US$ per ton of CO2 in the period 1900-2000, and from 13 to 179US$ in 2000-2050.

In the first scenario (using lower bound values of ES), in both periods WFP and NWFP are the most affected by the loss in MSA area, followed by forest passive use and carbon. On the other side, grassland ES register a much lower damage, as well as recreational activities in forests.

In the second scenario (using upper bound values of ES) in both periods carbon in forests largely dominates attaining 51% and 68% of the total impact. WFP/NWFP and forest passive use follow. Again, grassland services and forest recreation are the less impacted.

Figure 5. Economic loss registered by ES, 1900-2000, percent on total loss (lower bound scenario)

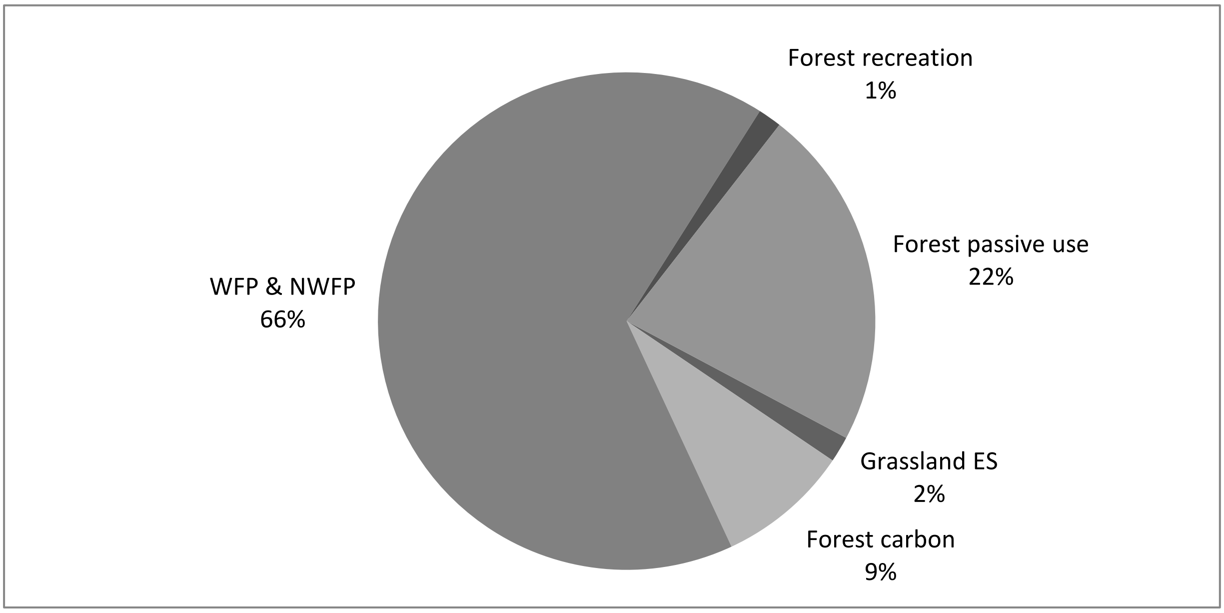


Figure 6. Economic loss registered by ES, 1900-2000, percent on total loss (upper bound scenario)

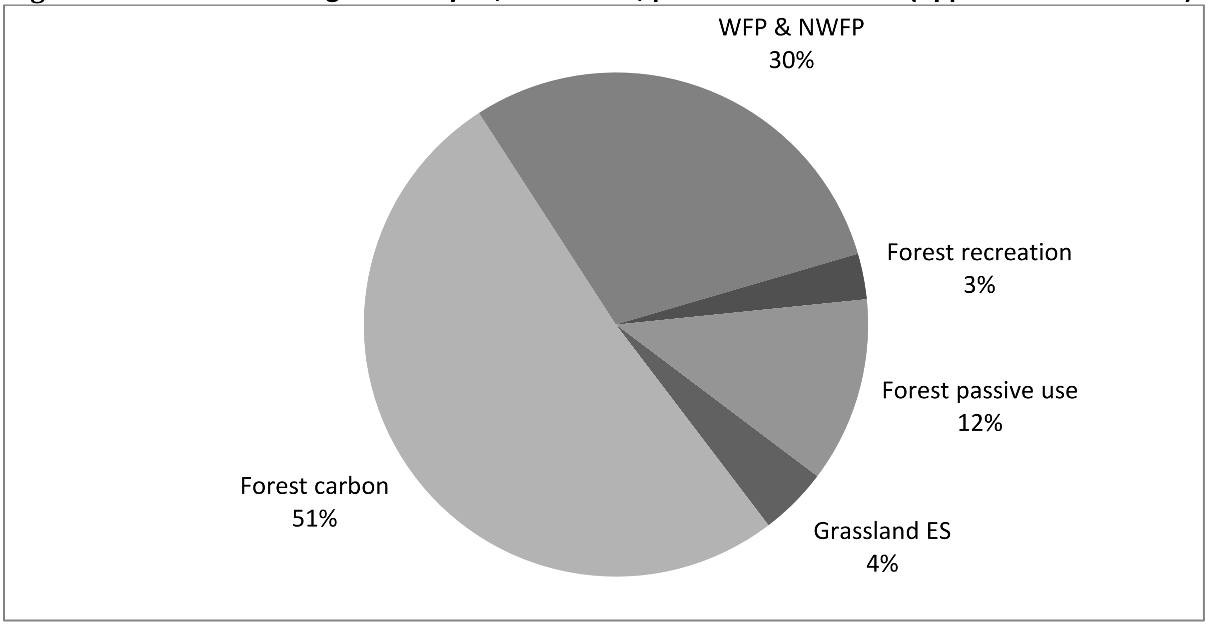


Figure 7. Economic loss registered by ES, 2000-2050, percent on total loss (lower bound scenario)

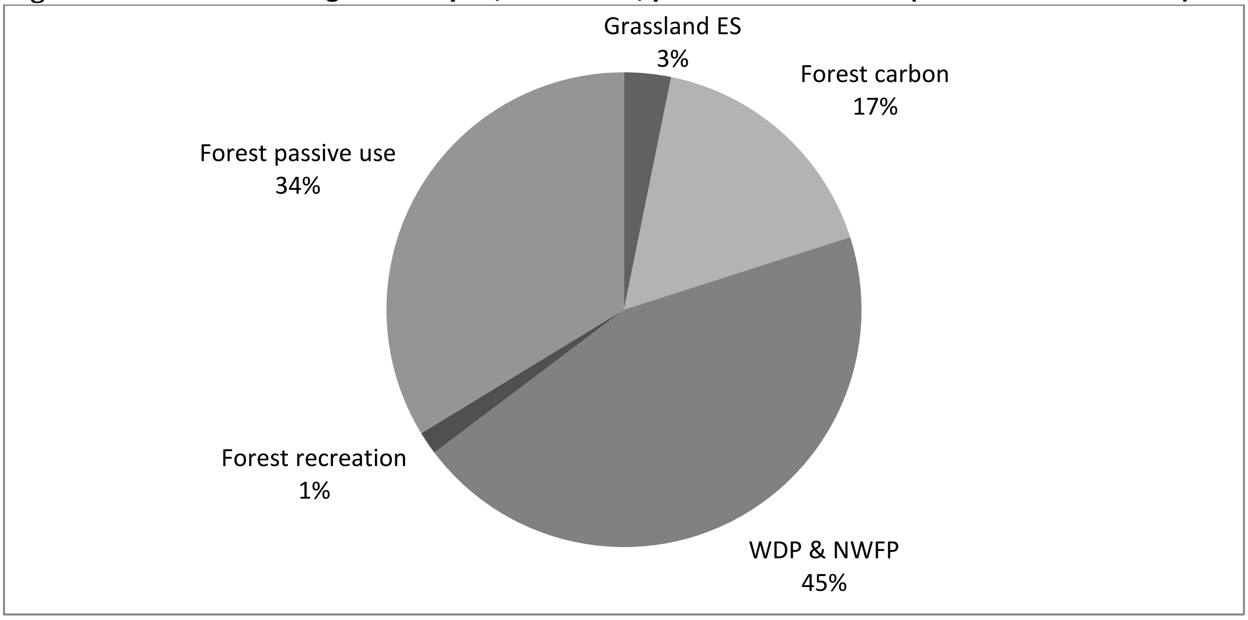
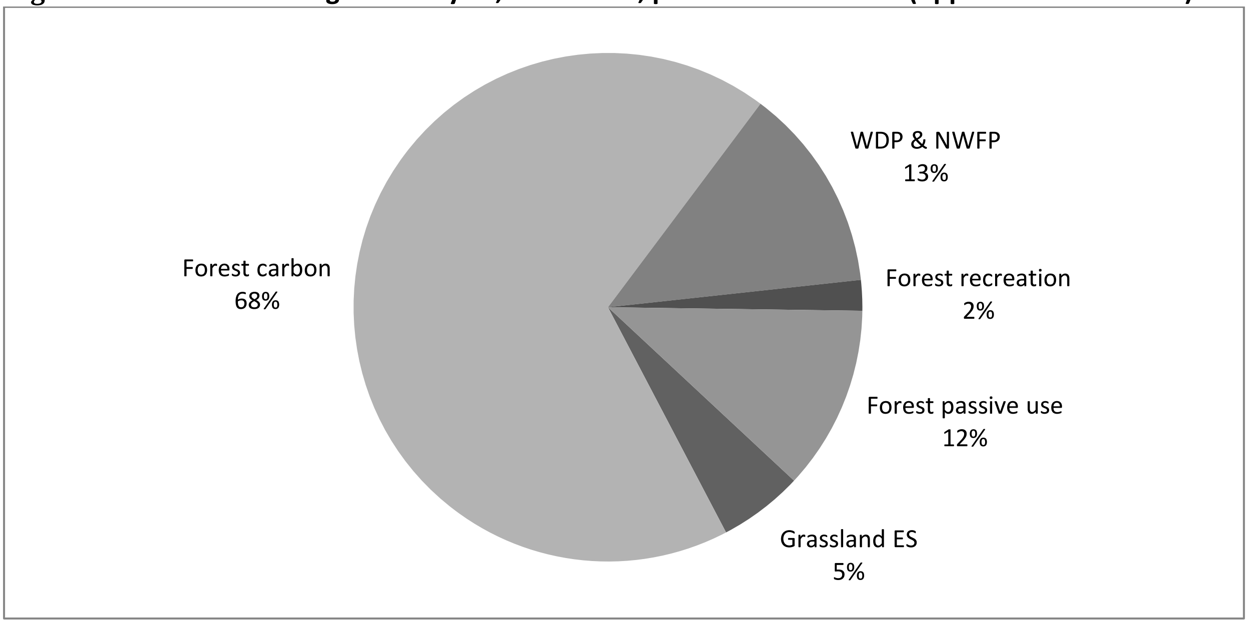


Figure 8. Economic loss registered by ES, 2000-2050, percent on total loss (upper bound scenario)



5. Conclusions

The analysis presented here provides a partial value of the losses of ecosystem services between 1900 and 2000 and between 2000 and 2050. These losses reflect in part the loss of biodiversity between these dates, captured through the use of the measure of mean species abundance (MSA). Before giving the main results it is important to note that the comparisons need to be qualified in a number of respects. First not all ecosystem services are covered. Data limitations only allow us to look at carbon, recreational and passive use, and wood and non-wood services derived from forests; and ecosystem services derived from grasslands. Second, while the links between biodiversity and ecosystem services are partly captured through the use of MSA, this measure has several limitations, which have been noted. Third, the comparison between the ecosystem services in 1900 and 2000 is based on the thought experiment that assumes the level of ecosystem services of 1900 to be available in 2000 at the prices for these services that actually prevailed in 2000. It is impossible to estimate actual values in 1900 based on socioeconomic conditions that prevailed then as the data are simply not available. As far as the comparison between 2000 and 2050 is concerned, the 2050 levels of services are valued at 2050 projected prices, and so in this respect the second comparison is more complete than that between 1900 and 2000.

Turning to the results we find significant gross losses in ecosystem services between both dates. The gross loss of natural capital between 1900 and 2000 is estimated at between US$20 trillion and US$45 trillion, which range from around 54 percent to over 100 percent of the GDP of 2000. Of course it is important to note that the loss is a capital loss and the GDP figure is a flow, so the former can be much greater than the latter. In terms of regions, the greatest losses occurred in the OECD region, followed by Central and South America and South Asia. In terms of biomes the most important sources of losses were the tropical forests, followed by temperate forests. Grassland losses contributed a small share of the total.

If one compares the losses in terms of flows, the total loss between 1900 and 2000 was between US$603 billion and US$1.3 trillion, which is around 1.7 and 3.8 percent of the GDP of 2000. However, against this loss we also have to account for the gain made by the conversion of forest and grassland to agriculture. This gain more or less cancels out the loss in the case of the lower bound figure. Only if the upper bound figure is valid is there a net loss, which is then about US$730 billion, or 2% of the 2000 GDP. It is also important to note that there are major differences in the net loss by region. In particular, Sub-Saharan Africa suffers a net loss of 13 to 32 percent of its 2000 GDP. The other regions all show a gain if we take the lower bound figure for their losses of ecosystem services and in two regions (South Asia and China) the net figure is a gain even in the case of the upper bound of the losses.

Looking at the comparison between 2000 and 2050 we find similar overall results but with some notable differences. In terms of the natural capital the losses range from US$11 trillion to US$39 trillion, with the greatest losses expected in Sub-Saharan Africa, OECD and South Asia. In terms of biomes, the most affected is tropical forests followed by boreal forests. In terms of flows, gross losses are between US$345 billion and US$1.2 trillion, representing between 0.9% and 3.2% of the GDP of 2000. In terms of net changes, however, after allowing for agricultural gains, we estimate a gain for between US$94 billion and US$930 billion. The only regions to show a net loss are Central and South America and Sub-Saharan Africa, but only with the upper bound of the gross loss figure.

The ecosystem services that contribute most to human well-being and to which we are most vulnerable when they are lost depend mainly on the valuations put on carbon. At a low value for carbon the main contributors are wood forest products, passive use of forests and carbon, in that order. At a high value of carbon the order changes, with carbon being the largest, followed by forest products and passive use.

As already noted, the results here are a partial valuation of ecosystem services and it is possible that a more complete coverage would give a higher gross loss as well as a greater net loss. More work is needed to establish the extent to which this is the case. More work is also needed to understand better the links between biodiversity and the ecosystem services that have been the main focus of this assessment.

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ANNEX A

Table A1. Change in present values for carbon 1900-2000 (bn US$2000)

Biome	**OECD**		**CSAM**		**MEA_NAFR**	**SAFR**		**RUS_CASIA**		**SASIA**		**CHN**		**Total**	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-70	-933	-1	-15	0	0	0	-102	-1,355	-3	-43	-14	-191	-191	-2,536
Temperate forests	-231	-3,059	-62	-816	0	-11	-140	-32	-428	-60	-797	-32	-430	-428	-5,671
Tropical forests	-21	-279	-510	-6,756	0	-241	-3,199	0	0	-335	-4,445	-2	-32	-1,110	-14,710
Total	**-322**	**-4,270**	**-573**	**-7,587**	**0**	**-252**	**-3,340**	**-135**	**-1,783**	**-399**	**-5,285**	**-49**	**-653**	**-1,730**	**-22,918**
% on tot	***-19%***		***-33%***		***0%***	***-15%***		***-8%***		***-23%***		***-3%***			

Table A2. Change in present values for carbon 2000-2050 (bn US$2000)

Biome	**OECD**		**CSAM**		**MEA_NAFR**	**SAFR**		**RUS_CASIA**		**SASIA**		**CHN**		**Total**	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-110	-1,509	-2	-28	0	0	0	-152	-2,087	-6	-88	-16	-216	-285	-3,927
Temperate forests	-141	-1,939	-23	-317	0	-29	-406	-44	-604	-71	-976	-26	-362	-334	-4,604
Tropical forests	-10	-131	-415	-5,719	0	-607	-8,357	0	0	-289	-3,975	-2	-30	-1,323	-18,212
Total	**-260**	**-3,580**	**-440**	**-6,064**	**0**	**-636**	**-8,763**	**-195**	**-2,691**	**-366**	**-5,039**	**-44**	**-607**	**-1,942**	**-26,743**
% on tot	***-13%***		***-23%***		-	***-33%***		***-10%***		***-19%***		***-2%***			

Table A3. Change in present values for WFP and NWFP 1900-2000 (bn US$2000)

Biome	**OECD**	**CSAM**	**MEA_NAFR**	**SAFR**	**RUS_CASIA**	**SASIA**	**CHN**	**Total**
Boreal forests	-2,456	-12	0	0	-840	-121	-1,820	-5,249
Temperate forests	-2,065	-2	0	-2	-105	-66	-881	-3,120
Tropical forests	-14	-864	0	-1,838	0	-2,166	-2	-4,883
Total	**-4,535**	**-878**	**0**	**-1,840**	**-945**	**-2,352**	**-2,703**	**-13,253**
% on tot	***-34%***	***-7%***	***0%***	***-14%***	***-7%***	***-18%***	***-20%***	

Table A4. Change in present values for WFP and NWFP 2000-2050 (bn US$2000)

Biome	**OECD**	**CSAM**	**MEA_NAFR**	**SAFR**	**RUS_CASIA**	**SASIA**	**CHN**	**Total**
Boreal forests	-1,177	-7	0	0	-383	-72	-609	-2,248
Temperate forests	-388	-0.2	0	-1.5	-44	-24	-219	-676
Tropical forests	-2	-217	0	-1,421	0	-574	-0.4	-2,214
Total	**-1,566**	**-224**	**0**	**-1,423**	**-427**	**-670**	**-829**	**-5,138**
% on tot	***-30%***	***-4%***	***0%***	***-28%***	***-8%***	***-13%***	***-16%***	

Table A5. Change in present values for recreation 1900-2000 (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR	SAFR		RUS_CASIA		SASIA		CHN		Total	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-52	-223	-1	-3	0	0	0	-15	-65	-0.5	-2	-6.2	-26	-75	-319
Temperate forests	-123	-523	-15	-64	0	-2	-6	-4	-16	-5	-20	-14	-59	-162	-688
Tropical forests	-6	-25	-35	-149	0	-10	-43	0	0	-19	-80	-0.3	-1	-71	-299
Total	**-182**	**-771**	**-51**	**-216**	**0**	**-12**	**-50**	**-19**	**-80**	**-24**	**-103**	**-21**	**-87**	**-308**	**-1,306**
% on tot	***-59%***		***-17%***		***0%***	***-4%***		***-6%***		***-8%***		***-7%***			

Table A6. Change in present values for recreation 2000-2050 (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR	SAFR		RUS_CASIA		SASIA		CHN		Total	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-41	-175	-1	-3	0	0	0	-20	-86	-1	-3	-6	-27	-70	-295
Temperate forests	-38	-161	-3	-13	0	-3	-11	-5	-19	-5	-20	-11	-45	-64	-270
Tropical forests	-1	-6	-15	-65	0	-16	-69	0	0	-14	-57	0	-1	-47	-199
Total	**-81**	**-342**	**-19**	**-81**	**0**	**-19**	**-81**	**-25**	**-106**	**-19**	**-80**	**-17**	**-73**	**-180**	**-763**
% on tot	***-45%***		***-11%***		***0%***	***-11%***		***-14%***		***-11%***		***-10%***			

Table A7. Change in present values for passive use 1900-2000 (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR	SAFR		RUS_CASIA		SASIA		CHN		Total	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-691	-822	-11	-13	0	0	0	-156	-186	-14	-17	-32	-38	-905	-1,077
Temperate forests	-1,623	-1,932	-226	-269	0	-43	-51	-38	-46	-133	-159	-73	-86	-2,137	-2,542
Tropical forests	-79	-94	-527	-627	0	-289	-344	0	0	-534	-636	-1.4	-1.7	-1,431	-1,702
Total	**-2,394**	**-2,848**	**-764**	**-909**	**0**	**-332**	**-395**	**-195**	**-232**	**-682**	**-811**	**-106**	**-126**	**-4,472**	**-5,321**
% on tot	***-54%***		***-17%***		***0%***	***-7%***		***-4%***		***-15%***		***-2.4%***			

Table A8. Change in present values for passive use 2000-2050 (bn US$2000)

Biome	OECD		CSAM		MEA_NAFR	SAFR		RUS_CASIA		SASIA		CHN		Total	
	LB	UP	LB	UP	LB UP	LB	UP	LB	UP	LB	UP	LB	UP	LB	UP
Boreal forests	-651	-774	-14	-17	0	0	0	-233	-277	-35	-42	-42	-50	-975	-1,161
Temperate forests	-599	-712	-59	-70	0	-140	-167	-52	-62	-205	-244	-71	-84	-1,126	-1,340
Tropical forests	-22	-26	-299	-356	0	-858	-1,021	0	0	-598	-711	-2	-2	-1,778	-2,116
Total	**-1,271**	**-1,512**	**-372**	**-443**	**0**	**-999**	**-1,188**	**-285**	**-339**	**-838**	**-997**	**-115**	**-137**	**-3,879**	**-4,616**
% on tot	***-33%***		***-10%***		***0%***	***-26%***		***-7%***		***-22%***		***-3%***			